DEVELOPMENT OF PARTHENOCARPIC GYNOECIOUS HYBRIDS IN CUCUMBER (*Cucumis sativus* L.) FOR PROTECTED CULTIVATION

By

AJAY BHARDWAJ

(2012-22-106)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

DOCTOR OF PHILOSOPHY IN HORTICULTURE

(Olericulture)

Faculty of Agriculture

Kerala Agricultural University, Thrissur

DEPARTMENT OF OLERICULTURE

COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2017

DECLARATION

I hereby declare that the thesis entitled **"Development of parthenocarpic gynoecious hybrids in cucumber (*Cucumis sativus* L.) for protected cultivation"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara

Date: 23/10/2017

Ajay Bhardwaj

(2012-22-106)

CERTIFICATE

Certified that thesis entitled **"Development of parthenocarpic gynoecious hybrids in cucumber (*Cucumis sativus* L.) for protected cultivation"** is a record of research work done independently by **Mr. Ajay Bhardwaj (2012-22-106)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Vellanikkara

Date: /10/2017

Dr. T. Pradeepkumar
Chairperson (Advisory Committee)
Professor (Hort.) & Director Planning
Kerala Agricultural University
Vellanikkara, Thrissur-680656

CERTIFICATE

We, the undersigned members of the advisory committee of **Ajay Bhardwaj (2012-22-106)**, a candidate for the degree of **Doctor of Philosophy in Horticulture**, with major in **Olericulture**, agree that the thesis entitled **"Development of parthenocarpic gynoecious hybrids in cucumber (*Cucumis sativus* L.) for protected cultivation"** may be submitted by **Mr. Ajay Bhardwaj** in partial fulfillment of the requirement for the degree.

Dr. T. Pradeepkumar
(Chairman, Advisory Committee)
Professor (Hort.) & Director Planning
Kerala Agricultural University
Vellanikkara, Thrissur - 680656

Dr. P. Indira 23/10/17
(Member, Advisory Committee)
Professor and Head
Dept. of Olericulture
College of Horticulture
Vellanikkara, Thrissur - 680656

Dr. S. Nirmala Devi
(Member, Advisory Committee)
Professor (Hort.) & P.I. (AICRP-VC)
Department of Olericulture
College of Horticulture
Vellanikkara, Thrissur - 680656

Dr. S. Krishnan 23/10/17
(Member, Advisory Committee)
Professor and Head
Department of Agricultural Statistics
College of Horticulture
Vellanikkara, Thrissur - 680656

Dr. B. Suma
(Member, Advisory Committee)
Professor (Hort.) & Head
Cadbury's Cocoa Research Project
Vellanikkara, Thrissur - 680656

23/10/17
EXTERNAL EXAMINER
Dr. L. Pugalendhi
Professor and Head
Horticultural Research Station (T.N.A.U.)
Yercaud-636602, Salem (District)

ACKNOWLEDGEMENTS

"Pride, Praise and Perfection Belongs to "The Almighty"

Every effort is motivated by ambition and all ambitions have inspirations behind. I owe this pride place to my parents, Sh. Ratan Chand Bhardwaj & Smt. Meera Devi, who always believed in giving strong educational wings to their son. Their selfless persuasions, sacrifices, heartfelt blessings and firm faith have made this manuscript a feeble recompense to translate their dreams into reality.

Indeed, the words of my command are not adequate to pen down my sense of heartfelt gratitude to my major advisor, Dr. T. Pradeepkumar, Professor, Department of Olericulture, for his incessant guidance, deep scientific vision and affectionate attitude. I shall ever be indebted to him for the attention paid and care shown by him to me through entire course of investigation. I shall never forget his efforts for developing in me the desire to work hard and for keeping my moral up through persistent encouragement, valuable suggestions, extreme patience, understanding and wholehearted co-operation which evoked in the bestir to achieve the destination successfully resulting in this manuscript.

I consider it as my privilege to express my deep-felt gratitude to Dr. P. Indira, Professor and Head, Dept. of Olericulture, for her constant support, valuable suggestions and critical scrutiny of the manuscript. I sincerely thank Dr. S. Nirmala Devi and Dr. Sarah T. George, Professors, Dept. of Olericulture for their generous support, constructive criticisms and valuable suggestions during my entire study which helped in successful completion of this work. Thanks are also due to Dr. Suma B., Professor, CCRP, and Dr. Deepu Mathew, Assistant Professor, Centre of Plant Biotechnology and Molecular Biology for rendering the help as and when required in a friendly manner and homely environment. I express my gratitude to Dr. S. Krishnan, Professor and Head, Dept. of Agricultural Statistics, College of Horticulture, for his valuable assistance, immense help and guidance during the statistical analysis of the data.

Words fall short as I place on record my indebtedness to all the teachers, Dr. T. E. George, Dr. Salikutty Joseph, Dr. K. P. Prasanna, Dr. P. G. Sadhan Kumar, Dr. K. Suresh Babu, Dr. Sainamol Kurien and Dr. Anitha K. of Department of Olericulture for their untiring support and immense help rendered during my course of study and all the phases of stay at Kerala Agricultural University, Thrissur. I never felt away from home as the atmosphere I received here was home alike.

I record my sincere thanks to my teachers, Dr. Vidyasagar, Dr. Desh Raj, Dr. Pardeep Kumar, Dr. Akhilesh Sharma, Dr. N. K. Pathania and Dr. S. K. Upadhyay from CSKHPKV, Palampur, for providing me the moral support and being the source of my inspiration to complete this task. My whole hearted thanks are also due to Dr. Ajoy Kumar Singh (Hon'ble Vice Chancellor), Dr. Arun Kumar (Director Planning and Dean Agriculture), Dr. B. C. Saha (Dean PGS), Dr. Feza Ahmed (Chairman, Dept. of Hort-Fruits), BAU, Sabour for providing me the needed encouragement and opportunity to complete my course of study. I also take this opportunity to thank Paramveer Sir, Dr. Randhir, Dr. R.B. Verma, Dr. Sangeeta, Dr. V. K. Singh, Dr. R. K. Sharma, Dr. Kamal Kant, Deepti mam, Shirin mam, Solankey Sir, Dr. A. B. Singh, Dr. Awadhesh Pal, Dr. Ravi Shankar Singh,

Dr. Anil Jakhar, Dr. C. S. Prabhakar , Dr. S. Raghavana, Dr. Lokesh Meena, Dr. S. K. Mahiddur Rehman, Dr. Shridhar Patil and Dr. Samik Sen Gupta, BAU, Sabour for being a source of motivation to complete the task.

I also cordially acknowledge the assistance extended by all the field and office staff for timely and sincere help especially Joy Sir, Santosh Sir, Shali Chechi, Unni Chettan, Pradeep Chettan, Joy Chettan and all. I also kindly acknowledge my sincere heartfelt gratitude to all the research associates of the Department of Olericulture especially Geethu chechi, Rekha chechi, Praseeda Chechi, Reshma Chechi, Rajeswari Chechi, Divya chechi, Teena chichi and Greeshma Chechi for their whole hearted cooperation and timely assistance.

I duly acknowledge the encouragement and timely persuasions by my dear batchmates, Vikram, Harikumar, Amarnatha, Siddhesh, Remya, Sreeja and Roshin; my juniors Narender Negi, Pawan Saini, Rohit, Yogesh, Sachin, Audumbar, Basavaraj, Yashwant, Arunkumar, Karthika, Airene, Girdhar Gopal, Reshmika, Silpa, Ajinkya and Swapnil, not only in my research work but also throughout my PhD programme. I thank my dear friends Suneel Thakur, Susheel Sharma, Subhash, Vishal, Ashu, Kaza, Sandy Sir, Ritu, Anuradha, Indu, Kusum, Devanshi, Gaurav Kaushik and Varun Roch for their affection, prayers and empathy which gave me enough mental strength to get through all odds and tedious circumstances.

I am very much indebted to the friends which I made during five years at Kerala, without them this journey was not possible, they created homely environment for me far away from my actual home. May I name them as Varun Roch, Adarsh ji, Shine ji, Arun ji, Rajesh Ji, Ajeesh ji, Aswin etc. My special thanks also goes to the office staff of College of Horticulture for helping in every possible manner. Special thanks to Shakeela Mam (Hindi speaking) and Arvind chetta for computer related support.

I am in dearth of words to express my love towards my beloved Parents, Parents – in - laws and my all time loving and inspiring wife Ranjna for their boundless affection, moral support, eternal love, deep concern, prayers and personal sacrifices which sustains peace in my life.

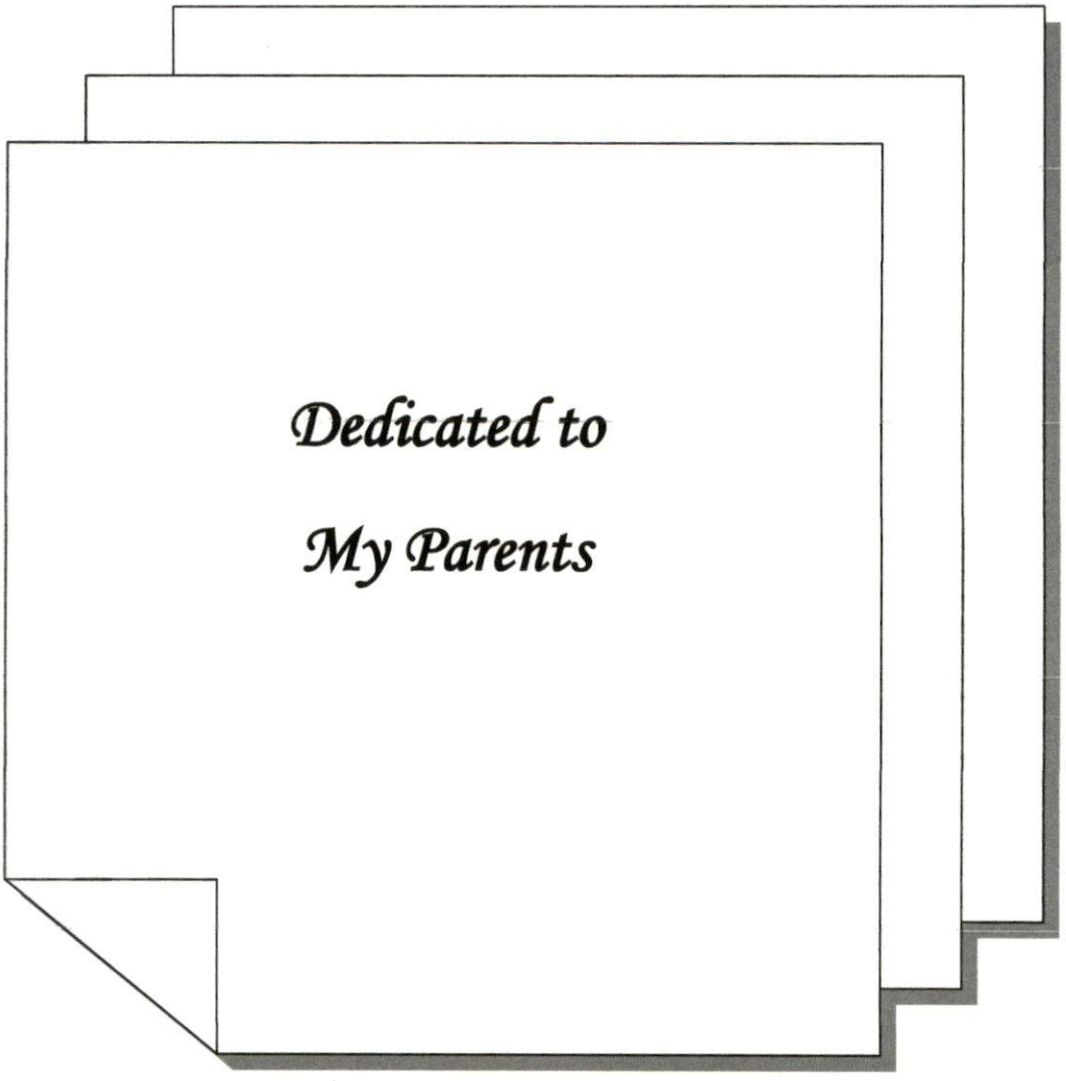
I express my deep sense of gratitude to Kerala Agricultural University, University Grants Commission (UGC), Horticulture library and Central library for informational, financial and technical support for persuasion of my study and research work.

Language seems to be inadequate medium to express my feeling to my Dadaji (Late Sh. Paras Ram Bhardwaj) and my Dadiji (Late Smt. Premi Devi) who though rests in heaven are always in my mind & had always encouraged me to go for higher studies. My words cannot substitute my feelings towards my Nanaji & Naniji, my Uncle & Aunts, younger brothers Vijay, Anuj, Shivam, Deepak, Rocky, Lucky and my sisters Ritu, Eshly, Brisha, Isha, Sonia, Anju, Ritika, Aastha, Kaki and my two dolls Nishka and Advika for their love.

I once again express my heartful thanks to all those who helped me in completing this venture.

Needless, to say, errors and omissions are mine.

Ajay Bhardwaj


Dedicated to
My Parents

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviation	Meaning
1	*et al.*	et alii (and co-workers)
2	i.e.	Id est (that is)
3	*viz.*	Vi delicet (namely)
4	p	Page
5	pp	Pages
6	°C	Degree Celsius
7	g	Gram
8	kg	Kilogram
9	l	Litre
10	/	Per
11	%	Per cent
12	Fig.	Figure
13	cm	Centimeter
14	ml	Milliliter
15	mg	Milligram
16	mm	Millimeter
17	nm	Nanometer
18	a.i.	active ingredient
19	&	And
20	@	at the rate
21	v/s	Against
22	ppm	parts per million
23	MSL	mean sea level
24	df	degree of freedom
25	N	north; normal solution
26	E	East
27	conc.	Concentrated
28	ha	Hectare

29	mM	milli molar
30	μM	micro molar
31	hr	Hour
32	B/W	black and white
33	t	Tones

Introduction

1. INTRODUCTION

Cucumber (*Cucumis sativus* L., 2n = 2x = 14) is an important and very popular vegetable crop, belongs to the genus *Cucumis* of the family Cucurbitaceae, having 118 genera and 825 species (Jeffrey, 1980). It is grown all over the world including tropical and sub-tropical regions and is thought to be indigenous to India (Harlan, 1975) because *Cucumis sativus* var. *hardwickii*, progenitor of cultivated cucumber, is found in the Himalayan foothills of the country. According to de Candolle (1886) cucumber has been cultivated for over 3000 years in India, which has been corroborated by Seshadri and More (2009), that the remains of cucumber in India are very old.

Being an internationally acclaimed warm season vegetable, it is also grown widely in India for its high nutritive value and medicinal properties. It is the fourth important vegetable crop after tomato, cabbage and onion and the second most widely cultivated cucurbit after water melon (Tatlioglu, 1993). Globally cucumber and gherkins are cultivated in an area of 21,78,613 hectares with annual production of 7,49,75,625 tonnes. In India, cucumber and gherkins cover an area of 26,982 hectares with the production of 1,71,100 tonnes (FAO, 2014). The important cucumber and gherkins growing states of India are Arunachal Pradesh, Assam, Bihar, Haryana, Orissa, Punjab, Rajasthan, Uttar Pradesh and West Bengal.

As a vegetable crop, cucumber has tremendous economic importance. It is an ideal summer vegetable crop predominantly grown for its edible tender fruits, preferred as salad ingredient, pickles, dessert fruit and as a cooked vegetable. Its fruits are mainly used as refreshing material due to their low energy content. Cucumbers possess cooling, astringent and antipyretic properties and the fruits are natural remedial options for people suffering from constipation, jaundice and indigestion (Vashista, 1974). In African region, ripe raw cucumber fruits are being used as a cure for spruce, which causes flattening of the villi and inflammation of the

lining of small intestine. In Indo-China region, cooked immature fruits are used to treat dysentery in children (Grubben and Denton, 2004).

Cucumber is also a good source of vitamin C, carbohydrates and phosphorus (Yawalkar, 1985). Takei and Ono (1939) attributed the flavour of cucumber to two compounds, 2,6-nonadenal and 2,6-nonadenol. One hundred gram of edible cucumber fruit contains 96 g water, 0.6 g protein, 0.1 g fat, 2.2 g carbohydrate, 45 IU vitamin A, 0.03 mg vitamin B_1, 0.02 mg vitamin B_2, 0.3 mg niacin, 12 mg vitamin C, 12 mg calcium, 0.3 mg iron, 15 mg magnesium and 24 mg phosphorus (Alcazar and Gulick, 1983).

Sex expression especially gynoecy is an important factor which has a positive effect on yield and constitutes a major component of cucumber improvement programs (Serquan *et al.*, 1997) and this feature can easily be manipulated for production of F_1 hybrids. Another important feature which can be clubbed with gynoecy in cucumber is Parthenocarpy, which occurs within the species of *Cucumis sativus* L. as reported long back by Sturtevant (1890). Parthenocarpy can be defined as the ability to develop fruits without pollination and thus fertilization. The term parthenocarpy was coined by Noll (1902) and he was the first person to observe it in cucumber. Parthenocarpic varieties out yield normal types by about 20 per cent and have better quality (Chen and Cao, 1994). Parthenocarpy circumvents the inhibitory effect of seed creation on succeeding fruit development. The fruit of parthenocarpic cucumber are mild in flavor, without seeds and have edible skin that requires no peeling while eating (Tiwari, 2015).

Hayes and Jones (1916) were the first to demonstrate heterosis in cucumber. Considerable heterosis has been reported in cucumber for various traits such as number of fruits, early and high yield. Heterosis in cucumber has been exploited to its maximum advantage in developed countries. The first commercial hybrid (F_1) in vegetables released for cultivation was in cucumber in 1935 in Japan. The development of hybrid cultivar became easy after gynoecious sex expression was

obtained from Korean cultivar. The gynoecious allele is dominant and gynoecious hybrid cultivars often bear a high proportion of female flowers, resulting in earliness, good yield and give many fruits in a single harvest. At national level, F_1 hybrid 'Pusa Sanyog' has been released from IARI, Katrain (Gill *et al.*, 1973) by crossing gynoecious line, isolated from a Japanese variety 'Kaga Aomoga Fushinavi' with 'Green Long of Naples', an Italian variety, which out yielded the recommended variety by 128.78 per cent.

Utilization of parthenocarpic gynoecious lines in breeding programme favored maximum exploitation of heterosis in cucumber (Kumar *et al.*, 2016). Heterosis has contributed towards increased crop production and it has become the basis of multi-billion dollar agro-business in the world (Phillips, 1999). Hybrid under optimum crop production and protection management, give economically more yield than that the improved varieties and also provides uniform size, earliness, better keeping quality and resistance to biotic and abiotic stresses (Kalloo *et al.*, 2000).

Higher manifestation of hybrid vigour over parents for yield and other characters suggests a tremendous scope for the exploitation of heterosis. The combining ability analysis offers an opportunity to identify best parent which in combination may provide desirable segregants or may be utilized either to exploit heterosis or to accumulate fixable genes. For development of promising F_1 hybrids, the identification of genetically superior parents is an important factor. The lack of progress in improvement of cucumber might be partially due to the meagre breeding effort compared to other crops or lack of variability for yield (Wehner *et al.*, 1989).

True breeding parthenocarpic lines in cucumbers are reported from GBPUAT, Pant Nagar (Singh, 2012), MPKV, Rahuri and IARI, New Delhi (More and Budgujar, 2002). These lines were used for heterosis breeding programme for developing F_1 hybrids. True breeding gynoecious lines in cucumber are reported from University of Wisconsin, Madison, USA. At Indian Agricultural Research Institute, New Delhi, More and Seshadri (1988), attempted the transfer of gynoecy into tropical varieties of

cucumber and thus four stable tropical gynoecious lines *viz.*, 87-304-6, 87-316, 87-319-12 and 87-338-15 were recognized. This was corroborated by the development of parthenocarpic tropical gynoecious cucumber lines (PKG-1 series) in Poona Khira background (More and Munger, 1986). One of these lines was used as female parent for developing tropical gynoecious lines and development of F_1 hybrids at IARI, New Delhi and MPKV, Rahuri (More, 2002).

In Kerala no attempt has been made to exploit parthenocarpy in cucumber. The lack of progress in cucumber breeding might be partially due to the non availability of parthenocarpic and gynoecious lines and conflicts on the information for the inheritance pattern of parthenocarpy. Being a high value vegetable crop suitable to both protected and open cultivation, development of parthenocarpic gynoecious F_1 hybrids in cucumber help to boost the production and ensure more returns to farmers.

Cultivation of parthenocarpic cucumber in greenhouses having partial environment control has been undertaken during last decade in our country. However, very little work has been done for developing varieties and hybrids for protected environment (Singh and Malhotra, 2012). But still, the growers are left with the option of choosing from the private sector hybrids which costs very high (Rs. 4 to 7 per seed) or from very limited public sector hybrids which are yet to be tested at various places. Development of parthenocarpic hybrids along with various useful yield attributing characters is a tedious and very risky affair because if a generation is missed for inducing male flowers or failed under *in vitro* regeneration for seed production which will result in complete loss of genetic material. Thus, there is a need to develop methods for the maintenance of germplasm, and to develop and identify parthenocarpic gynoecious hybrids/cultivars suitable for protected cultivation in different regions of the country.

Hence, the present study 'Development of parthenocarpic gynoecious hybrids in cucumber (*Cucumis sativus* L.) for protected cultivation' was undertaken to isolate

the parthenocarpic lines with improved fruit quality and to develop the parthenocarpic gynoecious hybrids suitable for protected cultivation.

Review of literature

2. REVIEW OF LITERATURE

The available review of literature concerning the research topic is presented under the following headings:

2.1 Parthenocarpy in cucumber

2.2 *In vitro* regeneration of cucumber

2.3 Maintenance of parthenocarpic and gynoecious lines in cucumber with growth regulators

2.4 Development of parthenocarpic gynoecious inbred lines, genetic variability and performance analysis in cucumber

2.5 Combining ability in cucumber

2.6 Heterosis in cucumber

2.1 Parthenocarpy in cucumber

Parthenocarpy is the growth of ovary into seedless fruit in the absence of pollination and fertilization. It may occur naturally or can be induced artificially by exogenous application of hormones or their enhanced endogenous level. Parthenocarpy improves the yield, quality and processing attributes of vegetable crops like cucumber, eggplant and watermelon, where seed is a limiting factor during consumption (Dhatt and Kaur, 2016). This trait proved highly useful to develop fruits under environmental conditions that are unfavorable for successful pollination and fertilization, particularly in green house cultivation and especially in cross-pollinated crops. It is an established fact that phytohormones play an important role in fruit setting and their genetic handling can lead to seedlessness. Apical shoot is considered as source of inhibitors preventing fruit growth in the absence of stimulus like pollination or application of phytohormones (Pandolfini *et al.*, 2009). The exploitation of biotechnological tools can further enhance its utility for the benefit of mankind. Therefore, present review is focused on factors and potential of parthenocarpy in vegetable crops.

Parthenocarpy has an old history of its presence within the species of *Cucumis* as mentioned by Strutevant (1890). Parthenocarpy can be defined as the capability to develop fruits without pollination and fertilization. The term parthenocarpy was introduced by Noll (1902) after observing it for the first time in cucumber. In other words, the process which limits female fertility and allows growth of seedless fruits without fertilization is known as parthenocarpy (Schwabe and Mills, 1981).

The biological function of the fruit is to protect the embryos and seeds during their development and the facilitation of seed dispersal after maturation. The onset of fruit development from the ovary, the so-called fruit set, occurs after fertilization of the ovules (Dhatt and Kaur, 2016). Fertilization of the ovule generally triggers the ovary development into fruit (Nancy, 2015). The processes of seed and fruit development are intimately connected, synchronized and controlled by phytohormones (Pandolfini *et al.*, 2009). Thus, a chain of signaling processes are required for the development of the fertilization products necessary for the initiation of seed and fruit development (Raghavan, 2003). Various phytohormones, especially gibberellins, cytokinins and auxins, are involved in the signaling processes that follow pollination and fertilization and these are the main requirements for further growth and development of seeds and the fruit (Fos *et al.*, 2001). Developing seeds are source of phytohormones and stimulate fruit growth and development (Ozga *et al.*, 2002). However, in some vegetables presence of seeds in fruit are undesirable due to hard or leathery texture, bitter taste and presence of toxic compounds, allergens and affect on the palatability (Dalal *et al.*, 2006). Seedless fruits are desirable for improving the quality of fresh as well as of the processed fruit and it has been observed in cucumber, eggplant watermelon and tomato (Varoquaux *et al.*, 2000; Yin *et al.*, 2006). Therefore, replacing the seeds and seed cavities with edible fruit tissue is an attractive offer to the consumers and challenge to the researchers (Dhatt and Kaur, 2016).

Majority of the studies on causes of abortion and parthenocarpy have focused on the four theoretical determinants for study of the biological problems: causes (physiological, genetical, and ecological), development, evolution, and function (Verdu and Garcia-Fayos, 1998). Several hypotheses were formulated regarding causes and function of abortion (Stephenson, 1981), but parthenocarpy has received less attention. Hypotheses in relation to abortion can be placed into three groups, (i) environmental uncertainty (ii) the male role of hermaphroditic flowers, and (iii) the improvement of the quality of seed produced through selective abscission (Stephenson, 1981). The causes of parthenocarpy include frost damage to the ovule or stimulation by foreign pollen or changes in the competitive balance between vegetative and reproductive structures or a spatial or temporal failure on auxin synthesis (Gillaspy *et al.*, 1993). Burley and Willson (1983) considered that parthenocarpic fruits develop when resources are not limiting, or when there is a developmental error. The role of parthenocarpy has also been considered as an exaptation related to the improbability of seed predation (Traveset, 1993).

Fertilization is generally decisive for fruit set and pericarp development. As fertilized ovules develop into seeds, this influence on pericarp growth continues where production of hormones by the endosperm and developing embryo promotes pericarp growth (Brummell, 2006). The importance of seeds as sources of hormones for initiation and stimulation of fruit growth is implied by fruit response to exogenous hormones in parthenocarpic systems (development of fruit without seeds). Applying auxin and gibberellins to unfertilized embryos is one way of achieving parthenocarpy; another is to use auxin transport inhibitors such as chloroflurenol to prevent loss of auxin from embryos so that a threshold level for pericarp response is exceeded. Studies on parthenocarpy in tomato and cucumber indicate that high auxin levels enhance embryo cell division, and this cell division phase seems to be more critical than subsequent cell expansion in determining final fruit size. Such results entail a cooperative mode of action where gibberellins combined with auxins to start

cell division. Seed cytokinins and cell division are similarly related because tomato seeds accumulate cytokinins that subsequently influence cell division in surrounding pericarp tissue (Gillaspy *et al.*, 1993). Such interdependence between seed development and fruit growth shows up in final fruit size. Parthenocarpic fruit have reduced auxin content and are generally smaller than wild-type fruits.

Chen and Cao (1994) opined that the evidence on the inheritance of parthenocarpy is conflicting, with reports of control by a single partially dominant gene *P* and by three independent major genes with additive and epistatic effects, as well as reports of inheritance typical of quantitative traits. Yan *et al.* (2008) investigated the inheritance of the parthenocarpy in gynoecious cucumbers using a joint analysis of multi-generations derived from crossing a highly parthenocarpic gynoecious line with two non-parthenocarpic inbred lines and found that the inheritance with different genetic backgrounds was fitted into the same genetic model. It was expressed as incompletely recessive and controlled by two additive-dominant-epistatic major genes and additive-dominant polygenes. Yan *et al.* (2012) also analyzed the inheritance of parthenocarpy in cucumber in four generations derived from crosses of a highly parthenocarpic monoecious line and a gynoecious line to a non-parthenocarpic inbred line. The inheritance of parthenocarpy in gynoecious cucumber was controlled by two additive-dominant-epistatic major genes and additive-dominant polygenes, and the major gene heritability of F_2 was 83.5 per cent. While that in monoecious cucumber was controlled by two additive-dominant-epistatic major genes and additive-dominant-epistatic polygenes, and the major gene heritability of F_2 was 42.1 per cent. An incomplete dominant gene *Pc* administers inheritance of parthenocarpy in cucumber. Parthenocarpy circumvents the inhibitory effect of seed creation on succeeding fruit development. The fruits of parthenocarpic cucumber are mild in flavor, without seeds and have edible skin that requires no peeling while eating (Tiwari, 2015).

2.2 *In vitro* regeneration of cucumber

Handley and Chambliss (1979) successfully cultured axillary buds of gynoecious cucumber on MS medium supplemented with 0.1 mg/l NAA and kinetin which resulted in the formation of plantlets. The seedlings obtained were successfully established in green house. Wehener and Locy (1981) reported that when hypocotyl and cotyledon explants from seven day-old cucumber seedlings were established on Murashige and Skoog (MS) medium containing 1 mg/l each of benzyl amino purine (BAP) and NAA, 32.9 per cent of cotyledonary explants produce shoots whereas no shoots were obtained from hypocotyl explants, instead roots were formed from hypocotyl explants.

Custers and Verstappen (1989) used shoots tips and nodal explants from seedlings grown *in vitro* and cultured in MS medium resulted in formation of normal cucumber plant. Organogenesis of cucumber depends upon the type and concentration of auxins used in the culture medium.

Rhonda and William (1990) described a technique for the production of cucumber (*Cucumis sativus* L.) shoots using cotyledon explants in which the axillary bud were removed to promote induction of shoots from adventitious buds in the presence of cytokinins. Cytokinins such as BAP, Kinetin and 2-iP at concentration of 4 mg/l were effective in producing adventitious buds. A yield of 23 shoots per cotyledon was achieved by removal of axillary buds.

Cade *et al.* (1990) observed that when six day old cotyledons were cultured on MS medium supplemented with 0.3 mg/l BAP, 60 per cent shoot production was achieved. Formation of roots was influenced by hormones BAP and NAA among which rooting percentage was high in media supplemented with NAA but lacking BAP. They also reported that somatic embryogenesis can be induced from cotyledonary tissue of cucumber using MS media supplemented with 1 to 2 mg/l 2,4-D and 0.5 mg/l kinetin. It was also found that more plantlets developed on further sub

culturing the tissue after three weeks to multiplication media containing 1 mg/l NAA and 0.5 mg/l kinetin.

Hooymans *et al.* (1994) found that regeneration of shoots was cent per cent with normal morphology from cotyledons of three to five day-old seedlings of cucumber. Induction of buds was noted on MS medium composed of 40 g/l sucrose, 500 mg/l tryptone L 42, 50 μM IAA and 0.1 μM kinetin. The bud later on developed to plants after sub culturing to medium supplemented with 20 g/l sucrose, 500 mg/l tryptone L 42, 0.5 μM kinetin and 0.1 μM IAA.

Misra and Bhatnagar (1995) utilized leaf explants of 14 day-old cucumber seedlings for *in vitro* culture in media containing 5 μM BAP for maximum shoot differentiation. They also found development of roots on further sub culture to MS media supplemented with 1.0 μM of IBA.

Sarowar *et al.* (2003) used shoot–tip explants and cultured it on MS medium containing two plant growth regulators 6-BAP and NAA with various combinations and concentrations for shoot induction. The best results for shoot growth were found with 3 mg/l 6-BAP in MS medium showing the shooting frequency of 84 per cent and with development of five shoots from each explant after 30 days of culture.

Vasudevan *et al.* (2004) cultured shoot tip explants of cucumber cv. Poinsett 76 on MS medium with various nitrogen sources along with optimal concentration of 0.04 mM BA to study their effects on *in vitro* morphogenesis. The explants grown with 0.07 mM L-glutamine displayed the highest culture response (74.6 %) and highest shoot numbers per explant (13.6) after two subcultures.

Mohiuddin *et al.* (2005) found maximum shoot regeneration of 96 and 92 per cent in proximal cotyledon of Spring Swallow (SS) and Tasty Green (TG) cultivars, respectively with $AgNO_3$ at 30 μM combined with 1.0 mg/l BAP. Shoot regeneration from proximal hypocotyl explants of SS (72 %) was also found with the same treatment.

Embryonal axis explants of 2-day-old *in vitro* germinated seeds induced multiple shoots with the combination of 4.44 µM BA and 1.59 µM NAA in MS medium. The shoot buds explants produced the maximum number of shoots per explant (10.6) in MS medium supplemented with 4.44 µM BA and 0.07 mM L-glutamine in three consecutive transfers. The elongated shoots showed rooting on MS medium with 4.92 µM IBA. Survival rate of 65 per cent was achieved in rooted plants when transferred to soil (Vasudevan *et al.*, 2007).

Chovelon *et al.* (2011) used cucumber cotyledons and young leaves from 4 and 13 day-old seedlings, respectively as explants for shoot regeneration. After cutting transversely into four equal pieces and placing on two different regeneration media *viz.*, MS medium with 0.2 mg/l BAP + 0.2 mg/l 2-iP and MS medium with 1.12 mg/l BAP + 0.88 mg/l IAA + 0.26 mg/l abscisic acid (ABA), they observed very low regeneration rates with different explants sources of both genotypes placed on MS medium supplemented with 1.12 mg/l BAP, 0.88 mg/l IAA and 0.26 mg/l ABA. The maximum regeneration rates were found from cotyledon explants cultured on MS medium supplemented with 0.2 mg/l BAP and 0.2 mg/l 2-iP. Shoots were formed in 12 days from each bud, when young main and lateral apices of cucumber were cultured on agar medium containing 20-30 ppm 2-iP. Additionally, both elongation and rooting was achieved on MS medium containing 1.0 ppm each of IAA and 2-iP and 0.03 ppm GA_3.

Kielkowska and Havey (2011) produced flowers on sterile cucumber (*Cucumis sativus* L.) plants grown *in vitro* from seed and micro-propagated shoots produced from stem fragments. Maximum flowers were produced on Murashige and Skoog (MS) medium without plant growth regulators (PGR), as well as with 6 µM of kinetin. Plants cultured on MS medium supplemented with 8.9 µM benzyladenine (BA) and 1.1 µM 1-naphthaleneacetic acid (NAA) failed to flower. *In vitro* grown plants had less and small flowers than greenhouse-grown plants. Male and female flowers were morphologically similar on plants grown *in vitro* from seed as

greenhouse grown plants. The highest pollen viability (72.9±4.2 %) was exhibited by the plants grown from seed on MS medium supplemented with 6 µM Kinetin.

In vitro plantlet regeneration was obtained from cotyledon and hypocotyls segments of 15-20 day old cucumber seedlings. They were cultured on MS semi-solid medium supplemented with BAP (1-5 mg/l), kinetin (1-5 mg/l), IAA (0.5 mg/l) + BAP (1-5 mg/l) and IAA (0.5 mg/l) + kinetin (1-5 mg/l) for shoot proliferation. IAA (0.5 mg/l) + BAP (3 mg/l) medium gave best response for induction of shoots from cotyledon and hypocotyl explants. Rooting was observed on all regenerated plantlets on MS medium supplemented with (1 mg/l) IAA. The regenerated plants grew normally in the green house (Ugandhar *et al.*, 2011).

Pakarla (2013) achieved direct shoot regeneration using cotyledonary explants cultured on MS medium supplemented with different concentrations of kinetin *i.e.* 1.8 mg/l, 2 mg/l, and 2.5 mg/l. The highest number of multiple shoots was obtained with kinetin 2 mg/l. Rooting of the regenerants was observed while using IBA 2 mg/l.

An efficient protocol for *in vitro* multiple shoot formation and subsequent root induction considering various cultural aspects using nodal explants of *Cucumis anguria* L. derived from 20 day - old *in vitro* seedlings was developed by Margaret *et al.* (2014). High multiple shoot regeneration was achieved on MS medium containing BAP (1 mg/l), NAA (0.2 mg/l) and L - glutamine (20 mg/l). Shoot elongation was achieved with MS medium fortified with GA_3 (0.5 mg/l). Rooting was observed in MS medium supplemented with IBA (0.6 mg/l). Seventy per cent survival of plantlets was seen.

Alam *et al.* (2015) developed a rapid and efficient *in vitro* multiplication and regeneration system of cucumber using *in vitro* nodal explants. Among the two cytokinins, BAP was found to be more effective than kinetin at concentration of 1.5 mg/l for best response (87 %) on shoot formation. For shoots development, greater frequency (70 %) was observed with IAA (0.5 mg/l) + BAP (3.0 mg/l). For root

induction, four concentration of NAA were used. The maximum frequency of root formation (83 %) was achieved on MS medium containing 0.5 mg/l NAA within three weeks when isolated *in vitro* raised shoots were cultured.

2.3 Maintenance of parthenocarpic and gynoecious lines with growth regulators in cucumber

The primary principle behind maintaining a gynoecious/parthenocarpic line is for induction of staminate flowers and production of seeds by crossing male and female flowers in isolation. This non-heritable, phenotypic adjustment can be achieved by exogenous application of various chemicals and growth regulators. The commercial production of gynoecious and parthenocarpic gynoecious cucumber seeds was achieved after induction of male flowers with the help of growth regulators for self reproduction (Robinson, 1999). Peterson and Anhder (1960) were the first to accomplish male flower induction with giberellic acid (GA_3) in cucumber. But, due to changeable male flower induction response of GA_3, application of silver nitrate ($AgNO_3$) is followed to induce male flowers. These silver ions hold back ethylene action and thus endorse male flower formation in gynoecious cucumber plants (Beyer, 1976).

In three glasshouse trials, male flower induction in seven gynoecious (ranging from weakly to strongly female) cultivars and lines of pickling and slicing cucumbers with silver nitrate and silver thiosulphate was observed by Nijs and Visser (1980). They found that male flowering happened about three weeks after a single spray at the first true-leaf stage and stayed for about four weeks. The single spray was effective in yield of more male flowers from the first node onwards, than other treatments with GA_3 and almost as many as three consecutive sprayings with $GA_{4/7}$. The silver ions treated plants did not show any elongation and were normal in growth, however the treatments (3 mM and 12 mM) of silver nitrate were phytotoxic. It was concluded that the different results achieved were due to differences in femaleness of the lines and cultivars.

Milotay (1983) revealed that silver compounds were superior than GA compounds for inducing staminate flowers on gynoecious cucumbers. They applied silver nitrate and silver thiosulphate at 600-800 ppm twice at the first true leaf stage for getting the induction of staminate flowers for adequate pollination and seed production. Silver thiosulphate efficiently showed greater stability and less sensitivity to pollution and water quality of the treatment solution.

More and Munger (1986) while experimenting on gynoecious sex expression and stability in two gynoecious cucumber lines and its hybrids, found that genotypic stability showed variation between treatments and genotypes. The F_1 hybrids were found with high gynoecious constancy after one spray of 150 ppm $AgNO_3$ at first true leaf stage. Two applications of 250 ppm $AgNO_3$ at two-true leaf stage inducted more staminate flowers in all the genotypes. Plants exposed to 15 to 20 hours of light produced more male flowers than the ones exposed to light for 10 hours after $AgNO_3$ application.

Scrutu and Scrutu (1995) observed that a single spray with silver thiosulphate or silver nitrate (500 ppm) at the first true leaf stage inducted both male and hermaphrodite flowers in gynoecious plants in the ratio 1.4:1 (range from 1.1:1 to 2.6:1) in the case of silver thiosulphate and 2.6:1 (range from 0.7:1 to 2.75:1) in the case of silver nitrate.

Chaudhary *et al.* (2001) exhibited that $AgNO_3$ was better over $[Ag(S_2O_3)_2]^3$ and GA_3 for male flower induction in gynoecious cucumber, although the effects were variable for different genotypes and environments. They also found that lateral axis application of $AgNO_3$ at 300 and 400 ppm produced the highest sex ratio, and measured it as the best method for maintenance of gynoecious lines.

In an experiment for investigating the effect of $AgNO_3$ concentration (0, 100, 200, 300, 400 and 500 ppm) and number of sprays (once, twice or thrice) on the sex expression of gynoecious parthenocarpic cucumbers, where the initial sprays were

applied at the first true leaf stage, and subsequent treatments were applied at weekly intervals, Hallidri (2004) found that induction of male flowers depended on the $AgNO_3$ concentration and number of times the sprays were scheduled. All treatments with one spray of 100 ppm $AgNO_3$ failed to produce male flowers. The maximum male flowering nodes were achieved with two and three sprays of 400-500 ppm $AgNO_3$. Plants recovered within 7-10 days, which showed the injury symptoms after spraying with 400-500 ppm $AgNO_3$.

Sharma *et al.* (2004) in an experiment studied the use of $AgNO_3$ and GA_3 for maintaining the gynoecious parent with the foliar spraying treatments of $AgNO_3$ at 250 ppm once at 2-3 leaf stage, and twice at 2-3 and 4-6 leaf stages; and at 600 ppm, sprayed before flowering; and GA_3 at 1500 and 2500 ppm before flowering. GA_3 treatment at both concentrations failed to induce male flowers in the gynoecious line. Treatment with two sprays of $AgNO_3$ at 250 ppm was best for induction of maximum number of male flowers (4 males and 1 female) in gynoecious parent with maximum pollen viability (56.20 %). Treatment of $AgNO_3$ at 600 ppm also produced more male buds but with poor pollen viability.

Zhang *et al.* (2007) observed male flower induction with $AgNO_3$ in a gynoecious line of cucumber. They sprayed $AgNO_3$ solution at 0, 100, 200, 300, or 400 mg/l on the gynoecious seedlings of cucumber inbred line S17 at the two, three, and four leaf stages (at 5 day intervals). The best male flower inducing result was obtained with two successive sprays at the two-leaf stage at the rate of 300 mg/l (w/v). The number of induced male flowers was more (in 20 nodes), the node position of the first male flowers was the lowest and the rate of mortality was also minimum.

Nagar *et al.* (2014) investigated the effect of silver nitrate (SN) and silver thiosulphate (STS) concentration, number of sprays and method of applications for induction of staminate flower in parthenocarpic gynoecious cucumber cv. 'Infinity'. Higher dose (400 ppm) of $AgNO_3$ and lower dose (2 mM) of STS was found

effective. Further, twice application was found more effective over once for influencing all the characters in the desired direction. All treatments performed better when applied as foliar application than that of soil application. All treatments, irrespective of dose and methods of application, induced staminate flower in all the plants. Besides, foliar application of STS at 2 mM twice (at 2-3 true leaf stage and thereafter 7 days) followed by SN at 400 ppm twice produced greatest number of staminate flowers (151), more number of staminate nodes (20), earlier staminate flowers (27.83 days) and up to maximum nodes (25.17) in a plant.

Nagar *et al.* (2015) in their experiment during Kharif season under natural ventilated polyhouse (NPV) at Jhalawar, Rajasthan with two chemical treatments of silver nitrate (200 and 400 ppm) and silver thiosulphate (2 and 4 mM) applied once (at 2-3 true leaf stage) and twice (at 2-3 true leaf stage and 7 days after the first application) in soil and as foliar application on ten parthenocarpic gynoecious plants of cv. Infinity and Hilton found that silver thiosulphate and foliar spray performed better over silver nitrate and soil application. Two sprays of the same treatment performed better over single application. Foliar spray of silver thiosulphate @ 2 mM (twice) followed by silver nitrate @ 400 ppm (twice) was found superior for induction of male flowers, staminate flowers (%), total number of staminate flowers/plant, node number up to which staminate flowers appeared and number of pollens per flower in the experimented parthenocarpic gynoecious lines of cucumber. Higher doses of silver nitrate resulted in toxicity on leaves, however the plants recovered within seven to ten days.

2.4 Development of parthenocarpic gynoecious inbred lines, genetic variability and performance analysis in cucumber

Cucumber improvement programmes have been in practice for more than five decades but most of the improvement achieved is in cultural practices and incorporation of better levels of disease resistance. The lack of progress in cucumber breeding might be due to the less breeding efforts as against other crop species or

lack of genetic variability and information on heritability and genetic advance. The success in any crop improvement programme is dependent on the amount of genetic variability available and the methods for its exploitation. In general, the traits which show greater variability possess more genetic advance. The heritability is a parameter which helps in improving selection efficiency based on constituent traits. Greater accuracy should be practiced when heritability and genetic advance are studied simultaneously (Swarup and Chaughale, 1962). High heritability coupled with high genetic gain exhibit additive gene effects (Panse and Sukhatme, 1957). On the contrary, non-additive gene effects (dominance or epistasis) are connected with the traits exhibiting high heritability coupled with low genetic advance.

Solanki and Seth (1980) found phenotypic coefficient of variation ranging from 10.43 for number of fruits per plant to 71.80 for plant height. Low value of genotypic coefficient of variation was observed for number of fruits per plant (5.99) and highest for plant height (69.03). Cucumber genotypes exhibited variation for fruit number in a range of 2.7 fruits per plant to 46.75 fruit per plant, fruit yield in the range from 238 g per vine to 2755 g per vine, weight of first harvested fruits ranging from 14.45 to 62.50 g. Least number of fruit production was connected to fewer female flowers produced and fruit set (Patil and Patil, 1985).

Choudhary *et al.* (1985) recorded maximum range of variation for vine length from 1.76 to 3.16 m, fruit diameter from 4.96 to 5.60 cm. High heritability and low genetic advance for number of days for appearance of first female flower, number of flowers per vine and fruit length were observed, indicating non-additive gene effects.

Prasad and Singh (1992) collected information on heritability derived from data on 13 characters in 23 cucumber genotypes collected from different regions of India. They found that heritability estimates varied from 0.02 (number of fruits) to 48 per cent (fruit length). Low heritability values for number of fruits and yield per plot exhibited that environmental effects had the greater role towards total phenotypic variation.

Saikia *et al.* (1995) found high variability for yield per plant followed by node to first female flower and number of leaves per plant in their study on cucumber. The phenotypic coefficient of variation was highest for yield per plant and lowest for days to first picking. Genotypic coefficient of variation also behaved the same way and indicated that environmental variability was not much to alter the expression of traits.

Staub *et al.* (2002) developed 168 F_2S_6 recombinant inbred lines (RILs) resulting from GY7 × H-19 mating following self-pollination and single seed descent method. Self pollination was done by inducing male flowers in the gynoecious lines using silver thiosulfate.

Gulam-ud-Din *et al.* (2006) found significant differences among all the twenty-five genotypes together with significant variation for all the characters studied. The GCV and PCV values were moderate to high for all the characters with high broad sense heritability and expected genetic gain, except fruit width, which exhibited moderate heritability.

Afangideh and Uyoh (2007) while evaluating eleven exotic and six indigenous cultivars of cucumber (*Cucumis sativus* L.) for yield and quality characteristics, found that total fruit yield was significantly higher ($P < 0.01$) in the indigenous cultivars; while some exotic cultivars like W12757, Ashley, Addis and Regal resulted in longer vines ($P < 0.01$) and minimum days to flowering ($P < 0.05$). Genetic analyses revealed that the magnitude of PCV were higher than GCV in all of the studied traits. Length of vine at 6 weeks showed the highest genetic gain. High heritability (broad sense) estimates of 94 and 85 per cent were observed for days to flower initiation and days to 50 per cent flowering, respectively. Length of vine at 6 weeks, days to flower initiation and days to 50 per cent flowering showed high to moderate genotypic variance, high to moderate heritability and high genetic gain. Selection can be practiced for these characters and their phenotypic expression would be a good indicator for measuring their genotypic potentiality.

While studying variability, heritability, genetic gain, correlation coefficients and path coefficients in 25 diverse cucumber genotypes for fruit yield and yield attributing traits Kumar *et al.* (2008), found wide range of variability for estimates of PCV and GCV for days to first female flower anthesis, number of primary branches/plant, number of fruits/plant, number of node bearing female flowers/plant, fruit length, fruit weight and fruit yield/plant. High heritability coupled with high genetic gain were observed for all characters including 100 seed weight which exhibited additive gene effect for these traits and therefore, are more consistent for effective selection.

Oviedo *et al.* (2008) developed the F_2 population from a commercial hybrid (Natsu suzumi), which was considered as S_0 population. S_1, S_2, S_3, S_4 and S_5 progenies were developed by the 'Single Seed Descent' methodology. Number of leaves, length of the main stem, number and weight of fruits (total and commercial) number of nodes and vines percentage were evaluated in a complete blocks design with seven treatments (different generations of self pollination - S_0 to S_5 and the hybrid Natsu suzumi) and six replications of five plants per plot. For most of the traits studied differences were not found among populations indicating no loss of vigor due to inbreeding.

Mehdi and Khan (2009) reported that there was wide range of phenotypic variation along with high heritability in cucumber. The traits *viz.*, fruit girth (cm), fruit length (cm), fruit weight (g), number of fruits per plant and fruit yield per plant were observed with high GCV and high heritability along with high genetic advance attributing that these traits were controlled by additive gene effects.

Yadav *et al.* (2009) indicated existence of considerable amount of genetic variability for all the traits except cavity of fruit at edible stage in their study on genetic variability, heritability and genetic advance for different characters in 20 cucumber genotypes. They also found maximum phenotypic and genotypic coefficient (PCV and GCV) for number of days to first female flower anthesis. High

heritability (broad sense) high genotypic coefficient of variation (GCV) and high genetic advance were exhibited by some traits.

In an experiment on 11 open pollinated varieties/hybrids of cucumber in open conditions for fruit yield and twelve other characters, Bisht *et al.* (2010) observed significant differences among the genotypes for all the characters except internodal length. High PCV and high GCV were found for number of fruits per plant. Number of fruits per plant and number of nodes on main shoot showed high heritability values.

Hossain *et al.* (2010) recorded high GCV values for yield per plant (42.75 %), number of fruits per plant (33.41 %), fruit length (27.57 %), number of lateral shoots (24.19 %), average fruit weight (22.14 %), petiole length (16.10 %), node order at which male and female flower opened (13.28 and 12.62 %) while experimenting with 58 long type cucumber accessions. Among all cucumber accessions, CSL51 gave the highest yield per plant (2.69 kg).

Gaikwad *et al.* (2011) reported low estimates of GCV as compared to estimates of PCV indicating the apparent modifying effect of environment in the expression of the traits studied in cucumber. The high GCV and PCV estimates were observed for characters such as percent disease index (PDI) followed by length of fruit, number of fruits per vine, weight of fruit and node number of first female flower. They found high heritability estimates (broad sense) for all the characters. The high estimates of genetic advance were also observed for final vine length and weight of fruit.

Dogra (2012) observed sufficient genetic variability for most of the traits studied during summer and winter seasons under modified naturally ventilated greenhouse in mid hills of Himachal Pradesh. Parthenocarpic hybrids Claudia, Isatis, Hilton and Kian were found promising on the basis of mean performance and other desirable horticultural traits. High PCV and GCV estimates were exhibited by nodal

position of first female flower, number of female flowers per node, marketable yield per plant and duration of availability of marketable fruits during spring summer and for number of fruits per plant and marketable yield per plant during autumn winter, High heritability coupled with high genetic advance was obtained for number of fruits per plant and marketable yield per plant during both the environments.

Golabadi *et al.* (2012) studied twenty genotypes of cucumber (*Cucumis sativus* L.) for yield and yield components and reported significant variation between genotypes for the traits studied. A wide phenotypic variation was also observed in the genotypes for studied traits, such as total fruit yield per pickling ranged from 474.3 g (Gohar) to 338.3 g (Tornado). They concluded that selection of superior genotypes for desirable morphologic traits, with high genetic variability could be selected for hybridization programmes and identification of best genotypes for different traits to produce new pioneer hybrids in cucumber.

Singh *et al.* (2012) revealed from their results in an experiment for finding most appropriate hybrid of cucumber for off-season cultivation at the experimental farm of VCSG College of Horticulture, Bharsar, that out of five cultivars, Malini and Pant Shankar Khira-1 were suitable for mid-high hill conditions of Uttarakhand.

Ullah *et al.* (2012) observed high GCV and PCV estimates for yield per plant, fruits per plant, fruit weight and fruit length in cucumber. Broad sense heritability estimates for various traits varied between 42.26 to 89.55 per cent. Veena *et al.* (2012) evaluated thirty-eight advanced lines of cucumber (*Cucumis sativus* L.) for variability, heritability and genetic advance for yield and contributing traits. High GCV and PCV values were recorded for node at first female flower appearance followed by node at first male flower appearance, yield per plant, seed cavity breadth, average fruit weight and number of fruits per plant. High heritability in association with high genetic advance over mean were exhibited by nodes per vine, node at first female flower appearance, days to first female flower opening, days to first male flower opening, days to first harvest, number of fruits per plant, fruit length, fruit

breadth, seed cavity length, seed cavity breadth, number of seeds per fruit and 100 seed weight.

Dutta (2013) evaluated twelve genotypes for ten characters in RBD and found high magnitude of genotypic coefficient of variation (GCV) along with phenotypic coefficient of variation (PCV) for fruit yield per plant, fruit weight, fruit length, number of branches per plant, number of fruits per plant, node at which first female flower appeared and vine length. Moderate level of GCV and PCV was exhibited for days to first flowering. Very low level of GCV along with PCV was observed for fruit width and days to 50 per cent flowering. All the characters exhibited high heritability except fruit width. The highest estimates of genetic advance (as per cent of mean) were noted for fruit yield per plant, number of branches per plant, fruit length, fruit weight, number of fruits per plant and vine length.

Kumar *et al.* (2013) found high phenotypic coefficient of variability (PCV), genotypic coefficient of variability (GCV) and heritability estimates coupled with high genetic gain for yield per plot in thirty diverse genotypes of cucumber collected from different indigenous sources for different horticultural traits which indicated the existence of wide range of variations. The genotype LC-1 was observed with maximum fruit weight and yield per plot.

Basavarajeshwari *et al.* (2014) evaluated fifty-two cucumber (*Cucumis sativus* L.) genotypes for genetic variability, heritability and genetic advance. They observed that variance due to genotypes were highly significant for average fruit weight, length of fruit, number of fruits per vine, flesh thickness and total soluble solids. Moderate to high values of GCV and PCV were exhibited by number of fruits per plant and fruit yield per vine.

Ranjan *et al.* (2015) characterized and evaluated 42 indigenous cucumber accessions including two checks with respect to agro-morphological traits and reaction to different biotic stresses. High (>20 %), PCV and GCV were exhibited by

node number bearing first female flower, primary branches, fruit weight, fruits/plant, shelf-life, 100 seed weight, seeds/fruit. Low GCV (<10 %) was observed in vine length and seed cavity breadth. The estimates of heritability were high (>90 %) for all the characters except primary branch; fruit length with moderate heritability (80-90 %); and vine length, fruit diameter, seed cavity breadth and fruit weight with low heritability (<80 %) indicating major role of genotypes in expression of these characters. Genetic advance as per cent of mean was observed as high (>50 %) for node number bearing first female flower, fruits/plant and seeds/fruit; moderate (40-50 %) for primary branch, fruit weight, shelf-life and 100 seed weight. High heritability coupled with moderate genetic gain was exhibited by fruit length, seed cavity length, shelf-life and seed length.

Karthika (2016) observed significant differences for all the characters in F_1 hybrids and parents, while developing tropical gynoecious lines in cucumber. She noted high heritability with moderate genetic advance for all the characters except for parameters like fruit length, fruit girth and flesh thickness. Among the F_1 hybrids, EC 709119 × CS 127, EC 709119 × IC 410617, EC 709119 × IC 538155 and EC 709119 × IC 538186 were found to be moderately resistant for downy mildew incidence.

2.5 Combining ability in cucumber

The concept of combining ability in terms of genetic variation was first given by Sprague and Tatum (1942) using single crosses in maize. Allard (1960) defined general combining ability as the average performance of a strain in a series of crosses and specific combining ability as the deviation from the performance predicted on the basis of general combining ability. Information on the relative importance of general (GCA) and specific combining ability (SCA) is of significance in breeding programmes for crop species which are amenable to the development of F_1 hybrid cultivars. Such information on combining ability in cucumber would aid the breeder in developing improved hybrids (Tasdighi and Baker, 1981).

Table 2.1 : Literature on general combining ability (GCA) and specific combining ability (SCA) in cucumber for various quantitative traits

Traits	GCA	SCA	References
Length of main vine (cm)	8.53 to 34.85	-17.86 to 29.97	Abhang (1987)
	-33.43 to 26.21	-69.67 to 47.37	Hanchinamani (2006)
	-0.17 to 0.09	0.50	Singh *et al.* (2010)
	-10.28 to 10.41	-	Mule *et al.* (2012)
	-0.69 to 0.83	-0.44 to 0.85	Tiwari (2015)
	-27.36 to 15.55	-34.63 to 42.83	Kaur and Dhall (2017)
Branches/plant	-0.92 to 0.68	-0.86 to 0.87	Lopez- Sese and Staub (2002)
	-0.66 to 0.54	-1.50 to 1.48	Hanchinamani (2006)
	-0.09 to 0.11	0.35	Singh *et al.* (2010)
	-0.82 to 0.63	-1.07 to 1.22	Mule *et al.* (2012)
Days to first female flower anthesis	-0.60 to -2.37	-4.58 to -1.02	Abhang (1987)
	-1.09 to 0.53	-1.23 to 1.27	Lopez-Sese and Staub (2002)
	-2.51 to 1.91	-2.4 to 2.48	Hanchinamani (2006)
	-12.13 to 9.80	-9.42 to 14.94	Dogra and Kanwar (2011)
	-3.64 to 5.66	-2.56 to 3.86	Kumar (2013)

	-1.46 to -0.36	-3.27 to 2.17	Vidhya and Kumar (2014)
	-0.81 to 2.39	-2.03 to 1.64	Tiwari (2015)
Node at which first female flower emerged	-0.24 to -0.65	-2.60 to -0.23	Abhang (1987)
	-0.89 to 0.91	-1.68 to 2.80	Hanchinamani (2006)
	-3.29 to 4.04	-2.57 to 2.07	Dogra and Kanwar (2011)
	-0.84 to 0.54	-1.17 to 0.96	Mule *et al.* (2012)
	-2.04 to 2.06	-1.30 to 1.96	Kumar (2013)
	-0.39 to 0.54	-0.84 to 1.00	Tiwari (2015)
	-0.98 to 0.68	-1.85 to 1.49	Kaur and Dhall (2017)
Days to first harvest	-0.94 to -3.45	-5.35 to -0.40	Abhang (1987)
	-3.13 to 2.08	-3.10 to 3.49	Hanchinamani (2006)
	-12.22 to 9.95	-9.82 to 15.62	Dogra and Kanwar (2011)
	-3.86 to 5.99	-3.07 to 3.85	Kumar (2013)
	-2.50 to 2.00	-4.48 to 4.49	Tiwari (2015)
Duration of the crop	-5.33 to 5.94	-5.50 to 3.60	Kumar (2013)
	-2.00 to 2.50	-4.25 to 4.00	Tiwari (2015)

Fruits/plant	0.31 to 1.18	0.07 to 2.31	Abhang (1987)
	-1.00 to 1.45	-1.46 to 1.44	Lopez-Sese and Staub (2002)
	-1.51 to 2.19	-2.01 to 2.24	Hanchinamani (2006)
	-1.28 to 1.58	-1.99 to 2.69	Dogra and Kanwar (2011)
	-2.37 to 2.78	-3.67 to 4.38	Mule *et al.* (2012)
	-1.92 to 2.04	-1.96 to 1.30	Kumar (2013)
	-0.90 to 0.54	-0.77 to 1.01	Vidhya and Kumar (2014)
	-1.42 to 1.57	-3.28 to 2.30	Tiwari (2015)
	-0.40 to 0.32	-	Golabadi *et al.* (2015)
Yield/ plant (kg)	45.08 to 215.9	49.50 to 421.5	Abhang (1987)
	-0.86 to 0.87	-0.78 to 1.05	Hanchinamani (2006)
	-0.15 to 0.20	0.61	Singh *et al.* (2010)
	-0.38 to 0.30	-0.66 to 1.02	Dogra and Kanwar (2011)
	-0.51 to 0.51	-0.64 to 0.82	Mule *et al.* (2012)
	-14.97 to 14.96	-12.92 to 11.17	Kumar (2013)
	-29.10 to 23.77	-	Golabadi *et al.* (2015)
	-0.16 to 0.14	-0.45 to 0.57	Kaur and Dhall (2017)

Average fruit weight (g)	8.86 to 21.60	5.29 to 42.18	Abhang (1987)
	-38.00 to 17.86	-24.20 to 34.20	Hanchinamani (2006)
	-8.78 to 14.24	46.51	Singh *et al.* (2010)
	-25.25 to 32.75	-38.59 to 55.41	Dogra and Kanwar (2011)
	-12.98 to 19.39	-25.28 to 25.92	Mule *et al.* (2012)
	-40.51 to 55.44	-56.07 to 33.29	Kumar (2013)
	-52.33 to 40.77	-119.3 to 187.5	Vidhya and Kumar (2014)
	-3.47 to 6.10	-	Golabadi *et al.* (2015)
	-36.20 to 35.57	-42.93 to 53.37	Tiwari (2015)
	-21.64 to 13.20	-35.02 to 39.20	Kaur and Dhall (2017)
Fruit length (cm)	0.08 to 0.91	0.07 to 1.77	Abhang (1987)
	-3.05 to 3.08	-4.12 to 4.07	Hanchinamani (2006)
	-1.53 to 1.42	5.30	Singh *et al.* (2010)
	-1.40 to 1.43	-2.48 to 2.62	Dogra and Kanwar (2011)
	-2.16 to 3.07	-2.03 to 2.55	Mule *et al.* (2012)
	-2.19 to 2.93	-3.04 to 2.21	Kumar (2013)
	-2.99 to 2.87	-7.43 to 5.72	Vidhya and Kumar (2014)

	-0.50 to 0.70	-	Golabadi *et al.* (2015)
	-1.31 to 0.92	-2.12 to 2.71	Tiwari (2015)
	-1.90 to 0.70	-1.97 to 3.45	Kaur and Dhall (2017)
Fruit girth (cm)	-0.47 to 0.51	-0.86 to 0.93	Hanchinamani (2006)
	-0.72 to 0.57	2.81	Singh *et al.* (2010)
	0.53 to 0.36	-0.68 to 0.76	Dogra and Kanwar (2011)
	-0.40 to 0.60	-0.79 to 1.30	Mule *et al.* (2012)
	-1.21 to 1.18	-0.38 to 0.78	Kumar (2013)
	-1.94 to 2.20	-5.45 to 5.68	Vidhya and Kumar (2014)
	-0.22 to 0.17	0.18 to 0.50	Golabadi *et al.* (2015)
	-0.45 to 0.35	-0.83 to 0.54	Tiwari (2015)
	-0.37 to 0.34	-0.45 to 0.96	Kaur and Dhall (2017)
Flesh thickness (cm)	0.02 to 0.03	0.06 to 0.21	Abhang (1987)
	-0.30 to 0.41	-0.45 to 1.02	Hanchinamani (2006)
	-0.19 to 0.18	-0.35 to 0.38	Vidhya and Kumar (2014)
Downy mildew PDI (%)	-9.38 to 8.71	-4.99 to 9.59	Kumar (2013)

Parthenocarpy (%)	High	High	El-Shawaf and Baker (1981)
	High	High	Guseva and Mospan (1984)
TSS (°Brix)	-0.02 to 0.04	-0.26 to 0.28	Dogra and Kanwar (2011)
	-0.36 to 0.25	-0.44 to 0.49	Kumar (2013)
	0.03 to 0.10	-0.11 to 0.40	Vidhya and Kumar (2014)
	-0.20 to 0.16	-0.46 to 0.96	Kaur *et al.* (2016)

2.5.1 Reciprocal effects in cucumber

Kanobdee *et al.* (1990) conducted an experiment for combining ability of fruit yield per plant, number of fruits per plant and flesh thickness by using two local and three introduced pickling cucumber varieties. Significant differences among genotypes were obtained for all characters, while reciprocal effect was significant for number of fruits per plant and flesh thickness. Non-additive gene effect was found to control yield per plant, whereas equally important in conditioning number of fruit per plant and flesh thickness.

Chezian *et al.,* (2000) developed 5 × 5 diallel crosses in Eggplant (*Solanum melongena* L.) and analysed for combining ability variances and effects for days to flowering plant height, number of fruits per plant, fruit weight and fruit yield per plant. Among genotypes, SM-124, Pusa Kranti and SM-91 were the best general combiners and exhibiting reciprocal effects in the crosses whenever they were involved as female parents in characters like fruit yield per plant, number of fruits per plant, fruit weight and plant height. Such expression of reciprocal differences was attributed to either cytoplasmic or maternal effects. Hence care should be exercised while utilizing such parents which might exhibit the reciprocal effects for expression of characters.

During the analysis of full diallel for five genotypes and 20 F_1 hybrids, Vidhya and Kumar (2014) assessed combining ability and found the parents, P5 (CS-39), P4 (CS-37) and P3 (CS-17) as best combiners for yield and yield contributing traits. They also observed that the reciprocal hybrids P4 × P5 and P5 × P3 were good specific combiners for the first female flowering, P4 × P3 for the number of fruits and P4 × P5 and P5 × P4 for both tender and ripe fruit weight per vine.

Shen *et al.* (2015), produced double haploids (DH) from divergent cucumber populations, generated reciprocal hybrids in a diallel crossing scheme and estimated combining ability for early plant growth, and also assessed performance differences between reciprocal hybrids with identical nuclear genotypes. They observed significant general, specific combining abilities, reciprocal effects and their interactions with replicated experiments. A mitochondrial mutant (MSC3) was found with negative effects when used as the male due to paternal transmission of mitochondria, but not as the female parent. Reciprocal hybrids among wild-type DH parents differed significantly for dry and fresh weights across experiments, indicating that cucumber breeders should evaluate both directions of crosses when producing hybrid cultivars.

2.6 Heterosis in cucumber

The term heterosis was coined by Shull (1914) and explained it as "Interpretation of increased vigour, size, fruitfulness and speed of development, resistance to diseases and insect pests, or climate vigour of any kind, manifested by crossbred organism as compared with corresponding inbreds, as the specific results of unlikeness in the constituents of the uniting parental gametes". It can be divided into three types, depending upon those parents or checks with which the performance of the hybrid is compared. The three type of heterosis are (i) relative heterosis: the increase or decreased vigour of the hybrid over mid parental value (Richey, 1922), (ii) heterobeltiosis: the superiority of the heterozygote/hybrid over the better parent (Bitzer *et al.*, 1968; Fonesca and Patterson, 1968) and (iii) standard heterosis: the

increased or decreased vigour of the hybrid over standard check variety (Tysdal *et al.*, 1942).

Allard (1960) defined heterosis as the hybrid vigour, such that the F_1 hybrid falls outside the range of parents with respect to one or more character(s). Heterosis in seeded cucumber was first reported by Hayes and Jones (1916). They reported 24 to 30 per cent increase in yield over better parents. Heterosis was reported for various other traits in cucumber by Hutchins (1938) and Robinson and Whitaker (1974).

Table 2.2 : Literature on relative heterosis (RH), heterobeltiosis (HB) and standard heterosis (SH) in cucumber for various quantitative traits

Traits	**Heterosis (%)**	**Researchers**
Length of main vine (cm)	22.60 (SH)	Vijayakumari *et al.* (1993)
	58.14 (RH) 32.51(HB) 25.90 (SH)	Gayathri (1997)
	19.70 (HB) 19.00 (SH)	Bairagi *et al.* (2005)
	34.05 (RH)	Yadav *et al.* (2008)
	-56.04 to 30.74 (RH) -46.02 to 14.52 (HB)	Hanchinamani and Patil (2009)
	33.12 (HB)	Singh *et al.* (2010)
	Positive (SH)	Batakurki *et al.* (2011)

	21.35 (HB)	Mule *et al.* (2012)
	-21.51 to 86.35 (HB) -34.84 to 48.47 (SH)	Airina (2013)
	-51.54 to 24.21 (HB) 30.17 to 178.97 (SH)	Arya and Singh (2014)
	8.08 to 11.26 (HB) -8.18 to 10.78 (SH)	Sharma *et al.* (2016)
Branches/plant	51.41(RH) 46.0 (HB) 45.9 (SH)	Gayathri (1997)
	9.46 to 21.46 (HB) 15.63 to 68.31(SH)	Singh *et al.* (1999a)
	46.1(HB) 21.0 (SH)	Bairagi *et al.* (2005)
	10.83 (HB) 15.06 (RH)	Pandey *et al.* (2005)
	60.88 (RH)	Yadav *et al.* (2008)
	29.00 (HB)	Singh *et al.* (2010)
	41.67 (HB)	Mule *et al.* (2012)

	-42.22 to 37.50 (HB) -18.18 to 72.78 (SH)	Airina (2013)
	-11.55 to 26.67 (HB) -5.32 to 32.89 (SH)	Sharma *et al.* (2016)
Days to first female flower anthesis	22.2 (HB, Rainy) 14.2 (HB, Summer)	Hormuzdi and More (1989)
	15.5 (SH)	Vijayakumari *et al.* (1993)
	-14.29 (RH) -10.29 (HB) -14.41(SH)	Gayathri (1997)
	-15.1 (HB) -13.0 (SH)	Bairagi *et al.* (2005)
	-11.72 to 82.65 (HB) -17.72 to 65.19 (SH)	Dogra *et al.* (2007)
	-7.92 (RH)	Yadav *et al.* (2008)
	-0.52 to 16.49 (RH) -1 to -19 (HB)	Hanchinamani and Patil (2009)
	-0.53 to -9.51(HB) -2.89 to -17.84 (SH)	Kumar *et al.* (2010)

	-12.71 (RH) -8.83 (SH) -8.99 (HB)	Kumar (2013)
	-4.46 to 12.74 (HB)	Airina (2013)
	28.17 to 5.43 (HB) -35.86 to -15.61 (SH)	Arya and Singh (2014)
	-9.98 to 9.28 (HB) -12.98 to 6.28 (SH)	Sharma *et al.* (2016)
Node at which first female flower emerged	43.8 (HB, Rainy) 53.2 (HB, Summer)	Hormuzdi and More (1989)
	37.3 (SH)	Vijayakumari *et al.* (1993)
	53.41(HB) 51.89 (SH)	Dogra *et al.* (1997)
	-27.3 (RH) -38.5 (HB)	Gayathri (1997)
	-13.85 to -33.19 (HB) 0.0 to -21.36 (SH)	Singh *et al.* (1999a)
	-24.7 (HB) 48.0 (SH)	Bairagi *et al.* (2005)

	-40 to 62.5 (HB) -38.46 to 207.69 (SH)	Dogra *et al.* (2007)
	-29.10 (RH)	Yadav *et al.* (2008)
	0 to 46.15 (RH) -9.52 to -47.61(SH)	Hanchinamani and Patil (2009)
	16.32 (SH)	Singh and Ram (2009)
	-16.31(HB)	Kushwaha *et al.* (2011)
	-30.06 (HB)	Mule *et al.* (2012)
	-43.64 (RH) -37.87 (HB) -49.26 (SH)	Kumar (2013)
	-33.33 to 23.53 (HB)	Airina (2013)
	-65.45 to 532.08 (HB) 70.91 to 549.75 (SH)	Arya and Singh (2014)
	-10.06 to 34.23 (HB) -15.14 to 14.29 (SH)	Sharma *et al.* (2016)
Days to first harvest	61.71(HB)	Kumbhar *et al.* (2005)
	-10.32 to 74.29 (HB)	Dogra *et al.* (2007)

	-11.58 (RH) -8.34 (HB) -8.38 (SH)	Kumar (2013)
	-21.43 to 6.60 (HB)	Airina (2013)
	-10.00 to 15.99 (HB) -12.20 to 10.15 (SH)	Sharma *et al.* (2016)
Number of harvests	-7.89 to 112.5 (HB) -11.76 to 64.71 (SH)	Airina (2013)
Duration of the crop	15.15 (RH)) 6.99 (HB)	Gayathri (1997)
	-13.81 to 57.46 (SH) -1.92 to 7.06 (HB) -1.50 to 12.54 (SH)	Kumar *et al.* (2010)
	10.78 to 19.36 (SH)	Airina (2013)
	-18.89 to 15.59 (HB) -6.58 to 29.85 (SH)	Sharma *et al.* (2016)
Fruits/plant	94.8 (SH)	Vijayakumari *et al.* (1993)
	75.80 (RH) 62.38 (HB)	Gayathri (1997)

	42.32 (SH)	
	67.12 (HB)	Kumbhar *et al.* (2005)
	67.7 (HB) 22.2 (SH)	Bairagi *et al.* (2005)
	43.51 (HB) 52.79 (RH)	Pandey *et al.* (2005)
	-45.71 to 15.79 (HB) -50 to 25.18 (SH)	Dogra *et al.* (2007)
	22.2 (RH)	Yadav *et al.* (2008)
	-24.99 to 42.49 (RH) -37.93 to 27.59 (HB)	Hanchinamani and Patil (2009)
	48.58 (SH)	Singh and Ram (2009)
	0.84 to 25.21 (HB) 7.70 to 55.13 (SH)	Kumar *et al.* (2010)
	110.59 (HB)	Kushwaha *et al.* (2011)
	66.7 (HB)	Mule *et al.* (2012)
	-46.3 to 45.5 (HB) -31.90 to 45.07 (SH)	Singh *et al.* (2012)

	77.13 (RH) 68.03 (HB) 25.05 (SH)	Kumar (2013)
	-29.94 to 271.05 (HB) 1.35 to 244.59 (SH)	Airina (2013)
	-74.40 to 16.08 (HB) -69.87 to 118.92 (SH)	Arya and Singh (2014)
	-1.42 to 72.50 (HB) -2.42 to 70.75 (SH)	Sharma *et al.* (2016)
Yield/ plant (kg)	247.3 (HB)	Hormuzdi and More (1989)
	51.34 (HB) 51.15 (SH)	Dogra *et al.* (1997)
	111.80 (RH) 106.92 (HB)	Gayathri (1997)
	146 (RH) 83.1 (HB)	Cramer and Wehner (1999)
	32.55 (SH)	Singh *et al.* (1999a)
	187.80 (SH)	Singh *et al.* (1999b)

	88.92 to 147.34 (RH) 62.29 to 136.39 (HB) 64.21 to 90.08 (SH)	Rawat (2002)
	145.9 to184.2 (SH)	More (2002)
	45.5 (HB) 20.2 (SH)	Bairagi *et al.* (2005)
	80.69 (HB)	Kumbhar *et al.* (2005)
	29.2 -45.0 (SH)	Munshi *et al.* (2005)
	-46.07 to 38.79 (HB) -47.97 to 38.25 (SH)	Dogra *et al.* (2007)
	-19.03 to 60 (RH)	Yadav *et al.* (2008)
	-43.43 to 60.47 (RH) -50.51 to 31.73 (HB)	Hanchinamani and Patil (2009)
	65.50 (SH)	Singh and Ram (2009)
	-0.53 to 44.82 (HB) 2.85 to 44.81(SH)	Kumar *et al.* (2010)
	80.95 (HB)	Singh *et al.* (2010)
	136.49 (HB)	Kushwaha *et al.* (2011)

	57.96 (HB)	Mule *et al.* (2012)
	0.87 to 34.45 (HB) 43.77 to 70.81 (SH)	Singh *et al.* (2012)
	148.25 (RH) 141.80 (HB) 55.44 (SH)	Kumar (2013)
	-24.28 to 445.82 (HB) -2.74 to 309.93 (SH)	Airina (2013)
	-77.86 to 27.08 (HB) -78.52 to 77.78 (SH)	Arya and Singh (2014)
	-6.97 to 91.63 (HB) -14.21 to 79.91 (SH)	Sharma *et al.* (2016)
Average fruit weight (g)	48.78 (RH) 33.19 (HB)	Gayathri (1997)
	7.1 (RH) 5.4 (HB)	Cramer and Wehner (1999)
	16.2 (HB) 13.9 (SH)	Bairagi *et al.* (2005)

	100.08 (HB) 140.66 (RH)	Pandey *et al.* (2005)
	-25.44 to 18.75 (HB) -21.74 to 40.99 (SH)	Dogra *et al.* (2007)
	28.39 (RH)	Yadav *et al.* (2008)
	18.9 (SH)	Singh and Ram (2009)
	-29.12 to 15.33 (RH) -25.69 to 13.28 (SH)	Hanchinamani and Patil (2009)
	7.29 to 22.96 (HB) 7.07 to 22.96 (SH)	Kumar *et al.* (2010)
	30.09 (HB)	Singh *et al.* (2010)
	58.91(HB)	Kushwaha *et al.* (2011)
	22.68 (HB)	Mule *et al.* (2012)
	-46.5 to 33.3 (HB)	Singh *et al.* (2012)
	46.29 (RH) 43.83 (HB) 45.41 (SH)	Kumar (2013)
	-26.63 to 5.79 (HB) -33.28 to -10.06 (SH)	Arya and Singh (2014)

	-18.86 to 27.92 (HB) -21.86 to 24.89 (SH)	Sharma *et al.* (2016)
Fruit length (cm)	12.54 (RH) 12.16 (HB) 30.0 (SH)	Gayathri (1997)
	-60.20 (HB) to -41.78 -46.04 to 10.99 (RH)	Pandey *et al.* (2005)
	-27.62 to 25.88 (HB) -14.30 to 20.60 (SH)	Dogra *et al.*(2007)
	34.89 (RH)	Yadav *et al.* (2008)
	-15.24 to 44.45 (RH) -29.27 to -6.63 (HB)	Hanchinamani and Patil (2009)
	16.56 (SH)	Singh and Ram (2009)
	11.76 to 33.11(HB) 12.32 to 44.70 (SH)	Kumar *et al.* (2010)
	27.81 (HB)	Singh *et al.* (2010)
	25.22 (HB)	Kushwaha *et al.* (2011)
	22.35 (HB)	Mule *et al.* (2012)

	-49.25 to 13.39 (HB) -44.24 to 26.60 (SH)	Singh *et al.* (2012)
	37.14 (RH) 34.75 (HB) 41.02 (SH)	Kumar (2013)
	-24.69 to 13.78 (HB)	Airina (2013)
	-24.13 to -7.70 (HB) 9.28 to 21.53 (SH)	Arya and Singh (2014)
	-44.21 to 22.71 (HB) -7.47 to 66.82 (SH)	Sharma *et al.* (2016)
Fruit girth (cm)	20.81 (RH)	Gayathri (1997)
	18.26 (RH)	Pandey *et al.* (2005)
	-23.84 to 7.86 (HB) -11.89 to 27.89 (SH)	Dogra *et al.*(2007)
	56.03 (RH)	Yadav *et al.* (2008)
	-15.52 to 24.35 (RH) -25.69 to 13.28 (HB)	Hanchinamani and Patil (2009)
	9.52 (SH)	Singh and Ram (2009)
	27.30 (HB)	Singh *et al.* (2010)

	1.26 to 25.18 (HB) 7.07 to 17.97 (SH)	Kumar *et al.* (2010)
	16.0 (HB)	Kushwaha *et al.* (2011)
	35.94 (HB)	Mule *et al.* (2012)
	38.44 (RH) 14.69 (HB) 17.55 (SH)	Kumar (2013)
	-6.08 to 19.50 (HB) -20.15 to 50.00 (SH)	Airina (2013)
	-16.27 to 13.89 (HB) -17.07 to 8.12 (SH)	Arya and Singh (2014)
	-25.93 to 14.08 (HB) -13.22 to 34.57 (SH)	Sharma *et al.* (2016)
Flesh thickness (cm)	-32.93 to 26.67 (HB) -38.75 to 48.44 (SH)	Dogra *et al.* (2007)
	Positive (SH)	Batakurki *et al.* (2011)
	-32.17 to 10.53 (HB) -12.33 to 40.00 (SH)	Airina (2013)

Downy mildew PDI (%)	-35.02 (RH) -22.95 (HB) -37.61 (SH)	Kumar (2013)
TSS (˚Brix)	14.29 (RH) 12.50 (HB) 18.66 (SH)	Kumar (2013)
	-11.40 to 25.29 (HB) -9.39 to 19.05 (SH)	Sharma *et al.* (2016)

Materials and methods

3. MATERIALS AND METHODS

The present study 'Development of parthenocarpic gynoecious hybrids in cucumber (*Cucumis sativus* L.) for protected cultivation' was carried out at Department of Olericulture, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur during the period of 2012-2017. The field experiments were conducted at rainshelter and polyhouses of the department. The lab experiments were conducted in the biotechnology laboratory, Department of Olericulture, KAU, Thrissur.

The field experimental site was located at an altitude of 22.5 m above MSL between 10°32'N latitude and 75°16'E longitude. The location experienced warm humid climate. Soil of experimental site was textured class of sandy loam and was acidic in pH (5.7).

3.A Experimental materials and methods

3.A.1 Experimental materials

Experimental materials consisted of nine cucumber (*Cucumis sativus* L.) genotypes, including four parthenocarpic lines collected from different parts of the country, a stable gynoecious inbred introduced from University of Wisconsin, USA and four F_1 parthenocarpic gynoecious hybrids. Name and source of genotypes are presented in Table 3.1.

Table 3.1 : List of cucumber accessions/varieties collected

S. No	Accession/ Variety	Source
1.	CS 132	Local collection from H. P.
2.	CS 133	Local collection from H. P.
3.	CS 130	GBPUAT, Pant Nagar

4.	CS 131	GBPUAT, Pant Nagar
5.	EC 709119 (Gy-14)	University of Wisconsin, USA
6.	Hilton (F_1)	Nickerson Zwaan, Holland
7.	Isatis (F_1)	Nunhems India Pvt. Ltd
8.	Asma (F_1)	Tropica Seeds Pvt. Ltd
9.	Aviva (F_1)	Tropica Seeds Pvt. Ltd

3.A.2 Experimental methods

3.A.2.1 Maintenance of parthenocarpic lines through tissue culture

For conducting the study four genotypes of cucumber were included (Table 3.2). Three sex forms/types of cucumber *viz.*, gynoecious, parthenocarpic and monoecious respectively were taken.

Table 3.2 : Details of genotypes used for tissue culture

Genotype	Sex form/type	Variety
G_1	Gynoecious cucumber	EC 709119 (GY-14)
G_2	Parthenocarpic cucumber	CS 130
G_3	Parthenocarpic cucumber	CS 131
G_4	Monoecious cucumber hybrid	L-04

The study was carried out in two phases namely *in vitro* seed germination, *in vitro* regeneration using cotyledonary leaf explants and *in vitro* regeneration through stem nodal explants. Details of these are given under following sub heads :

3.A.2.1.1 *In vitro* seed germination and *in vitro* regeneration of cucumber genotypes from cotyledonary leaf explants

The seeds of cucumber were washed in running tap water for three minutes and then washed repeatedly in double distilled water. The seeds were then soaked in mild detergent and 0.1 g Bavistin in 100 ml water for 10 minutes and were rinsed five times with distilled water. These were then sterilized in 50 per cent ethyl alcohol for five minutes and repeatedly washed in double distilled water for 3-4 times. The seeds were then surface sterilized with 0.05 per cent mercuric chloride ($HgCl_2$) for five minutes and rinsed five times in sterile distilled water. The sterilized seeds were then placed on half strength MS basal medium (Murashige and Skoog, 1962) solidified with agar for germination in 250 ml culture bottles, three seeds were cultured per bottle containing 30 ml of medium. This was incubated in dark at 26 °C till it germinated and then transferred to cool-white-fluorescent light room and incubated at 24±2 °C and allowed to grow. The data were recorded for days to 50 per cent germination, days to 100 per cent germination and germination percentage. The plant after reaching a height of five centimeters was taken in an aseptic condition and cotyledons were excised using a sterile scalpel and cut into two leaf sections. The seedling excised cotyledonary leaf explants were then placed on eight different media compositions of BAP and IAA in test tubes with half strength MS medium containing three per cent w/v sucrose (Table 3.3). The pH of the media was adjusted to 5.8±0.1 with 1 N HCL or 1 N NaOH and then solidified with agar and autoclaved at 121 °C at 15 *psi* for 15-20 minutes. Single cotyledonary leaf explants were inoculated in each culture tube and incubated at 25 ± 2 °C under white fluorescent light for 16 hrs light/8 hrs dark period. The data were recorded for shoot, root and callus initiation along with response (%) for consecutive three weeks.

Table 3.3 : Details of media composition for cotyledonary leaf explants

Media	Composition
M_1	Half MS (basal media)
M_2	Half MS + 2 mg/l BAP
M_3	Half MS + 0.25 mg/l IAA
M_4	Half MS + 0.25 mg/l IAA + 1 mg/l BAP
M_5	Half MS + 0.25 mg/l IAA + 2 mg/l BAP
M_6	Half MS + 0.50 mg/l IAA
M_7	Half MS + 0.50 mg/l IAA + 1 mg/l BAP
M_8	Half MS + 0.50 mg/l IAA + 2 mg/l BAP

3.A.2.1.2 *In vitro* regeneration of cucumber genotypes from stem nodal explants

The stem nodal explants were also taken from polyhouse grown plants for *in vitro* culture of four cucumber genotypes (Table 3.4). The plants of all the four genotypes of cucumber were sprayed with Bavistin @ 1 g/l twice at 6 and 24 hrs before taking the tender stem nodal cuttings. Then these cuttings were wiped with 70 per cent alcohol cotton swabs.

These stems were cut 2-3 cm below the node and 1-2 cm above the node. The bottom portion of the nodes was given a slant cut with the help of sterile blade. The cuttings were then soaked in mild detergent and Bavistin (0.1 g/100 ml distilled water) for 10 minutes and rinsed with distilled water for five times. These were then sterilized in 50 per cent ethyl alcohol for five minutes and washed again in double distilled water for 3-4 times.

The nodal cuttings were then surface sterilized with 0.05 per cent mercuric chloride ($HgCl_2$) for five minutes and rinsed five times in sterile distilled water. The sterilized stem nodal explants were then placed on two different media compositions in the test tubes containing 15 ml medium (Table 3.4). The pH of the media was adjusted to 5.8±0.1 with 1 N HCL or 1 N NaOH and then solidified with agar and autoclaved at 121 °C at 15 *psi* for 15-20 minutes.

Single stem nodal explants were inoculated in each culture tube and incubated at 24±2 °C under white fluorescent light for 16 hrs light/8 hrs dark period. The data were recorded for shoot, root and callus initiation along with response (%) for consecutive three weeks.

Table 3.4 : Details of media composition for stem nodal explants

Media	Composition
A_1	Half MS (basal media)
A_2	Full MS + 1.5 mg/l IAA + 2 mg/l BAP

3.A.2.1.3 Pollen fertility test

Anthers from *in vitro* developed male flowers were extracted and their pollen grains were recovered by crushing on the glass slide. A drop of one percent acetocarmine solution (ready to use; Make-Merck) was poured on the crushed anthers. The pollen grains were thoroughly mixed with stain. Prepared glass slide was covered with cover slip and observed under light microscope. Pollen grains which took the red stain were termed as fertile and without stain were termed as sterile.

3.A.2.1.4 Evaluation of regenerated plants in the polyhouse

The regenerated plants were then placed in cocopeat mixture bags in shade for hardening for two to three days in high humidity conditions and were then

transplanted in polyhouse for observing their sex expression. The data on survival percentage was recorded.

3.A.2.2 Induction of male flowers in parthenocarpic lines

The plants were subjected to foliar spray of various silver thiosulphate treatments at 2-4 leaf stage for male flower induction in gynoecious and parthenocarpic genotypes. Plants were sprayed twice a week in all the treatments. Details of genotypes used are given in Table 3.5.

Table 3.5 : Details of genotypes used for induction of male flowers

Genotype	Sex form/type
EC 709119	Gynoecious cucumber
CS 132	Parthenocarpic cucumber
CS 133	Parthenocarpic cucumber
CS 130	Parthenocarpic cucumber

The treatments were designed (Table 3.6) as per the literature available and executed in the same pattern as suggested in various reviews.

Table 3.6 : Details of silver thiosulphate treatments used for induction of male flowers

Treatment	Details
T_1	Spray of 150 ppm silver thiosulphate
T_2	Spray of 300 ppm silver thiosulphate
T_3	Spray of 450 ppm silver thiosulphate
T_4	Spray of 600 ppm silver thiosulphate

Observations for male flower induction were recorded for the following characters :

1. Days to anthesis of first staminate flower - Days were counted for the anthesis of first male flower after transplanting.
2. Node at which first staminate flower induced - Node at which first staminate flower inducted was noted.
3. Node upto which staminate flowers appeared - Node upto which the male flowers appeared was noted.

3.A.2.3 Inbred development

The experiment was carried out in rainshelter and polyhouses of Department of Olericulture, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur. Populations were collected from various parts of the country. This was considered as the initial population, called the I_0 population (Figure 3.1). All the plants of this population were self-pollinated in order to obtain the I_1, I_2, I_3, I_4 and I_5 progenies, through successive self-pollination using the SSD method (Single Seed Descent), proposed by Brim (1966). Population I_1 was obtained by mixing seeds of progenies of I_1 which showed parthenocarpic fruit development at the lower nodes (first ten nodes) and each progeny participated with the same number of seeds. The same procedure was performed for other generations to obtain populations I_2, I_3, I_4 and I_5. Self pollinations were made by selecting and covering well developed female buds with butter paper bags at evening hours on the day before anthesis. In the same way, the male buds of the same parents were selected and covered which were inducted through the application of silver thiosulphate solution. Anthesis took place between 5.30-7.00 am. Stigmatic receptivity is reported only for a short period and hence pollination was conducted within two hours after anthesis. At this time, pollen collected from covered male buds were brushed on to the stigma of covered female flowers and tagged. The selfed female flowers were kept covered for two more days, till the fruit developed to avoid foreign pollen contamination. The developed fruits

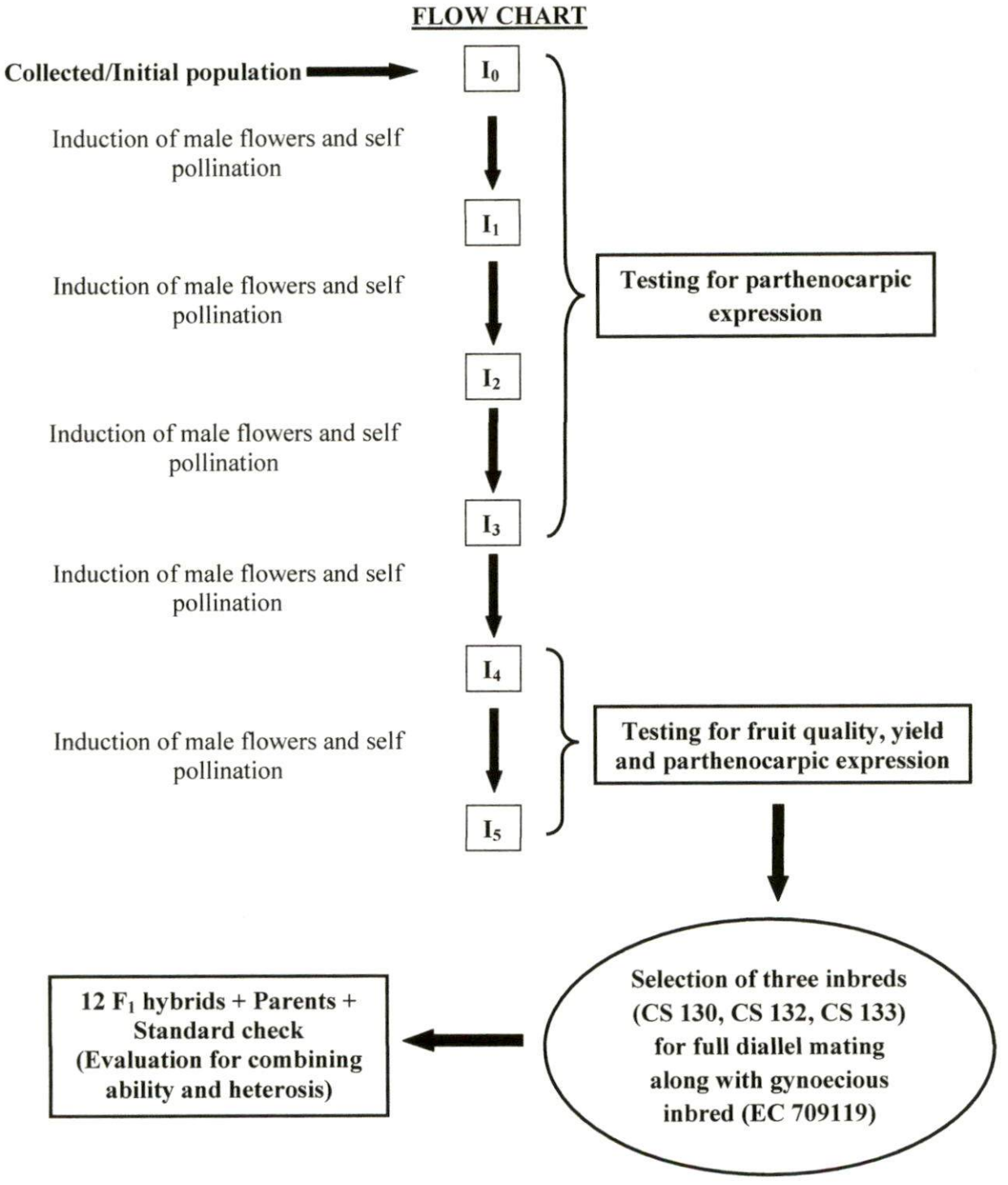


Figure 3.1 Flow chart of methodology adopted for parthenocarpic gynoecious hybrid development

were covered with perforated polythene bags. Seeds from all the self pollinated fruits were collected at seed maturity and stored in common refrigerator after drying in partial shade. Observations on various traits were recorded from I_0 to I_3 progenies raised from selected genotypes.

3.A.2.4 Evaluation of inbreds for isolation of improved parthenocarpic lines

The evaluation data of I_4 and I_5 progenies (generations) was recorded which was done in the saw toothed naturally ventilated polyhouse in North-South orientation along with commercial hybrids of parthenocarpic cucumbers for various quantitative and qualitative characters in randomized block design (RBD) with three replications in two seasons of 2014 *i.e.* January 2, 2014 transplanting and August 1, 2014 transplanting.

3.A.2.5 Diallel mating

The crosses were made in between one gynoecious inbred and three parthenocarpic inbreds in I_5 generation in the following fashion (Table 3.8):

Table 3.7 : Crossing pattern of selected parents in diallel mating design

Parents	EC 709119	CS 130	CS 132	CS 133
EC 709119	Self	EC 709119 × CS 130	EC 709119 × CS 132	EC 709119 × CS 133
CS 130	CS 130 × EC 709119	Self	CS 130 × CS 132	CS 130 × CS 133
CS 132	CS 132 × EC 709119	CS 132 × CS 130	Self	CS 132 × CS 133
CS 133	CS 133 × EC 709119	CS 133 × CS 130	CS 133 × CS 132	Self

3.A.2.6 Evaluation of parents and F_1 hybrids

In the summer season *i.e.* from March 20, 2017, the four parents, 12 hybrids including reciprocals with one commercial check 'Hilton' (F_1) were evaluated in a randomized block design (RBD) with three replications in the saw toothed naturally ventilated polyhouse (20 m × 20 m) oriented in North-South direction with the

spacing of 1.5 m × 0.50 m (bed system with drip irrigation). There were six plants/replication. Seedlings raised in protrays were transplanted after 14th day on raised beds covered with polythene mulch (B/W 25 micron). FYM was applied at the rate of 20 kg/m^2 during the preparation of bed. Fertilizer was applied at the rate of 120 kg N, 100 kg P and 160 kg K per hectare (IIHR, 2012) through fertigation. Twenty per cent of N and K, and entire quantity of P were applied as basal dosage. Fertigation was given through inline dripper starting from 3rd week after transplanting at a frequency of twice a week. The crop was trained vertically on nylon floriculture net. During the cropping period various cultural practices were adopted as per KAU Package of Practices (2011).

3.B Plant characters studied

Observations on important vegetative, fruit and yield characters were recorded from four randomly selected plants. Procedures followed for recording observations on quantitative and qualitative traits are furnished below. Two sets of observations were recorded, one for the isolation of parthenocarpic lines with improved fruit quality and another for the evaluation of F_1 hybrids.

3.B.1 For the isolation of parthenocarpic lines with improved fruit quality

1. Days to first female flower anthesis - Number of days was counted from the date of transplanting to the date when first female flower opened.
2. Node at which first female flower emerged - Nodes were counted from the lowest to the one at which the first female flower emerged.
3. Parthenocarpy (%) – Five flowers were bagged and fruit development was observed. The percentage was recorded for the development of fruits out of bagged flowers.
4. Sex form – The plants were characterized as per the flowering pattern observed into androecious/gynoecious/andromonoecious/gynomonoecious/hermaphrodite/ parthenocarpic gynoecious.

5. Average fruit weight (g) - Weight of five fruits at third harvest was recorded and average was calculated.
6. Fruit length (cm) - Length of five fruits at third harvest was recorded and average was calculated.
7. Fruit girth (cm) - Girth of five fruits at third harvest was recorded and average was calculated.
8. Flesh thickness (cm) - Flesh thickness of fruits at central part from five selected fruits after cutting vertically was recorded separately and average was calculated.
9. Days to harvest - Number of days taken from transplanting to the harvest of first formed tender fruit in each plant was recorded.
10. Density of prickles at harvestable maturity – The plants were characterized based on the prickles present on the fruit surface at harvestable maturity (dense/sparse).
11. Colour of prickles on fruit at emergence and senescence – The colour of prickles was noted for the fruits as brown or black.
12. Stem pubescence – The presence or absence of stem hairs was noted and the plants were grouped as pubescent/ non-pubescent.
13. Colour of rind at tender harvestable maturity - Colour of fruit rind after seven days of emergence, *i.e.* tender harvestable stage was noted in the following categories; cream/ yellow/ light green/ green/dark green.
14. Colour of rind at mature stage - Colour of fruit rind after attaining physiological maturity was noted in the following categories; dark green/orange/pink/brown/others.
15. Presence or absence of cavity - Cavity present at the centre of fruit at harvestable maturity was observed as present/ absent.
16. Bitterness - Organoleptic evaluation was done for fruits at different stages of harvest and termed as present/absent.
17. Incidence of pest and diseases - Various diseases and pests like downy mildew, serpentine leaf miner, *etc.* and their occurrence in various genotypes (severe/moderate/mild/very low/nil).

a. Downy mildew PDI (%)

Observations on incidence of infection under natural conditions were recorded at maturity stage when the disease was at its peak. On the basis of leaf area infected, ten leaves from top to bottom on the tagged plants were observed from different levels of height and categorized according to the scale (Table 3.9) adopted by Reuveni (1983):

Table 3.8 : Description of downy mildew ratings in cucumber

Disease rating	Per cent infection	Description	Disease reaction
0	0	No symptoms	Highly Resistant (HR)
1	1-10	Scattered small lesions per leaf and less than 25 per cent leaf area turned yellowish	Resistant (R)
2	11-20	Scattered small lesions per leaf and yellowing covered > 25-50 per cent of leaf area	Moderate Resistant (MR)
3	21-40	Scattered or coalesced lesions per leaf and yellowing covered > 50 per cent of leaf area	Moderate Susceptible (MS)
4	> 40	> 40 coalesced lesions per leaf, the infected area turned brown and died and yellowing covered > 75 % of the leaf area	Susceptible (S)

Percent disease index (PDI) for downy mildew was calculated, using the following formula (Mckinney, 1923) :

$$\frac{\text{Sum of numerical ratings}}{\text{Total number of leaves observed}} \times \frac{100}{\text{Maximum disease grade in the score chart}}$$

18. TSS (°Brix) – The total soluble solids were measured in five random fruits selected with the help of ERMA hand refractrometer.

3.B.2 For evaluation of F_1 hybrids derived from full diallel mating

3.B.2.1 Quantitative characters

1. Length of main vine (cm) – The vine length was measured at the last harvest from bottom to the topmost tip of the plants.
2. Branches per plant – The total number of primary branches in two plants per replication were recorded.
3. Days to first female flower anthesis – Days were counted from the date of sowing to the appearance of first female flower.
4. Node at which first female flower emerged – Node number was noted where first female flower emerged.
5. Days to first harvest – Days were counted from the date of sowing to the first harvesting.
6. Number of harvests – The number of all harvestings done for each genotype was recorded.
7. Duration of the crop – Days were counted from date of sowing to the date of last harvest for five plants in each genotype.
8. Fruits per plant – The total number of fruits harvested from each plant were recorded.
9. Yield per plant (kg) – The fruit yield was recorded from all the harvests and average was calculated.
10. Average fruit weight (g)

11. Fruit length (cm)
12. Fruit girth (cm)
13. Flesh thickness (cm)
14. Downy mildew PDI (%)
15. Parthenocarpy (%)
16. TSS (^{o}Brix) – The total soluble solids were measured in five random fruits selected with the help of ERMA hand refractrometer.

3.B.2.2 Qualitative characters

1. Density of prickles at harvestable maturity
2. Sex form
3. Colour of prickles on fruit at emergence and senescence
4. Stem pubescence
5. Colour of rind at tender harvestable maturity
6. Colour of rind at mature stage
7. Presence or absence of cavity
8. Bitterness
9. Incidence of pest and diseases
10. Crispness/texture - Sensory evaluation of cucumbers with preference rating for texture/crispness by a 12 member panel using 9 point Hedonic scale was done (Amerine *et al.*, 1965), where,

    9 – Like extremely

    8 – Like very much

    7 – Like moderately

    6 – Like slightly

    5 – Neither like or dislike

4 – Dislike slightly

3 – Dislike moderately

2 – Dislike very much

1 – Dislike extremely

3.C STATISTICAL ANALYSIS

Data recorded from the inbreds, parents and hybrids were initially subjected to analysis of variance to detect the genotypic variability among them.

3.C.1 Analysis of variance (ANOVA)

ANOVA was conducted for the inbreds, parents and hybrids involved. The calculated value, greater than table 'F value' at error degrees of freedom for a default significance level reflected significant variation among treatments. A significant variation implied the computation of critical difference (Sharma, 1988).

3.C.2 Estimation of variability among the genotypes

The mean values observed for inbreds, parents and 12 hybrids were taken for statistical analysis. The data-set thus obtained was processed for analysis of variance, range, standard deviation, genotypic and phenotypic variance, genotypic and phenotypic coefficient of variation, genetic advance as per cent of mean (genetic gain), heritability etc.

3.C.2.1 Standard deviation

$$SD = \sqrt{var}$$

3.C.2.2 Standard error

$$SE = \frac{SD}{\sqrt{n}}$$

Where 'n' = number of genotypes

3.C.2.3 Coefficient of variation

The formula for C.V. was suggested by Snedecor and Cochran (1968).

$$C.V. = \frac{SD}{Mean} \times 100$$

3.C.2.4 Phenotypic, genotypic and environmental variance

The variance components were estimated using the formula suggested by Burton (1952).

Phenotypic variance (V_p) = $V_g + V_e$

Where,

V_g – genotypic variance

V_e - environmental variance

Genotypic variance (V_g) = $(V_T - V_E)/N$

Where,

V_T – mean sum of squares due to treatments

V_E – mean sum of squares due to error

N - number of replications

Environmental variance, $V_e = V_E$

3.C.2.5 Phenotypic and genotypic coefficient of variation

The phenotypic and genotypic coefficients of variation were calculated by the formula suggested by Burton and De Vane (1953).

Phenotypic coefficient of variation (PCV) = $(V_p^{1/2}/ X) \times 100$

Where,

V_p = Phenotypic variance

X = Mean of character under study

Genotypic coefficient of variation (GCV) = $(V_g^{1/2}/X) \times 100$

Where,

V_g = Genotypic variance

X = Mean of character under study

3.C.2.6 Heritability

Heritability in broad sense was estimated by the formula suggested by Burton and De Vane (1953). Heritability in broad sense,

$$H = (V_g / V_p) \times 100$$

Where,

V_p = Phenotypic variance

V_g = Genotypic variance

3.C.2.7 Expected genetic advance

The genetic advance expected for the genotype at five percent selection pressure was calculated using the formula by Lush (1949) and Johnson *et al.* (1955) with the value of constant 'K' as given by Allard (1960).

Expected genetic advance, $GA = (V_g / V_p) \times K$

Where,

V_p = Phenotypic variance

V_g = Genotypic variance

K = 2.04

3.C.2.8 Genetic advance as percentage of mean

Genetic advance (%) = (GA/X) × 100

Where,

GA = Genetic advance

X = Mean of character under study

3.C.2.9 Combined analysis of variance over environments

The combined analysis of variance over the environments was computed as per the procedure given by Verma *et al.* (1987).

The analysis was based on the following model:

$$Y_{ijk} = m + \alpha_i + \beta_j + \alpha\beta_{ij} + r_k + e_{ijk}$$

Where,

Y_{ijk} = Phenotype of the i^{th} genotype grown in j^{th} environment in the k^{th} block

m = General population mean

α_i = Effect of i^{th} genotype

β_j = Effect of j^{th} environment

$\alpha\beta_{ij}$ = Effect of interaction of i^{th} genotype with j^{th} environment

r_k = k^{th} replication effect

e_{ijk} = Random error

3.C.2.10 Analysis of variance combined over environments

Source of variation	Degree of freedom	Mean Sum of Squares	F-Value	Expected Mean Squares
Replications	(r-1)	Mr	Mr/Me	$\sigma_e^2 + gy\sigma_r^2$
Environments	(y-1)	My	My/Me	$\sigma_e^2 + rg\sigma_e^2 + r\sigma_{gy}^2$
Replication × Environments	(r-1)(y-1)	Mry	Mry/Me	$\sigma_e^2 + g\sigma_{ry}^2$
Genotypes	(g-1)	Mg	Mg/Me	$\sigma_e^2 + r\sigma_{gy}^2 + yr\sigma_g^2$
Genotype × Environments	(g-1)(y-1)	Mgy	Mgy/Me	$\sigma_e^2 + r\sigma_{gy}^2$
Pooled error	y(r-1)(g-1)	Me	----	σ_e^2

Where,

r = Number of replications

g = Number of genotypes

y = Number of environments

σ_e^2 = Error variance = Me

σ_g^2 = Variance due to genotypes = Mg

σ_r^2 = Variance due to replication = Mr

σ_y^2 = Variance due to environments = My

σ_{ry}^2 = Variance due to replication × environments = **Mry**

σ_{gy}^2 = Variance due to genotype × environments = **Mgy**

3.C.2.11 Standard errors

Standard Error of mean SE (m) = $\pm$ $(Me/ry)^{1/2}$

Standard Error of difference between two genotypic means SE(d) = $\pm(2\ Me/ry)^{1/2}$

3.C.2.12 Critical difference

For comparing the means of any two genotypes

CD = SE (d) × 't' value at 5% level of significance at combined error degrees of freedom

3.C.2.13 Coefficient of variation

CV (%) = $[(Me)^{1/2} / x] \times 100$

3.C.2.14 Estimation of parameters of variability in combined over environments

Phenotypic Coefficient of Variation (PCV %) = $[(\sigma_g + \sigma_{gy} + \sigma_e) / x] \times 100$

Genotypic Coefficient of Variation (GCV %) = $(\sigma_g / x) \times 100$

Heritability (h^2_{bs}) in broad sense (%) = $[\sigma_g{}^2 / (\sigma_g{}^2 + \sigma_{gy}{}^2 + \sigma_e{}^2)] \times 100$

Genetic advance (GA) at 5% selection intensity = $K \times \sigma^2_g / \sqrt{(\sigma^2_g + \sigma^2_{gy} + \sigma^2_e)}$

Genetic advance expressed as (%) of mean (GA %) = $(GA / x) \times 100$

Where, σ_g = Genotypic standard deviation

σ_{gy} = Genotypic environmental standard deviation

σ_e = Error standard deviation

Following classifications were used for describing various parameters in the text.

PCV, GCV and ECV: >20 % - high; 10 - 20 % - moderate; <10 % - low

Heritability in broad sense: >70 % - high; 50 - 70 % - moderate; <50 % - low

Genetic advance: >30 % - high; 20 - 30 % - moderate; <20 % - low

3.C.2.15 Test of Homogeneity

The F–test (Test of Homogeneity) or the 'variance ratio' test was used to test the significance whether error variances are homogeneous or not. In order to carry the test of significance, F–ratio was calculated as:

$$F = \frac{S_1^2}{S_2^2}$$

Where

S_1^2 = Large estimate of variance

S_2^2 = Smaller estimate of variance

and $S_1^2 > S_2^2$

at, $v_1 = n_1\text{-}1$ and $v_2 = n_2\text{-}1$ degrees of freedom

Where

v_1 = degrees of freedom for sample having larger variance

v_2 = degrees of freedom for sample having smaller variance

The calculated value of 'F' was compared with the table value for v_1 and v_2 degrees of freedom at 5 per cent level of significance. If calculated value of 'F' was greater than the tabulated value, the F-ratio was considered as significant. If the calculated value of 'F' was less than the table value, F-ratio was considered as non significant and it was inferred that both the samples have come from the population having same variance.

3.C.3 Diallel analysis

Diallel mating entails all possible single crosses among a set of inbred lines, and the analysis of such crosses is known as diallel analysis. The diallel set consists of three kinds of progenies: (i) parental selfs, (ii) direct F_1s and (iii) reciprocal F_1s.

Thus, among n inbred lines, n^2 single crosses are possible including n selfs and n(n-1)/2 F_1s and reciprocals each. There were four methods described for the analysis of diallel set of cross, *viz.* (I) with all the n^2 progenies, *i.e.* parents with F_1s and reciprocals, (II) with n parents and n(n-1)/2 F_1s, (III) with n(n-1)/2 F_1s and reciprocals and (IV) with n(n-1)/2 F_1s. The present investigation was carried out with method (I), *i.e.* with all the n^2 progenies.

The two approaches being followed for diallel analysis are Hayman's approach and Griffing's approach. The diallel analysis was done as per Griffing's approach for this study. Details of which are given below.

3.C.3.1 Griffing's approach

Data generated from the method (I) (with all the n^2 progenies, *i.e.* parents with F_1s and reciprocals) of diallel mating design were subjected to the statistical analysis in order to estimate the general and specific combining ability (GCA and SCA) variances and effects, as described by Griffing (1956). The analysis, as suggested by Griffing (1956), was based on the fixed effect model (Model I). The mathematical model for the combining ability analysis was assumed to be

$$x_{ij} = \mu + g_i + g_j + s_{ij} + r_{ij} + \frac{1}{bc}\sum_k \sum_t e_{ijkl} \begin{cases} i, j = 1, \ldots \ldots p \\ k = 1, \ldots \ldots b \\ l = 1, \ldots \ldots c \end{cases}$$

where, μ is the population mean, g_i and g_j are the GCA effect for the i^{th} and j^{th} parents respectively, s_{ij} is the SCA effect for the cross between the i^{th} and j^{th} parents such that $s_{ij} = s_{ji}$, r_{ij} is the reciprocal effect involving the reciprocal crosses between the i^{th} and j^{th} parents such that $r_{ij} = - r_{ji}$ and e_{ijkl} is the environmental effect associated with the $ijkl^{th}$ individual observation. The following restrictions are imposed on the combining ability elements:

$$\sum_i g_i = 0 \text{ and } \sum_i s_{ij} = 0 \text{ (for each J)}$$

3.C.3.2.1 ANOVA for combining ability

Source	d.f.	SS	MS	E(MS)	F test	
					F_{cal}	F_{tab}
GCA	(p - 1)	S_g	M_g	$\partial_e^2 + \left(\frac{2p}{P-1}\right).\sum_i^p g_i^2$	$\frac{M_g}{M_e}$	(p – 1) and (r - 1). (p + F_1 -1) d.f. at 5%
SCA	$\frac{p(p-1)}{2}$	S_s	M_s	$\partial_e^2 + \left\{\frac{2}{p(p-1)}\right\}.\sum_{\substack{i=1\\j=1}}^p s_{ij}^2$	$\frac{M_s}{M_e}$	$\frac{p(p+1)}{2}$ and (r - 1). (p + F_1 -1) d.f. at 5%
R	$\frac{p(p-1)}{2}$	S_R	M_R	$\partial_e^2 + \left\{\frac{2}{p(p-1)}\right\}.\sum_{\substack{i=1\\j=1}}^p r_{ij}^2$	$\frac{M_r}{M_e}$	$\frac{p(p+1)}{2}$ and (r - 1). (p + F_1 -1) d.f. at 5%
Error	(r - 1).(p + F_1 – 1)	S_e	M_e	∂_e^2		

Where,

GCA = General combining ability

SCA = Specific combining ability

R = Reciprocals

P = Number of parents

r = Number of replications

F_1 = Number of hybrids

S_g = Sum of squares due to GCA

$= \frac{1}{2n}\left[\sum(y_i + y_{ji})^2 - \frac{2}{n^2_{..}}.Y^2_{..}\right]$

Ss = Sum of squares due to SCA

$= \frac{1}{2}\sum\sum Y_{ij}\left(Y_{ij} + Y_{ij}\right) - \frac{1}{2n}\sum(Y_{.j} + Y_{i.})^2 + \frac{1}{n^2}Y^2_{..}$

S_r = Sum of the squares due to reciprocals

$$= \frac{1}{2}\sum\sum(Y_{ij} - Y_{ji})^2$$

Where,

$Y_{i.}$ = Total of the array involving i^{th} parent

Y_{ii} = Value of the i^{th} parent in the array

$Y_{..}$ = Grand total

3.C.3.2.2 Estimation of GCA, SCA and Reciprocal effects:

General combining ability (GCA) effect of the i^{th} parent = g_i

$$\frac{1}{2n}\left[\sum(Y_{i.} + Y_{i.}) - \frac{1}{n^2}.Y_{..}\right]$$

Specific combining ability (SCA) effect of the ij^{th} cross = s_{ij}

$$\frac{1}{2}(Y_{ij} + Y_{ji}) - \frac{1}{2n}.(Y_{i.} + Y_{.i} + Y_{j.} + Y_{ij}) + \frac{1}{n^2}.Y_{..}$$

Where, $Y_{i.}$ = total of arrays involving i^{th} parent

Y_{ii} = value of the i^{th} parent in the array

$Y_{..}$ = Grand total

Reciprocal effects of the ij^{th} cross $= r_{ij}$

$$= \frac{1}{2}.(Y_{ij} - Y_{ji})$$

Standard errors of the estimate:

$$SE_{(gi)} = \sqrt{\frac{(n-1).\sigma_e^2}{2n^2}}$$

$$SE_{(g_i - g_j)} = \sqrt{\frac{1}{n}\sigma_e^2}$$

$$SE_{(s_{ij})} = \sqrt{\frac{(n-1)^2}{n^2}\sigma_e^2}$$

$$SE_{(s_{ij}-s_{kl})} = \sqrt{\frac{(n-2).}{n}\sigma_e^2}$$

$$SE_{(r_{ij})} = \sqrt{\frac{\sigma_e^2}{2}}$$

$$SE_{(r_{ij}-r_{kl})} = \sqrt{\sigma_e^2}$$

Where, σ_e^2 = mean sum of square due to error

Now, the 't' calculated values are as follows

$$t_{(gi)} = \frac{g_i}{SE_{gi}}$$

$$t_{(sij)} = \frac{S_{ij}}{SE_{s_{ij}}}$$

$$t_{(rij)} = \frac{r_{ij}}{SE_{r_{ij}}}$$

The $t_{(gi)}$ and $t_{(sij)}$ and $t_{(rij)}$ are used for test of significance of the GCA effects of parents and SCA effects and reciprocal effects of crosses, respectively. Whereas, $SE_{(gi-gj)}$, $SE_{(sij-skl)}$ and $SE_{(rij-rkl)}$ are used for calculation of critical differences at 't' error degrees of freedom at 5 or 1 per cent to check at par of GCA, SCA and reciprocal effects, respectively.

3.C.4 Heterosis

Heterosis was calculated as the deviation of the mean performance of F_1s ($\overline{F1}$) from their mid parent ($\overline{MP}$), better parent ($\overline{BP}$) and the standard check ($\overline{SC}$) for each cross combination expressed as the percentage of the mean respectively as suggested by Hayes *et al.* (1965) and Briggle (1963). A commercial hybrid of parthenocarpic

cucumber, Hilton (Nickerson Zwaan, Holland) was taken as standard parent to estimate standard heterosis.

$$\text{Relative heterosis (\%)} = \frac{(\overline{F1} - \overline{MP})}{\overline{MP}} \times 100$$

$$\text{Heterobeltiosis (\%)} = \frac{(\overline{F1} - \overline{BP})}{\overline{BP}} \times 100$$

$$\text{Standard heterosis (\%)} = \frac{(\overline{F1} - \overline{SC})}{\overline{SC}} \times 100$$

To test the significance of difference of F_1 mean over mid and better parents, critical difference (CD) was worked out. CD was calculated from the standard error of difference as given below (Briggle, 1963).

To test the significance over mid-parent

$$CD\ (0.05) = te'\ (0.05) \times \sqrt{\frac{3MSE}{2r}}$$

$$= te'\ (0.05) \times SE$$

To test the significance over better parent and standard check

$$CD\ (0.05) = te'\ (0.05) \times \sqrt{\frac{2MSE}{r}}$$

$$= te'\ (0.05) \times SE$$

Where, te' - critical value of 't' statistic at 5 per cent level of significance

MSE - Error mean square

r - Number of replications

SE - Standard error of difference between two means

Results

4. RESULTS

Results obtained in all the experiments are presented under the following headings:

4.1 Maintenance of parthenocarpic lines through tissue culture

In vitro response of seed culture and regeneration of monoecious, parthenocarpic and gynoecious cucumber genotypes from cotyledonary leaf and stem nodal explants are presented in the respective subheads:

4.1.1 *In vitro* seed germination

The seed germination was achieved in average three to four days of inoculation in half strength MS basal medium without any hormones with 100 per cent germination rate for all the genotypes used (Table 4.1). The genotype G_1 (gynoecious cucumber: EC 709119; 1.25±0.16) took minimum days for 50 per cent germination followed by the genotype G_2 (parthenocarpic cucumber: CS 130; 1.33±0.19), G_4 (parthenocarpic cucumber: CS 131; 1.58±0.21) and G_3 (monoecious cucumber hybrid: L-04; 1.67±0.30), respectively in the homogeneous set of conditions. In case of days to 100 per cent germination, the genotype G_1 (3.50±0.25) took minimum days for germination followed by G_2 (3.50±0.50), G_3 (3.75±0.14) and G_4 (4.00±0.50), respectively.

4.1.2 Shoot initiation from cotyledonary leaf explants

The shoot initiation was achieved for all the genotypes in M_8 media composition with 100 per cent response (Table 4.2). M_8 (5.75±1.29) medium gave the best result for days taken for shoot initiation followed by M_3 (8.83±1.93) and M_1 (8.17±2.09), respectively. In addition, for the genotype G_1, the three media M_8, M_3 and M_1 had shown 100 per cent response for shoot initiation. All the remaining media failed for *in vitro* shooting. M_1 (5.00±0.58) media took minimum days for shooting followed by M_8 (5.67±0.67) and M_3 (8.00±0.58) for G_1 genotype whereas M_8 media showed 100 per cent response with minimum days taken for shoot initiation in the genotypes G_2 (4.67±0.67) and G_3

Table 4.1 : *In vitro* seed germination of cucumber genotypes

Genotype	Days taken for 50 per cent germination*	Days taken for 100 per cent germination*	Germination (%)
G_1	1.25±0.16	3.50±0.25	100
G_2	1.33±0.19	3.50±0.50	100
G_3	1.67±0.30	3.75±0.14	100
G_4	1.58±0.21	4.00±0.50	100

'*' Data are Mean ± Standard error, n=15

Table 4.2 : Effect of BAP and IAA for shoot initiation from cotyledonary leaf explants for different genotypes

	G_1		G_2		G_3		G_4		Mean	
	Days taken for shoot initiation*	Shoot initiation response (%)	Days taken for shoot initiation*	Shoot initiation response (%)	Days taken for shoot initiation*	Shoot initiation response (%)	Days taken for shoot initiation*	Shoot initiation response (%)	Days taken for shoot initiation*	Shoot initiation response (%)
M_1	5.00±0.58	100.00	9.50±0.41	66.67	4.67±0.33	100.00	13.50±0.41	66.67	8.17±2.09	83.33
M_2	NR	0.00	5.67±0.33	100.00	12.00±0.58	100.00	NR	0.00	8.83±2.24	50.00
M_3	8.00±0.58	100.00	14.00±0.82	66.67	8.67±0.67	100.00	4.67±0.33	100.00	8.83±1.93	91.67
M_4	8.50±0.41	66.67	NR	0.00	NR	0.00	7.33±0.33	100.00	7.92±0.41	41.67
M_5	NR	0.00	4.00±0.00	100.00	4.50±0.41	66.67	5.00±0.00	66.67	4.50±0.25	58.33
M_6	NR	0.00	16.33±0.33	100.00	NR	0.00	6.33±0.33	100.00	11.33±3.54	50.00
M_7	NR	0.00	7.33±0.33	100.00	12.67±0.88	100.00	NR	0.00	10.00±1.89	50.00
M_8	5.67±0.67	100.00	4.67±0.67	100.00	3.33±0.33	100.00	9.33±0.33	100.00	5.75±1.29	100.00

'*' Data are Mean ± Standard error, n=15; NR-No response

(3.33±0.33), respectively. There was no response in M_4 media for both the genotypes G_2 and G_3 (Table 4.2). In case of monoecious cucumber hybrid (G_4), M_3 media gave best response in terms of minimum days taken for shoot initiation (4.67±0.33) with 100 per cent response.

4.1.3 Root initiation from cotyledonary leaf explants

M_3 (5.17±0.91) media had shown 100 per cent response for root initiation by taking minimum days while M_2 had shown no response for all the genotypes used (Table 4.3). For gynoecious genotype, three media compositions gave cent per cent response with less number of days taken in M_3 (3.67±0.67) followed by M_8 (5.67±0.33), whereas five media compositions failed to show any response. In the case of parthenocarpic genotype (G_2), M_1 (5.33±0.33) followed by M_3 (6.00±0.58) took minimum days for root initiation with cent per cent response whereas for another parthenocarpic genotype (G_3), M_3 exhibited 100 per cent response which was found to be superior to other media for root initiation (3.67±0.33). Monoecious genotype (G_4) had shown cent per cent response with M_3 media and took less number of days (7.33±0.33) for root initiation (Table 4.3).

4.1.4 Callus initiation from cotyledonary leaf explants

Gynoecious genotype (G_1) showed 100 per cent callus initiation with M_5 (9.00±0.58) followed by M_7 (17.33±0.33) media and took minimum days for reaching callusing phase in comparison to others whereas M_1 showed no response for callus initiation in the genotype G_1 (Table 4.4). Parthenocarpic genotype (G_2) was better for callusing in M_5 (10.33±0.33) media while another parthenocarpic genotype (G_3) was better with M_2 (6.33±0.33) media showing 100 per cent response in the replications. No response was observed in M_1 and M_6 media compositions for the genotype G_2, and M_3 media for the genotype G_3, respectively. Four media *viz.*, M_1, M_6, M_7 and M_8 did not show any response for callus initiation in monoecious genotype (G_4). Two media, M_5 (11.33±0.33) followed by M_4 (13.00±0.58) had taken minimum number of days for callusing with 100 per cent response in the genotype G_4. On an average, irrespective of

Table 4.3 : Effect of BAP and IAA for root initiation from cotyledonary leaf explants for different genotypes

	G_1		G_2		G_3		G_4		Mean	
	Days taken for root initiation*	Root initiation response (%)	Days taken for root initiation*	Root initiation response (%)	Days taken for root initiation*	Root initiation response (%)	Days taken for root initiation*	Root initiation response (%)	Days taken for root initiation*	Root initiation response (%)
M_1	NR	0.00	5.33±0.33	100.00	12.00±0.82	66.67	13.00±0.82	66.67	10.11±2.08	58.33
M_2	NR	0.00	NR	0.00	NR	0.00	NR	0.00	NR	NR
M_3	3.67±0.67	100.00	6.00±0.58	100.00	3.67±0.33	100.00	7.33±0.33	100.00	5.17±0.91	100.00
M_4	NR	0.00	13.00±0.00	66.67	NR	0.00	NR	0.00	13.00±0.00	16.67
M_5	NR	0.00	8.00±0.00	33.33	9.00±0.00	66.67	NR	0.00	8.50±0.35	25.00
M_6	14.33±0.33	100.00	12.33±0.33	100.00	12.33±0.67	100.00	15.00±0.82	66.67	13.50±0.69	91.67
M_7	NR	0.00	NR	0.00	17.00±0.00	33.33	NR	0.00	17.00±0.00	8.33
M_8	5.67±0.33	100.00	14.00±0.00	33.33	14.00±0.00	66.67	NR	0.00	11.22±2.41	50.00

'*' Data are Mean ± Standard error, n=15; NR-No response

Table 4.4 : Effect of BAP and IAA for callus initiation from cotyledonary leaf explants for different genotypes

	G_1		G_2		G_3		G_4		Mean	
	Days taken for callus initiation*	Callus initiation response (%)	Days taken for callus initiation*	Callus initiation response (%)	Days taken for callus initiation*	Callus initiation response (%)	Days taken for callus initiation*	Callus initiation response (%)	Days taken for callus initiation*	Callus initiation response (%)
M_1	NR	0.00	NR	0.00	12.00±0.82	66.67	NR	0.00	12.00±0.00	16.67
M_2	15.50±0.41	66.67	12.00±0.58	100.00	6.33±0.33	100.00	11.00±0.00	66.67	11.21±1.89	83.33
M_3	17.00±0.00	33.33	8.50±0.41	66.67	NR	0.00	15.50±0.41	66.67	13.67±2.27	41.67
M_4	16.00±0.00	66.67	18.00±0.00	33.33	13.33±0.33	100.00	13.00±0.58	100.00	15.08±1.18	75.00
M_5	9.00±0.58	100.00	10.33±0.33	100.00	9.33±0.33	100.00	11.33±0.33	100.00	10.00±0.53	100.00
M_6	13.50±0.41	66.67	NR	0.00	17.00±0.82	66.67	NR	0.00	15.25±1.24	33.33
M_7	17.33±0.33	100.00	14.00±0.82	66.67	16.50±0.41	66.67	NR	0.00	15.94±0.87	58.33
M_8	15.00±0.00	33.33	10.67±0.33	100.00	11.00±0.58	100.00	NR	0.00	12.22±1.21	58.33

'*' Data are Mean ± Standard error, n=15; NR-No response

genotypes, M_5 was the only media which took minimum days (10.00±0.53) for cent per cent callusing (Table 4.4).

4.1.5 Shoot initiation from stem nodal explants

Monoecious and parthenocarpic genotype G_2 showed 100 percent response for shoot initiation with A_2 media (Table 4.5). Monoecious genotype (G_1) took minimum days (7.00±0.58) for shoot initiation followed by parthenocarpic genotype G_2 (11.00±0.58). On an average 83.34 per cent shoot initiation response was achieved and it took 13.00±2.52 days for shoot initiation irrespective of genotypes.

4.1.6 Root initiation from stem nodal explants

Gynoecious (G_1) and parthenocarpic genotype (G_2) showed 100 per cent response for root initiation (Table 4.5). Minimum days for rooting (6.50±0.41) were taken by parthenocarpic genotype (G_3) followed by monoecious genotype, G_4 (8.00±1.63). Gynoecious genotype (G_1) was late for showing root initiation response in A_1 media. On an average 83.34 per cent root initiation response was achieved and it took 7.86±0.46 days for root initiation irrespective of genotypes.

4.1.7 *In vitro* flowering

In vitro male and female flowers were noticed in all the media compositions. Male flowers were obtained in gynoecious genotype (G_1), parthenocarpic genotype (G_3) and monoecious genotype (G_4). The *in vitro* female flower from stem nodal explant was obtained in gynoecious genotype when cultured in A_1 media composition. The male flowers were extracted from the tubes and pollen fertility test was done with acetocarmine solution (1 %). It was found that the male flowers obtained from gynoecious and parthenocarpic genotypes were partially fertile and from monoecious genotypes were fully fertile.

4.1.8 Evaluation of regenerated plants in the polyhouse

On an average 61.11 and 48.15 per cent survival was recorded from the plants regenerated through cotyledonary leaf explants and stem nodal explants respectively (Table 4.6). Maximum survival percentage (87.50 %) was achieved

Table 4.5 : Effect of different media for shoot and root initiation from stem nodal explants for different genotypes

Media	G_1		G_2		G_3		G_4		Mean	
	Days taken for shoot initiation*	Shoot initiation response (%)	Days taken for shoot initiation*	Shoot initiation response (%)	Days taken for shoot initiation*	Shoot initiation response (%)	Days taken for shoot initiation*	Shoot initiation response (%)	Days taken for shoot initiation*	Shoot initiation response (%)
A_2	18.50±2.04	66.67	11.00±0.58	100	15.50±0.41	66.67	7.00±0.58	100.00	13.00±2.52	83.34
	Days taken for root initiation*	Root initiation response (%)	Days taken for root initiation*	Root initiation response (%)	Days taken for root initiation*	Root initiation response (%)	Days taken for root initiation*	Root initiation response (%)	Days taken for root initiation*	Root initiation response (%)
A_1	8.33±1.20	100.00	8.50±0.41	100	6.50±0.41	66.67	8.00±1.63	66.67	7.83±0.46	83.34

'*' Data are Mean ± Standard error, n=15; NR-No response

Table 4.6 : Survival percentage and sex expression of the plants regenerated from cotyledonary leaf and stem nodal explants in polyhouse

Variety	No. of surviving plants from cotyledonary explants	Survival percentage from cotyledonary explants (%)	No. of surviving plants from nodal explants	Survival percentage from nodal explants (%)	No. of plants having monoecious sex expression	No. of plants having gynoecious sex expression
G_1	6 (10)	60.00	3 (7)	42.86	7	2
G_2	4 (9)	44.44	3 (6)	50.00	7	0
G_3	5 (9)	55.56	0 (6)	0.00	3	2
G_4	7 (8)	87.50	7 (8)	87.50	14	0
Total	22 (36)	61.11	13 (27)	48.15	31	4

Value in parenthesis represents the total plants tried for polyhouse cultivation

4.1a. Seed germination

4.1b. Shoot initiation

4.1c. Multiple shoot regeneration

4.1d. Root initiation

Plate 4.1 : Stages of *in vitro* plant regeneration

4.1e. IAA treatment

4.1f. Hardening

4.1g. Transplanting

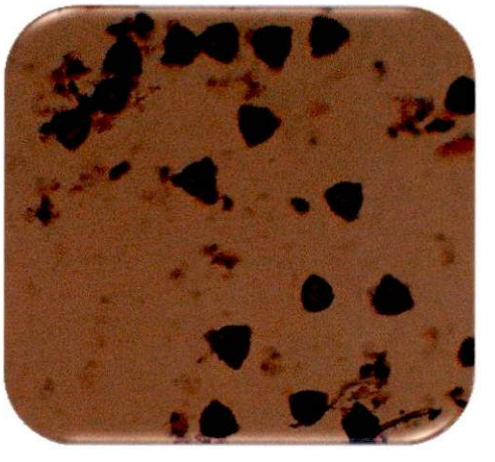
4.1h. Regenerated plant

Plate 4.1 : Stages of *in vitro* plant regeneration

4.2a. Female flowers

4.2b. Male flowers

4.2c. Pollen extraction



4.2d. Pollen fertility

Plate 4.2 : *In vitro* flowering

in monoecious genotype (G_4) and minimum survival percentage of 44.44 per cent was observed in parthenocarpic gynoecious genotype (G_2) regenerated through cotyledonary leaf explants. The maximum survival of 87.50 per cent was recorded in monoecious genotype (G_4) regenerated though stem nodal explants. Parthenocarpic genotype (G_3) failed to survive in the field condition. Out of the survived plants of gynoecious genotype (G_1), seven plants showed monoecious sex expression and two plants exhibited gynoecious sex expression (Table 4.6). In the parthenocarpic genotype (G_2) all the survived (seven) plants showed monoecious sex expression. Out of the five survived plants from parthenocarpic genotype (G_3) three plants have shown monoecious sex expression and two plants were with gynoecious sex expression. All the survived plants of the monoecious genotype (G_4) were monoecious in sex expression. On an average out of 35 plants, 31 plants showed monoecious sex expression irrespective of genotypes. Only four plants (two from gynoecious and two from parthenocarpic genotype) showed gynoecious sex expression in the field condition.

4.2 Induction of male flowers in parthenocarpic lines

Male flowers were induced through various treatments of silver thiosulphate. The data of three traits (days to anthesis of first staminate flower, node at which first staminate flower induced and node up to which staminate flower appeared) pertaining to male flower induction in various parthenocarpic and gynoecious genotypes with four treatments of silver thiosulphate is given in the Table 4.7.

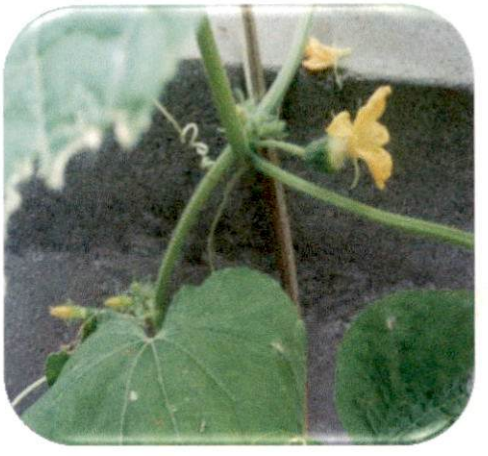
Minimum days to anthesis of first staminate flower in the genotypes EC 709119 (31.00±0.85), CS 132 (27.25±0.75), CS 133 (29.00±0.41) and CS 130 (26.75±0.48) were induced by the treatment T_2 *i.e.* STS @ 300 ppm. Maximum days were taken by the treatment T_1 (STS @ 150 ppm) in all the genotypes namely, EC 709119 (38.25±0.85), CS 132 (40.50±0.87), CS 133 (37.75±0.48) and CS 130 (33.75±0.48) for anthesis of first staminate flower (Table 4.7). Overall, irrespective of genotype, STS @ 300 ppm was the best which took minimum number of days (28.50±0.96) for anthesis of first staminate flowers.

Table 4.7 : Effect of different treatments of silver thiosulphate for induction of male flowers in gynoecious and parthenocarpic cucumber

Trait ↓	Genotype → / Treatment ↓	EC 709119	CS 132	CS 133	CS 130	Mean
Days to anthesis of first staminate flower*	T_1 (STS @ 150 ppm)	38.25±0.85	40.50±0.87	37.75±0.48	33.75±0.48	37.56±1.40
	T_2 (STS @ 300 ppm)	31.00±0.41	27.25±0.75	29.00±0.41	26.75±0.48	28.50±0.96
	T_3 (STS @ 450 ppm)	33.50±0.29	31.50±0.65	29.50±0.65	31.75±0.75	31.56±0.82
	T_4 (STS @ 600 ppm)	34.00±0.41	33.75±0.25	31.50±0.96	34.50±0.50	33.44±0.66
Node at which first staminate flower induced*	T_1 (STS @ 150 ppm)	4.50±0.29	4.75±0.48	5.25±0.25	4.75±0.25	4.81±0.16
	T_2 (STS @ 300 ppm)	3.50±0.29	3.25±0.25	4.25±0.25	3.75±0.25	3.69±0.21
	T_3 (STS @ 450 ppm)	3.75±0.25	3.50±0.29	3.75±0.25	3.25±0.25	3.56±0.12
	T_4 (STS @ 600 ppm)	3.25±0.25	2.75±0.25	3.50±0.29	2.50±0.29	3.00±0.23
Node upto which staminate flower appeared*	T_1 (STS @ 150 ppm)	8.25±0.63	10.25±0.63	13.00±0.91	11.25±1.49	10.69±0.99
	T_2 (STS @ 300 ppm)	19.50±1.66	17.00±0.41	23.00±0.91	21.00±1.08	20.13±1.26
	T_3 (STS @ 450 ppm)	18.00±0.82	14.75±0.48	20.75±1.11	18.75±0.95	18.06±1.25
	T_4 (STS @ 600 ppm)	13.25±0.75	11.50±0.96	15.75±0.63	15.25±0.48	13.94±0.98

'*' Data are Mean ± Standard error, n=4

4.3a. Hermaphrodite and male flower



4.3b. Hermaphrodite flower

4.3c. Male and female flowers

4.3d. Male flowers

Plate 4.3 : Induction of male flowers with silver thiosulphate sprays

The lowest first staminate flower inducing node was achieved with the treatment T_4 (STS @ 600 ppm) in the genotypes EC 709119 (3.25 ± 0.25), CS 132 (2.75±0.25), CS 133 (3.50±0.29) and CS 130 (2.50±0.29). The highest node at which first staminate flower was induced (Table 4.7) was exhibited by the treatment T_1 for the genotypes EC 709119 (4.50±0.29), CS 132 (4.75±0.48), CS 133 (5.25±0.25) and CS 130 (4.75±0.25). On an average treatment T_4 took lowest node for inducing first staminate flower (3.00±0.23) followed by the treatment T_3 (STS @ 450 ppm) with the value of 3.56±0.12.

The highest nodes up to which staminate flowers appeared which is an indication of male phase was found to be more for treatment T_2 for the genotypes EC 709119 (19.50±1.66), CS 132 (17.00±0.41), CS 133 (23.00±0.91) and CS 130 (21.00±1.08). The appearance of staminate flowers on the nodes was lowest with the treatment T_1 (Table 4.7) for the genotypes EC 709119 (8.25±0.63), CS 132 (10.25±0.63), CS 133 (13.00±0.91) and CS 130 (11.25±1.49). On an average, maximum male flowering nodes were noticed in the treatment T_2 (20.13±1.26) irrespective of the genotypes.

4.3 Inbred development

The inbreds were developed from the selfed populations as described in the material and methods chapter. Minimum number of 40 plants was maintained in I_0, I_1, I_2 and I_3 generation through SSD method. The data on range of various quantitative and qualitative traits in I_0, I_1, I_2 and I_3 generation of selected inbreds of various populations was recorded and depicted in Table 4.8.

Among all the four genotypes, CS 133 took minimum nodes (2-5) for first female flower emergence and maximum nodes (3-7) was observed for the genotype CS 132 in I_0 generation. Similarly, in I_1 generation minimum nodes (3-4) for first female flower emergence was taken by the genotype CS 133 and maximum (4-8) by the genotype CS 131. The minimum (3-6) number of nodes for first female flower emergence was observed for the genotype CS 132 and maximum (5-8) for CS 131 in I_2 generation. In the I_3 generation the minimum

Table 4.8 : Range for selected traits of cucumber inbred lines in I_0, I_1, I_2 and I_3 generations

Generation	Entry	Node at which first female flower emerged	Days to harvest	Fruit length (cm)	Fruit girth (cm)	Average fruit weight (g)	Parthenocarpy (%)*
I_0	CS 132	3.00-7.00	41-45	13.10-20.20	10.00-16.50	140.45-220.67	39.22-63.41
	CS 133	2.00-5.00	38-43	17.50-27.50	10.00-18.30	179.24-251.43	44.98-56.77
	CS 130	2.00-6.00	43-52	18.50-25.50	9.00-16.50	166.67-293.78	50.75-56.77
	CS 131	3.00-6.00	50-58	15.00-21.00	9.50-14.00	128.54-191.28	44.98-56.77
I_1	CS 132	4.00-7.00	43-48	10.30-16.40	7.00-12.30	109.44-257.92	33.20-71.54
	CS 133	3.00-4.00	47-52	9.00-15.50	8.70-14.10	134.34-270.41	56.77-71.54
	CS 130	3.00-5.00	53-55	16.10-24.30	10.00-17.40	139.00-272.36	50.75-63.41
	CS 131	4.00-8.00	44-49	14.00-21.30	10.60-14.00	114.26-179.04	26.55-63.41
I_2	CS 132	3.00-6.00	40-44	12.20-18.90	9.70-14.10	144.68-200.10	39.22-56.77
	CS 133	3.00-7.00	41-44	10.10-14.30	8.50-13.70	181.23-240.79	44.98-63.41
	CS 130	4.00-9.00	47-50	17.40-26.50	13.60-17.00	196.63-238.36	33.20-71.54
	CS 131	5.00-8.00	49-52	16.70-22.20	11.40-16.50	150.46-184.78	50.75-56.77
I_3	CS 132	4.00-5.00	38-42	14.40-18.00	11.00-16.20	187.85-221.39	56.77-63.41
	CS 133	2.00-4.00	40-43	15.10-18.70	12.90-17.00	201.22-260.67	56.77-71.54
	CS 130	4.00-6.00	46-52	17.00-24.10	13.40-18.80	183.96-228.49	44.98-63.41
	CS 131	3.00-5.00	50-54	14.30-23.20	12.90-19.10	167.00-191.33	39.22-56.77

'*' percentage values are Arc Sine transformed

4.4a. Seedling stage

4.4b. 2-4 leaf stage

4.4c. Flowering stage

4.4d. Fruiting stage

Plate 4.4 : Growth stages of parthenocarpic cucumber

4.5a. I_4 generation

4.5b. I_5 generation

4.5c. F_1 hybrid evaluation (30 DAS)

4.5c. F_1 hybrid evaluation (60 DAS)

Plate 4.5 : General view of the experimental plot

(2-4) and maximum (4-6) nodes for first female flower emergence was observed for the genotypes CS 133 and CS 130, respectively (Table 4.8).

CS 133 took minimum (38-43) number of days to harvest among all the genotypes and the maximum (50-58) by genotype CS 131 in I_0 generation. In I_1 generation, the minimum (43-48) number of days to harvest was taken by genotype CS 132 and the maximum (53-55) by the genotype CS 130. In generation I_2, minimum (40-44) days for harvest was taken by the genotype CS 132 and the maximum (49-52) number of days for harvest was taken by the by the genotype CS 131 (Table 4.8). In I_3 generation, the minimum (38-42) days to harvest was taken by the genotype CS 132 and the maximum (50-54) days by the genotype CS 131.

The genotype CS 130 exhibited longest fruit length (18.50-25.50 cm) in I_0 generation and the shortest fruit length (13.10-20.20 cm) was observed for CS 132 (Table 4.8). In generation I_1 the longest (16.10-24.30 cm) fruit length was noted in genotype CS 130 and the shortest (9.00-15.50 cm) in CS 133. Fruit length was maximum (17.40-26.50 cm) in the genotype CS 130 in I_2 generation and minimum (10.10-14.30 cm) in the CS 133. In I_3 generation, the maximum (17.00-24.10 cm) fruit length was obtained for the genotype CS 130 and the minimum (14.30-23.20 cm) fruit length in CS 131.

The maximum fruit girth (10.00-18.30 cm) was obtained in the genotype CS 133 in I_0 generation and minimum fruit girth (9.00-16.50 cm) in the genotype CS 130 (Table 4.8). In I_1 generation, maximum fruit girth (10.60-14.00 cm) was found in the genotype CS 131 and the minimum (7.00-12.30 cm) in CS 132. The wide (13.60-17.00 cm) fruit girth in I_2 generation was found in the genotype CS 130 and the narrow (8.50-13.70 cm) fruit girth in the genotype CS 133. For I_3 generation, the maximum (13.40-18.80 cm) fruit girth was obtained in the genotype CS 130 and the minimum (11.00-16.20 cm) in CS 132.

Highest (179.24-251.43 g) fruit weight was found in the genotype CS 133 and the lowest (128.54-191.28 g) in the genotype CS 131 in I_0 generation (Table 4.8). Similarly, the high fruit weight (139.00-272.36 g) was found in the genotype

CS 130 and low (109.44-257.92 g) in the genotype CS 132 in I_1 generation. In I_2 generation the highest (196.63-238.36 g) average fruit weight was obtained in CS 130 and the lowest (144.68-200.10 g) was found in the genotype CS 132. The highest (201.22-260.67 g) average fruit weight was noted in the genotype CS 133 and lowest (167.00-191.33 g) in the genotype CS 131 in I_3 generation.

Variation in range of parthenocarpy (%) was observed in all the generations (Table 4.8). The genotypes CS 132 (39.22-63.41 %) and CS 130 (50.75-56.77 %) exhibited minimum and maximum parthenocarpy percentage respectively. The genotypes CS 133 and CS 130 exhibited same values of parthenocarpy (%) as 44.98-56.77 per cent in I_0 generation. In I_1 generation, the genotypes CS 131 (26.55-63.41 %) recorded minimum and CS 133 (56.77-71.54 %) had recorded for maximum parthenocarpy percentage. The highest and lowest parthenocarpy percentage values were found in the genotypes CS 131 (50.75-56.77 %) and CS 130 (33.20-71.54 %) respectively in I_2 generation. In the I_3 generation, the genotypes CS 131 (39.22-56.77 %) and CS 133 (56.77-71.54 %) had shown minimum and maximum parthenocarpy percentage respectively.

4.4 Evaluation of inbred lines for isolation of improved parthenocarpic lines

The evaluation of I_4 and I_5 progenies was done for the selected four genotypes in the polyhouse along with four commercial hybrids of parthenocarpic cucumber. The data for various quantitative and qualitative characters in randomized block design with three replications in two generations and pooled over generations (Appendix I, II and III) was analyzed and results are given under the following subheads:

4.4.1 Analysis of variance

The analysis of variance revealed that mean squares due to genotypes were significant for all the traits studied in I_4 and I_5 generations (Table 4.9). The pooled analysis of variance over the generations revealed that mean squares due to genotypes were significant when tested against mean squares due to G × E interaction for all the traits (Table 4.10). The G × E interactions were also found

Table 4.9 : Analysis of variance for different characters in cucumber during I_4 and I_5 generations

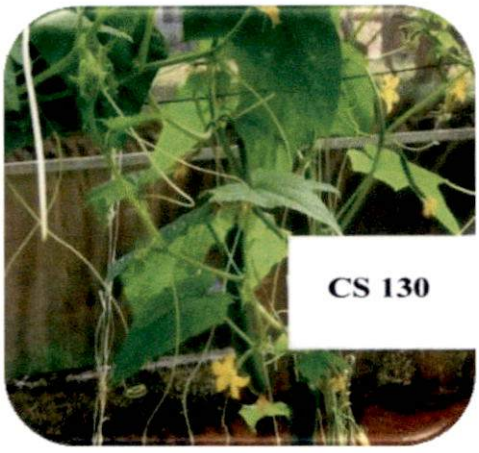
Source / Characters	Mean sum of squares					
	Replication		Treatment		Error	
	Generation I	Generation II	Generation I	Generation II	Generation I	Generation II
df	2		7		14	
Days to first female flower appearance	0.37	1.14	11.45*	8.20*	0.33	0.98
Node of first female flower emergence	0.07	0.02	1.36*	0.75*	0.11	0.05
Days to harvest	1.17	3.04	36.52*	51.24*	0.79	3.90
Fruit length (cm)	0.06	0.00	4.52*	2.30*	0.14	0.10
Fruit girth (cm)	0.20	0.18	2.60*	1.28*	0.06	0.06
Flesh thickness (cm)	0.03	0.01	0.18*	0.16*	0.01	0.01
TSS (°Brix)	0.06	0.04	0.18*	0.05*	0.02	0.01
Parthenocarpy (%)	280.50	49.45	394.53*	290.12*	105.86	60.76
Average fruit weight (g)	8.31	176.61	2020.29*	1104.84*	8.68	243.11
Fruits per plant	2.49	0.16	8.39*	12.25*	0.25	0.36
Downy mildew PDI (%)	2.24	6.50	1082.08*	1036.40*	4.01	4.20
Yield per plant (kg)	0.20	0.03	0.75*	0.57*	0.02	0.03

*Significant at $P \leq 0.05$; Generation I and II depicts I_4 and I_5 inbreds respectively

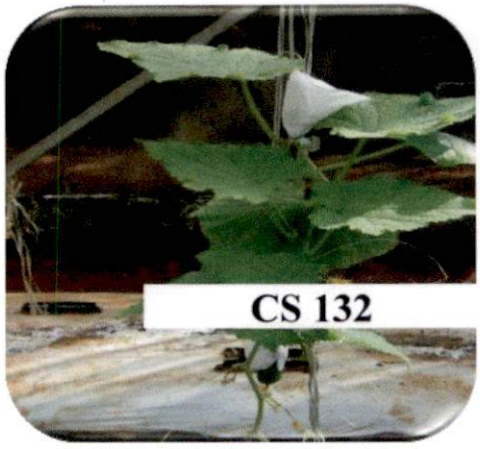
Table 4.10 : Pooled analysis of variance over generations for different characters in cucumber

Characters / Source	Mean sum of squares				F-Test (Test of Homogeneity)
	Genotypes	Environments	Genotype x Environment (G x E)	Pooled error	
Df	7	1	7	28	
Days to first female flower appearance	51.90*	131.96	7.06*	0.66	8.82*
Node of first female flower emergence	4.99*	1.72	1.33*	0.08	4.84*
Days to harvest	228.71*	612.56	34.56*	2.35	24.37*
Fruit length (cm)	19.16*	0.34	1.30*	0.12	1.96
Fruit girth (cm)	10.45*	1.04	1.21*	0.06	1.00
Flesh thickness (cm)	1.01*	0.07	0.02	0.01	1.00
TSS (°Brix)	0.31*	0.19	0.39*	0.02	4.00*
Parthenocarpy (%)	1825.86*	1970.63	228.65*	83.31	3.04*
Average fruit weight (g)	7185.45*	42623.93	2189.62*	125.90	784.45*
Fruits per plant	49.57*	162.44	12.34*	0.31	2.07
Downy mildew PDI (%)	6016.72*	543.28	338.70*	4.11	1.10
Yield per plant (kg)	2.99*	23.86	0.98*	0.03	2.25

* Significant at $P \leq 0.05$



4.6a. CS 130



4.6b. CS 132

4.6c. CS 133

4.6d. EC 709119

Plate 4.6 : Overview of parental genotypes

4.7a. Hilton

4.7b. Aviva

4.7c. Asma

4.7d. Isatis

Plate 4.7 : Overview of commercial hybrids

to be significant for all the characters excluding flesh thickness (cm). The test of homogeneity over generations showed significant differences for majority of the traits *i.e.* 6 out of 12, thereby suggesting that interpretation of the results on the basis of pooled over seasons would not provide clear picture (Table 4.10). Hence, the results of the individual generations along with pooled over generations have been discussed.

4.4.2 Range, Mean performance and parameters of variability

The variation in the performance of all the genotypes used in evaluation for different traits during I_4, I_5 and pooled over generations (Tables 4.11, 4.12 and 4.13) ranged from 22.00-27.00, 24.03-28.20 and 23.02-27.60 days to first female flower anthesis; 2.63-4.50, 2.48-3.97 and 2.75-4.19 for first female flower emergence node; 34.67-45.33, 32.33-43.00 and 33.50-43.67 days to harvest; 15.59-19.92, 16.55-19.29 and 16.07-19.60 cm for fruit length; 11.30-14.25, 12.39-14.59 and 11.84-14.42 cm for fruit girth; 1.06-1.83, 1.13-1.90 and 1.10-1.87 cm for flesh thickness; 2.65-3.48, 3.06-3.38 and 2.86-3.27 °Brix for total soluble solids (TSS); 46.91-81.11, 43.06-72.26 and 44.98-76.69 per cent for parthenocarpy; 158.67-235.51, 201.28-253.16 and 181.85 g for average fruit weight; 11.11-16.26, 12.47-18.96 and 12.65-17.61 fruits per plant; 0.85-64.59, 0.43-60.71 and 0.64-61.81 per cent downy mildew PDI; 2.13-3.62, 2.80-4.08 and 2.59-3.85 kg yield per plant, respectively.

Significant difference was noted in all the genotypes for days to first female flower anthesis (Appendix I, II and III). Minimum days to first female flower anthesis were taken by the genotype CS 132 (22.00, 24.03 and 23.02 days in I_4, I_5 and pooled over generations, respectively). Maximum days to first female flower anthesis were taken by the genotype Aviva (27.00 days in I_4 generation, 28.20 days in I_5 generation and 27.60 days in pooled over generations). The GCV (%) and PCV (%) values of 7.93 and 8.27 in I_4 generation (Tables 4.11, 4.12 and 4.13), 5.92 and 7.02 in I_5 generation, and 10.83 and 19.83 in pooled over generations were obtained for days to first female flower anthesis, respectively which corresponds to low, low and moderate classes in I_4, I_5 and pooled over

Table 4.11 : Estimates of parameters of variability for different characters in cucumber during I_4 generation

Traits	Range		Population Mean	GCV (%)	PCV (%)	ECV (%)	h^2_{bs}	GA (%)
	Min.	Max.						
Days to first female flower appearance	22.00	27.00	24.28	7.93	8.27	2.37	91.88	15.66
Node of first female flower emergence	2.63	4.50	3.56	18.14	20.29	9.32	79.88	33.39
Days to harvest	34.67	45.33	41.96	8.23	8.49	2.12	93.81	16.41
Fruit length (cm)	15.59	19.92	17.69	6.83	7.15	2.12	91.28	13.44
Fruit girth (cm)	11.30	14.25	13.37	6.89	7.11	1.83	93.83	13.74
Flesh thickness (cm)	1.06	1.83	1.35	17.91	18.78	7.41	90.88	35.17
TSS (°Brix)	2.65	3.48	3.12	7.59	8.63	4.53	77.34	13.75
Parthenocarpy (%)	46.91	81.11	62.08	15.80	22.90	16.57	47.61	22.46
Average fruit weight (g)	158.67	235.51	191.15	13.55	13.63	1.54	98.72	27.73
Fruits per plant	11.11	16.26	12.93	12.73	13.31	3.87	91.46	25.08
Downy mildew PDI (%)	0.85	64.59	44.81	42.30	42.54	4.47	98.90	86.66
Yield per plant (kg)	2.13	3.62	2.57	19.20	20.02	5.50	91.92	37.91

GCV, PCV and ECV represent genotypic, phenotypic and environmental coefficients of variations, respectively; h^2bs: Heritability in Broad sense; GA (%): Genetic advance (%) of mean

Table 4.12 : Estimates of parameters of variability for different characters in cucumber during I_5 generation

Traits	Range		Population Mean	GCV (%)	PCV (%)	ECV (%)	h^2_{bs}	GA (%)
	Min.	Max.						
Days to first female flower appearance	24.03	28.20	26.2	5.92	7.02	3.78	71.06	10.28
Node of first female flower emergence	2.48	3.97	3.34	14.47	15.83	6.69	83.5	27.23
Days to harvest	32.33	43.00	37.83	10.5	11.73	5.22	80.19	19.37
Fruit length (cm)	16.55	19.29	17.78	4.82	5.14	1.78	87.8	9.30
Fruit girth (cm)	12.39	14.59	13.53	4.71	5.06	1.81	86.88	9.05
Flesh thickness (cm)	1.13	1.90	1.40	16.17	17.29	7.14	87.49	31.16
TSS (°Brix)	3.06	3.38	3.19	3.67	4.62	3.13	63.09	6.00
Parthenocarpy (%)	43.06	72.26	54.68	15.99	21.42	14.26	55.72	24.59
Average fruit weight (g)	201.28	253.16	225.56	7.51	10.21	6.91	54.16	11.39
Fruits per plant	12.47	18.96	15.06	13.22	13.8	3.98	91.72	26.08
Downy mildew PDI (%)	0.43	60.71	40.93	45.32	45.6	5.01	98.79	92.80
Yield per plant (kg)	2.80	4.08	3.38	12.54	13.65	5.12	84.34	23.72

GCV, PCV and ECV represent genotypic, phenotypic and environmental coefficients of variations, respectively; h^2bs: Heritability in Broad sense; GA (%): Genetic advance (%) of mean

Table 4.13 : Estimates of parameters of variability for different characters in cucumber during pooled over generations

Traits	Range		Population Mean	GCV (%)	PCV (%)	ECV (%)	h^2_{bs}	GA (%)
	Min.	Max.						
Days to first female flower appearance	23.02	27.6	25.24	10.83	19.83	3.21	72.81	18.94
Node of first female flower emergence	2.75	4.19	3.45	22.65	49.53	8.20	55.21	34.51
Days to harvest	33.5	43.67	39.9	14.26	26.31	3.84	71.21	24.66
Fruit length (cm)	16.07	19.6	17.74	9.72	15.22	1.95	85.25	18.40
Fruit girth (cm)	11.84	14.42	13.45	9.23	15.65	1.82	77.64	16.67
Flesh thickness (cm)	1.10	1.87	1.38	29.55	40.24	7.25	93.13	58.46
TSS (°Brix)	2.86	3.27	3.16	3.55	18.58	3.88	9.96	2.30
Parthenocarpy (%)	44.98	76.69	58.38	27.95	55.50	15.63	66.89	46.86
Average fruit weight (g)	181.85	244.33	208.35	13.85	31.82	5.39	50.57	20.19
Fruits per plant	12.65	17.61	14.00	17.79	36.04	3.94	58.98	28.02
Downy mildew PDI (%)	0.64	61.81	42.87	71.76	101.12	4.73	89.11	138.86
Yield per plant (kg)	2.59	3.85	2.98	19.42	43.64	5.31	49.39	27.97

GCV, PCV and ECV represent genotypic, phenotypic and environmental coefficients of variations, respectively; h^2bs: Heritability in Broad sense; GA (%): Genetic advance (%) of mean

generations, respectively. High heritability (%) values of 91.88, 71.06 and 72.81 were obtained in I_4, I_5 and pooled over generations, respectively for the trait whereas low genetic advance (%) values of 15.66, 10.28 and 18.94 were obtained for this trait in all the generations, respectively.

Minimum and maximum number of nodes for first flower emergence were observed in Asma (2.63) and CS 130 (4.50) in I_4 generation, CS 133 (2.48) and CS 132 (3.97) in I_5 generation; and Asma (2.75) and CS 132 (4.19) in pooled over generations, respectively (Appendix I, II and III). Moderate values of GCV (18.14) and high PCV (20.29) in I_4 generation, moderate values of GCV (14.47) and PCV (15.83) in I_5 generation, and high values of GCV (22.65) and PCV (49.53) in pooled over generations were obtained for node of first female flower emergence (Tables 4.11, 4.12 and 4.13). The high heritability (79.88) and high genetic advance (33.39) values in I_4 generation, high heritability (83.50) and moderate genetic advance (27.23) values in I_5 generation, and moderate heritability value of 55.21 and high genetic gain value of 34.51 in pooled over generations were also obtained for this trait (Tables 4.11, 4.12 and 4.13).

The genotype CS 133 took 34.67, 32.33 and 33.50 days for harvest in I_4, I_5 and pooled over generations, respectively (Appendix I, II and III). Maximum days for harvest were taken by the genotype Isatis (45.33), Asma (42.33) and Aviva (43.67) in I_4, I_5 and pooled over generations, respectively. For this trait, low GCV (8.23) and PCV (8.49) values in I_4 generation, moderate GCV (10.50) and PCV (11.73) values in I_5 generation, and moderate GCV (14.26) and high PCV (26.31) values in pooled over generations were obtained (Tables 4.11, 4.12 and 4.13). High heritability (93.81) coupled with low genetic advance (16.41), high heritability (80.19) and low genetic advance (19.37), and high heritability (71.21) coupled with moderate genetic advance (24.66) values were also obtained in I_4, I_5 and pooled over generations (Tables 4.11, 4.12 and 4.13), respectively for days to harvest.

Long fruits measuring 19.92, 19.29 and 19.60 cm were recorded in the genotype CS 133 in I_4, I_5 and pooled over generations, respectively (Appendix I,

II and III). The short fruit length in I_4, I_5 and pooled over generations was recorded in the genotype Asma (15.59 cm), Hilton (17.01 cm) and Asma (16.07 cm), respectively. Low values of GCV (6.83, 4.82), PCV (7.15, 5.14), genetic advance (13.44, 9.30) and high heritability (91.28, 87.80) were observed in I_4 and I_5 generation, and low GCV (9.72), moderate PCV (15.22), low genetic advance (18.40) and high heritability (85.25) values in pooled over generations (Tables 4.11, 4.12 and 4.13).

Significant variation for the trait fruit girth was observed in all the genotypes. CS 130 (14.25, 14.59 and 14.42 cm) measured with high fruit girth in I_4, I_5 and pooled over generations, respectively (Appendix I, II and III). The minimum values for fruit girth were found in CS 131 (11.30, 12.39 and 11.84 cm) in I_4, I_5 and pooled over generations, respectively (Appendix I, II and III). Fruit girth (cm) exhibited low GCV (6.89, 4.71 and 9.23) in all the generations while low PCV (7.11 and 5.06) for I_4 and I_5 generation, and moderate PCV (15.65) was obtained in pooled over generations (Tables 4.11, 4.12 and 4.13). High heritability (93.83, 86.88 and 77.64) and low genetic advance (13.74, 9.05 and 16.67) values in all the generations were observed for this trait.

The maximum and minimum values for flesh thickness were found in the genotypes CS 133 (1.83, 1.90 and 1.87 cm) and CS 131 (1.06, 1.13 and 1.10 cm), respectively in all the generations (Appendix I, II and III). The trait exhibited moderate values of GCV (17.91 and 16.17) and PCV (18.78 and 17.29) in I_4 and I_5 generation, respectively whereas GCV (29.55) and PCV (40.24) values were high in pooled over generations. Flesh thickness (cm) also exhibited high heritability (90.88, 87.49 and 93.13) and high genetic advance (35.17, 31.16 and 58.46) in all the generations, respectively (Tables 4.11, 4.12 and 4.13).

The mean values for TSS also varied significantly. Highest TSS was found in the genotype Isatis (3.48 and 3.27 °Brix) in I_4 and pooled over generations, respectively (Appendix I, II and III). In generation I_5, genotype Hilton (3.38 °Brix) was having high TSS. The lowest TSS was found in CS 132 (2.65 °Brix) in generation I_4, Isatis (3.06 °Brix) in generation I_5, and CS 132 (2.86 °Brix) in

pooled over generations. In I_4 and I_5 generation, low values for GCV (7.59 and 3.67), PCV (8.63 and 4.62) and GA (13.75 and 6.00), respectively were obtained for TSS (Tables 4.11, 4.12 and 4.13). Low value of GCV (3.55), low value of genetic advance (2.30) and moderate value of PCV (18.58) was found in pooled over generations for TSS (°Brix). Heritability was high (77.34) in I_4 generation, moderate (63.09) in I_5 generation and low (9.96) in the pooled over generations.

Parthenocarpy (%) was maximum in the genotype CS 133 (81.11, 72.26 and 76.69 %) and minimum in the genotype CS 131 (46.91, 43.06 and 44.98 %) in I_4, I_5 and pooled over generations, respectively (Appendix I, II and III). Moderate values of GCV (15.80 and 15.99) and high values of PCV (21.42 and 22.90) were obtained in I_4 and I_5 generation whereas high GCV (27.95) and high PCV (55.50) values were recorded for parthenocarpy (%) in pooled over generations (Tables 4.11, 4.12 and 4.13). Low heritability (47.61) and moderate genetic advance (22.46) in I_4 generation, moderate heritability (55.72) and moderate genetic advance (24.59) in I_5 generation, and moderate heritability (66.89) and high genetic advance (46.86) in pooled over generations were also observed.

The average fruit weight was highest in the genotype CS 133 (235.51, 253.16 and 244.33 g) in I_4, I_5 and pooled over generations (Appendix I, II and III). Lowest average fruit weight was recorded for the genotype Hilton (158.67 and 181.85 g) in I_4, and pooled over generations whereas Aviva (201.28 g) recorded less average fruit weight in I_5 generation. The moderate GCV (13.55), moderate PCV (13.63), high heritability (98.72) and moderate genetic advance (27.73) values were obtained for average fruit weight (g) in I_4 generation. The low GCV (7.51), moderate PCV (10.21), moderate heritability (54.16) and low genetic advance (11.39) values were found in I_5 generation, and high PCV (31.82), moderate GCV (13.85), moderate heritability (50.57) and moderate genetic advance (20.19) values were obtained for pooled over generations (Tables 4.11, 4.12 and 4.13).

The genotype Hilton ranked first for maximum number of fruits per plant with the values 16.26, 18.96 and 17.61 in I_4, I_5 and pooled over generations,

respectively (Appendix I, II and III). The minimum fruits per plant were recorded for the genotypes CS 132 (11.11), Isatis (12.47) and CS 130 (12.65) in I_4, I_5 and pooled over generations, respectively. The trait exhibited moderate values of GCV (12.73 and 13.22), moderate PCV (13.31 and 13.80), high heritability (91.46 and 91.72) and moderate genetic advance (25.08 and 26.08) values in I_4 and I_5 generation, respectively (Tables 4.11, 4.12 and 4.13). While in pooled over generations, moderate GCV (17.79), high PCV (36.04), moderate heritability (58.98) and moderate genetic advance (28.02) values were recorded.

The downy mildew disease incidence (%) was lowest in the genotype CS 133 with the values of 0.85, 0.43 and 0.64 per cent in I_4, I_5 and pooled over generations, respectively (Appendix I, II and III). The highest downy mildew incidence was observed in the genotype CS 130 (64.59 %) in I_4 generation, CS 131 (60.71 %) in I_5 generation, and CS 130 (61.81 %) in pooled over generations. High values of GCV (42.30, 45.32 and 71.76), PCV (42.54, 45.60 and 101.12), heritability (98.90, 98.79 and 89.11) and genetic advance (86.66, 92.80 and 138.86) were estimated in I_4, I_5 and pooled over generations, respectively (Tables 4.11, 4.12 and 4.13).

Highest yield per plant was obtained in the genotype CS 133 with the values of 3.62, 4.08 and 3.85 kg in I_4, I_5 and pooled over generations, respectively (Appendix I, II and III). Lowest yield was recorded in the genotype CS 131 (2.13 kg) in I_4 generation, Aviva in I_5 and pooled over generations with the values of 2.80 and 2.59 kg, respectively. The moderate value of GCV (19.20), high value of PCV (20.02), heritability (91.92) and genetic advance (37.91) were observed in I_4 generation (Tables 4.11, 4.12 and 4.13). The moderate values of GCV (12.54), PCV (13.65), genetic advance (23.72) and high heritability (84.34) were found in I_5 generation. While high value of PCV (43.64), moderate values of GCV (19.42), heritability (49.39) and genetic advance (27.97) were recorded in pooled over generations.

For the qualitative traits, all the four inbreds and commercial hybrids in I_4, I_5 and pooled over generations behaved similarly for density of prickles at

Table 4.14 : Qualitative characters of cucumber inbreds and commercial hybrids

Entries	Density of prickles at harvestable maturity	Sex form	Colour of prickles at		Stem pubescence	Colour of rind at tender harvestable maturity	Colour of rind at mature stage	Presence/ absence of cavity	Bitterness
			emergence	senescence					
CS 132	Absent	PG	Absent	Absent	Present	Green	Cream	Present	Absent
CS 133	Absent	PG	White	Absent	Present	Green	Cream	Present	Absent
CS 130	Sparse	PG	White	White	Present	Green	Cream	Present	Absent
CS 131	Sparse	PG	White	White	Present	Green	Cream	Present	Absent
ISATIS	Absent	PG	Absent	Absent	Present	Green	Cream	Present	Absent
ASMA	Absent	PG	Absent	Absent	Present	Green	Cream	Present	Absent
AVIVA	Absent	PG	Absent	Absent	Present	Green	Cream	Present	Absent
HILTON	Absent	PG	Absent	Absent	Present	Green	Cream	Present	Absent

PG-Parthenocarpic gynoecious

Table 4.15 : Incidence of pest and diseases in inbreds and commercial hybrids

Parents	Serpentine leaf miner	Red spider mite	Aphids	White flies	Tobbaco caterpillar
CS 130	Mild	Mild	Mild	Nil	Moderate
CS 131	Mild	Mild	Mild	Nil	Moderate
CS 132	Mild	Mild	Mild	Nil	Moderate
CS 133	Mild	Mild	Mild	Mild	Moderate
Isatis	Mild	Mild	Mild	Nil	Moderate
Asma	Mild	Mild	Mild	Nil	Moderate
Aviva	Mild	Mild	Mild	Nil	Moderate
Hilton	Mild	Mild	Mild	Nil	Moderate

harvestable maturity, sex form, emergence, colour of prickles at senescence, stem pubescence, at tender harvestable maturity, colour of rind at mature stage and presence/ absence of seed cavity (Table 4.14). All the genotypes showed parthenocarpic gynoecious sex expression. The prickles on harvestable maturity were sparsely dense on the genotype CS 130 and CS 131 in all the generations while they were absent in the genotypes CS 132, CS 133, Isatis, Asma, Aviva and Hilton. The colour of prickles at emergence and senescence was white in the genotype CS 130 and CS 131 while it was absent in the genotypes CS 132, Isatis, Asma, Aviva and Hilton. White colour prickles at emergence and senescence were observed for the genotype CS 133. All the genotypes were pubescent and the seed cavity was present in all. The colour of rind at ripe stage was cream and it was green at harvestable maturity in all the genotypes. No bitter fruits were found over the generations in all the genotypes (Table 4.14).

The mild incidence of serpentine leaf miner, red spider mite and aphids was recorded in all the genotypes irrespective of generations (Table 4.15). Moderate incidence of tobacco caterpillar was also observed in all inbreds and commercial hybrids for all the generations.

4.5 Estimates of combining ability

The full diallel set of crosses grown in the year, 2017 were subjected to combining ability analysis by following Griffing's method I and model I. The ANOVA for RBD analysis and combining ability are presented in the Table 4.16 and 4.17, respectively.

The analysis of variance for RBD involving four parents, 12 crosses and one standard check for 16 quantitative traits revealed significant variation for all the traits studied (Table 4.16). The mean sums of squares due to treatments were significant for all the 16 quantitative traits. The mean sum of squares due to general combining ability (GCA), specific combining ability (SCA) and reciprocal effect were utilized for F test against error mean sum of squares for all the 16 quantitative traits (Table 4.17). The 'F test' for all the 16 traits indicated significant differences between GCA and SCA effects of parents and crosses,

Table 4.16 : ANOVA for RBD analysis of four parents, 12 crosses and one check for 16 quantitative traits in cucumber

Source of variation	df	Length of main vine (cm)	Branches/plant	Days to first female flower anthesis	Node at which first female flower emerged	Days to first harvest	Number of harvests	Duration of the crop	Fruits/plant
Replication	2	313.60	5.03	2.78	0.01	18.55	0.09	0.02	1.40
Treatment	16	10713.42**	14.44**	82.79**	28.11**	826.19**	12.24**	33.85**	235.42**
Error	32	1286.77	4.31	2.11	0.13	7.23	0.27	3.05	3.10

*Significant at 5% level; **Significant at 1% level

Table 4.16 : Continued

Source of variation	df	Yield/ plant (kg)	Average fruit weight (g)	Fruit length (cm)	Fruit girth (cm)	Flesh thickness (cm)	Downy mildew PDI (%)	Parthenocarpy (%)	TSS (°Brix)
Replication	2	0.01	326.31	0.98	1.46	0.01	66.41	1.94	0.01
Treatment	16	6.96**	10176.14**	99.01**	48.77**	0.42**	955.53**	1985.51**	2.02**
Error	32	0.15	122.14	0.33	0.30	0.01	52.59	105.02	0.02

*Significant at 5% level; **Significant at 1% level

Table 4.17 : ANOVA for combining ability analysis (4 × 4 full diallel, Griffing, 1956) for 16 quantitative traits in parents and hybrids in cucumber

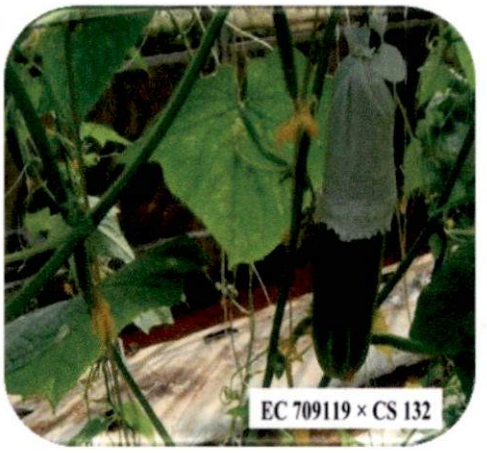
Source of variation	df	Length of main vine (cm)	Branches/plant	Days to first female flower anthesis	Node at which first female flower emerged	Days to first harvest	Number of harvests	Duration of the crop	Fruits/plant
GCA	3	29,645.95**	29.55**	36.70**	22.78**	243.45**	60.03**	76.73**	996.47**
SCA	6	8,483.41**	12.70*	71.53**	23.02**	2,037.31**	1.35**	15.40**	80.21**
RECIPROCAL	6	4,526.39**	9.08	112.20**	38.91**	33.05*	1.12*	9.30*	49.28**
ERROR	30	1,248.79	4.59	2.25	0.11	7.62	0.28	3.14	3.27

*Significant at 5% level; **Significant at 1% level

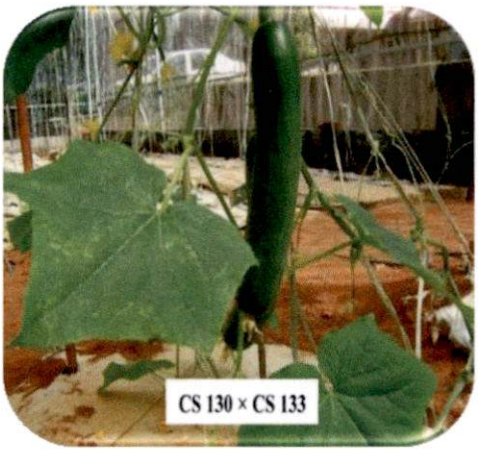
Table 4.17 : Continued

Source of variation	Df	Yield/ plant (kg)	Average fruit weight (g)	Fruit length (cm)	Fruit girth (cm)	Flesh thickness (cm)	Downy mildew PDI (%)	Parthenocarpy (%)	TSS (°Brix)
GCA	3	25.68**	7,122.50**	192.30**	7.85**	0.16**	3,909.35**	9,194.88**	5.17**
SCA	6	3.42**	22,053.25**	160.38**	122.50**	0.94**	184.38*	336.77*	2.64**
RECIPROCAL	6	2.22**	1,236.16**	5.96**	3.31**	0.07**	132.28*	290.35*	0.15**
ERROR	30	0.16	129.20	0.30	0.31	0.01	52.03	108.87	0.01

*Significant at 5% level; **Significant at 1% level



4.8a. EC 709119 × CS 132



4.8b. CS 130 × CS 133

4.8c. CS 132 × CS 133

4.8d. CS 133 × CS 132

Plate 4.8 : Overview of F_1 hybrids

4.8e. CS 133 × CS 130

4.8f. EC 709119 × CS 130

4.8g. CS 133 × EC 709119

4.8h. CS 130 × CS 132

Plate 4.8 : Overview of F_1 hybrids

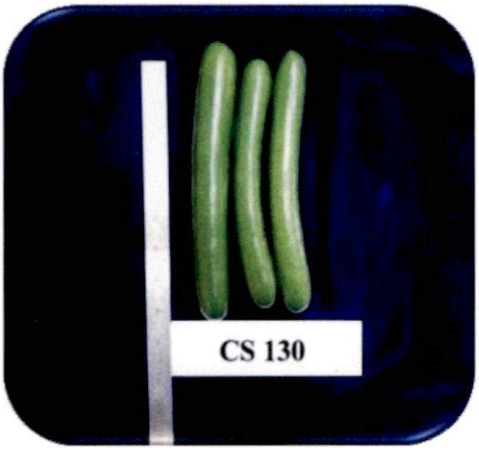
4.8i. EC 709119 × CS 133

4.8j. CS 132 × EC 709119

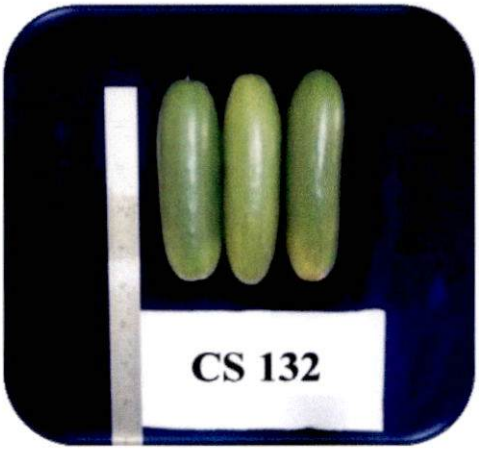
4.8k. CS 130 × EC 709119

4.8l. CS 132 × CS 130

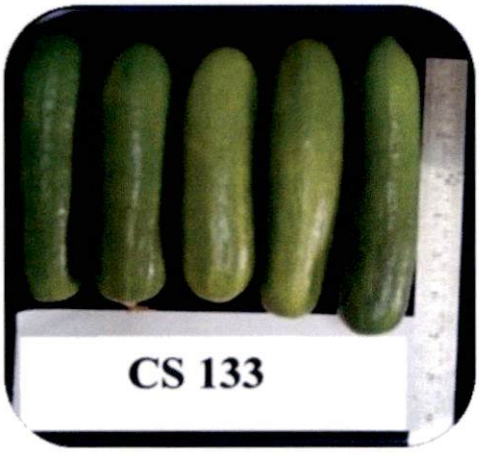
Plate 4.8 : Overview of F_1 hybrids



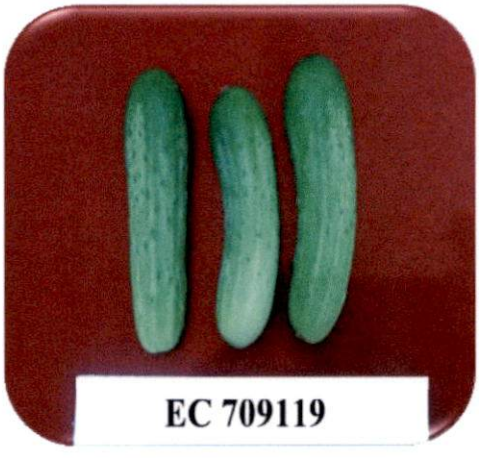
4.9a. CS 130



4.9b. CS 132

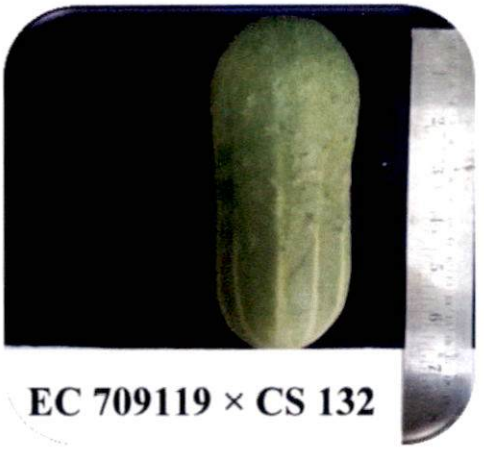


4.9c. CS 133

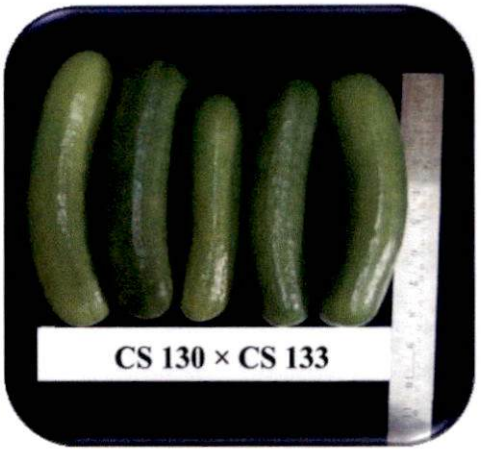


4.9d. EC 709119

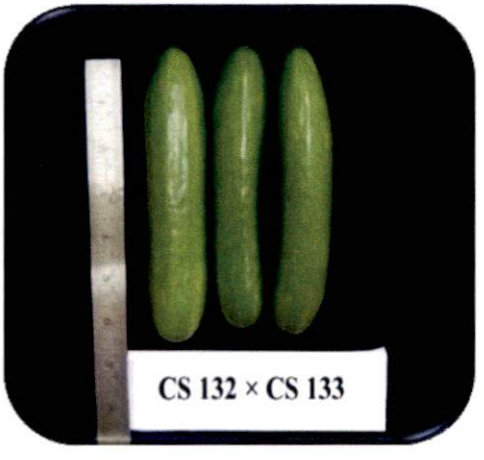
Plate 4.9 : Fruit morphology of parents



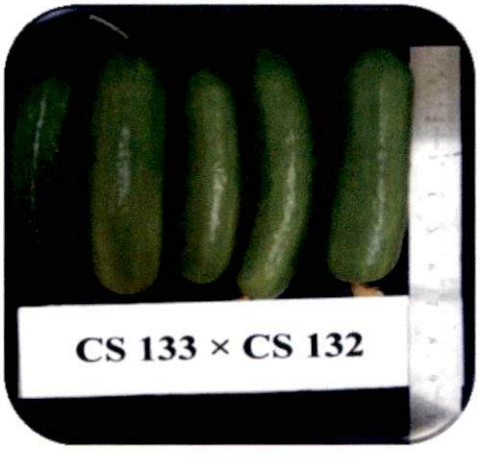
4.10a. EC 709119 × CS 132



4.10b. CS 130 × CS 133

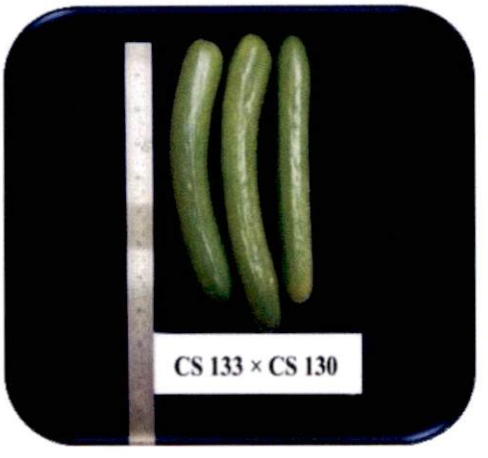


4.10c. CS 133 × CS 133

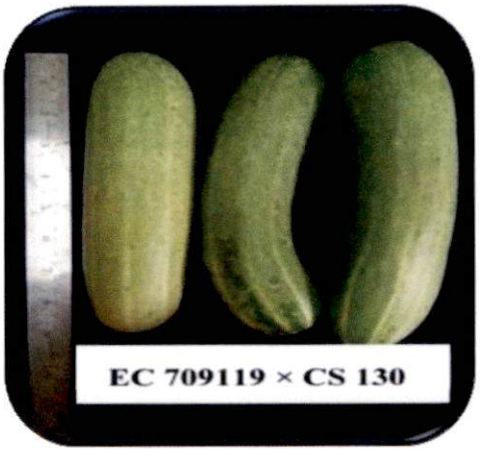


4.10d. CS 133 × CS 132

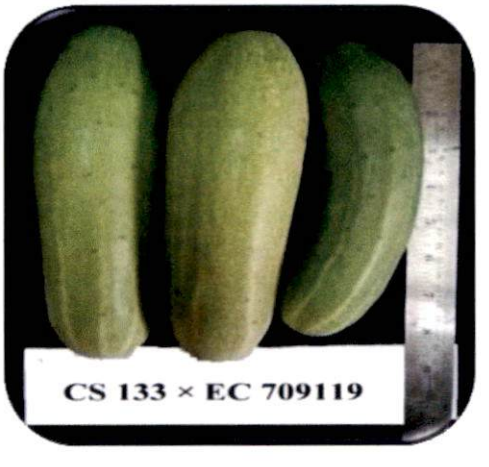
Plate 4.10 : Fruit morphology of F_1 hybrids



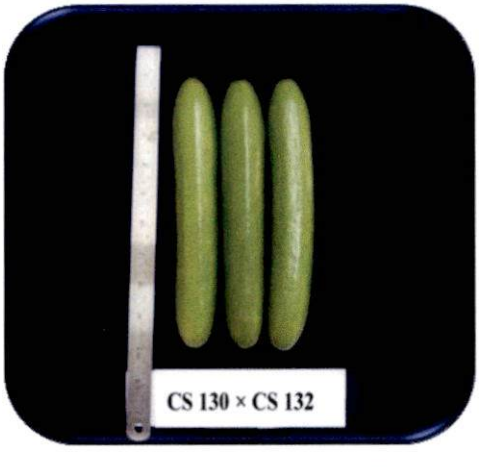
4.10e. CS 130 × CS 130



4.10f. EC 709119 × CS 130



4.10g. CS 133 × EC 709119



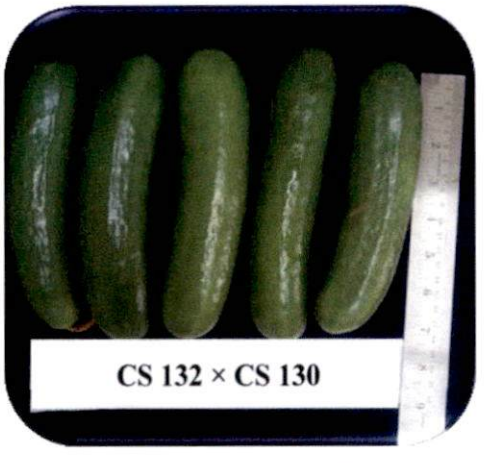
4.10h. CS 130 × CS 132

Plate 4.10 : Fruit morphology of F_1 hybrids

4.10i. EC 709119 × CS 133

4.10j. CS 132 × EC 709119

4.10k. CS 130 × EC 709119



4.10l. CS 132 × CS 130

Plate 4.10 : Fruit morphology of F_1 hybrids

respectively. Significant differences were also found in 'F test' for reciprocal effects in all the traits except branches per plant (Table 4.17).

4.5.1 Estimates of GCA (General combining ability) effects

The estimates of GCA effects of inbreds for 16 quantitative traits along with their mean performance in the year, 2017 are depicted in Table 4.18.

Length of main vine (cm)

Significant positive GCA effect for this trait was found in the parent CS 130 (29.48) and EC 709119 (26.09) while highly significant negative value was observed for the genotype CS 133 (-45.29).

Branches per plant

Positive and significant value of GCA was found in the parent EC 709119 (1.59) while parent CS 133 (-0.94) recorded significant negative value (Table 4.18).

Days to first female flower anthesis

Positive and significant GCA value of 1.21 was observed for the parent CS 132 while negative value of GCA was found in the parent CS 133 (-1.73), which was significant.

Node at which first female flower emerged

The parents EC 709119 (0.84) and CS 132 (0.66) recorded positive and significant GCA effects (Table 4.18). The negative and significant GCA effects were found in the parents CS 133 (-1.29) and CS 130 (-0.21).

Days to first harvest

The positive significant GCA effects were observed in the parents CS 133 (1.70), CS 132 (1.66) and CS 130 (1.41) while highly negative significant GCA effect was observed for the parent EC 709119 (-4.77).

Table 4.18 : Estimates of GCA effects of parental inbreds along with their mean performance for quantitative traits

Parents	Length of main vine (cm)		Branches/plant		Days to first female flower anthesis		Node at which first female flower emerged	
	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean
EC 709119	26.09**	497.38	1.59**	13.00	0.20	32.38	0.84**	5.13
CS 130	29.48**	472.50	-0.16	8.75	0.32	39.63	-0.21**	5.88
CS 132	-10.27	392.25	-0.50	8.25	1.21**	35.25	0.66**	4.88
CS 133	-45.29**	359.38	-0.94**	6.75	-1.73**	34.63	-1.29**	4.75
SE(gi) ±	6.25		0.38		0.27		0.06	
SE(gi-gj) ±	17.67		1.07		0.75		0.17	

*Significant at 5% level; **Significant at 1% level

Table 4.18 : Continued

Parents	Days to first harvest		Number of harvests		Duration of the crop		Fruits/plant	
	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean
EC 709119	-4.77**	0.00	-2.27**	0.00	-0.95**	85.00	-9.31**	0.00
CS 130	1.41**	54.75	0.22*	4.63	-1.93**	81.50	0.92**	11.25
CS 132	1.66**	48.13	0.69**	6.63	0.79**	91.00	3.25**	20.00
CS 133	1.70**	53.25	1.36**	7.25	2.09**	91.00	5.14**	21.25
SE(gi) ±	0.49		0.09		0.31		0.32	
SE(gi-gj) ±	1.38		0.27		0.89		0.90	

*Significant at 5% level; **Significant at 1% level

Table 4.18 : Continued

Parents	Yield/ plant (kg)		Average fruit weight (g)		Fruit length (cm)		Fruit girth (cm)	
	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean
EC 709119	-1.52**	0.00	-14.99**	0.00	-2.64**	0.00	-0.85**	0.00
CS 130	0.38**	2.30	24.16**	208.76	3.77**	22.95	0.42**	11.55
CS 132	0.33**	2.96	-9.05**	147.44	-1.63**	13.84	0.21*	14.27
CS 133	0.81**	3.47	-0.12	166.09	0.50**	15.19	0.23*	12.72
SE(gi) ±	0.07		2.01		0.10		0.10	
SE(gi-gj) ±	0.20		5.68		0.27		0.28	

*Significant at 5% level; **Significant at 1% level

Table 4.18 : Continued

Parents	Flesh thickness (cm)		Downy mildew PDI (%)		Parthenocarpy (%)		TSS (°Brix)	
	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean
EC 709119	-0.10**	0.00	11.15**	53.20	-29.15**	0.00	-0.68**	0.00
CS 130	0.10**	1.24	8.75**	62.00	6.95**	63.41	0.36**	3.58
CS 132	0.02	1.30	-3.25**	25.60	9.48**	57.08	0.08**	3.02
CS 133	-0.01	1.11	-16.65**	8.40	12.72**	76.69	0.24**	3.32
SE(gi) ±	0.01		1.28		1.84		0.02	
SE(gi-gj) ±	0.04		3.61		5.22		0.06	

*Significant at 5% level; **Significant at 1% level

Number of harvests

Parent CS 133 (1.36), CS 132 (0.69) and CS 130 (0.22) showed positive and significant GCA effects (Table 4.18). Negative and highly significant GCA effect was observed for parent EC 709119 (-2.27).

Duration of crop

Significant and negative GCA effects were observed for the parents CS 130 (-1.93) and EC 709119 (-0.95) whereas, the parents, CS 133 (2.09) and CS 132 (0.79) recorded positive and significant GCA effects.

Fruits per plant

Highly significant positive GCA effects were estimated in the parents CS 133 (5.14), CS 132 (3.25) and CS 130 (0.92) while parent EC 709119 (-9.31) observed negative and significant values of GCA effects.

Yield per plant (kg)

Highest GCA effects were estimated for the parents CS 133 (0.81), CS 130 (0.38) and CS 132 (0.33). Parent EC 709119 (-1.52) exhibited negative GCA effects (Table 4.18).

Average fruit weight (g)

CS 130 exhibited positive and significant GCA effect (24.16) while two parents EC 709119 (-14.99) and CS 132 (-9.05) showed negative and significant GCA effects.

Fruit length (cm)

Parents CS 130 (3.77) and CS 133 (0.50) showed positive significant GCA effects while parents EC 709119 (-2.64) and CS 132 (-1.63) exhibited significant negative GCA effects.

Fruit girth (cm)

The highest positive GCA effect was estimated in the parents CS 130 (0.42), CS 133 (0.23) and CS 132 (0.21). Negative GCA effect was found in EC 709119 (-0.85).

Flesh thickness (cm)

The significant positive GCA effect in parent CS 130 (0.10) and negative effect in EC 709119 (-0.10) were observed (Table 4.18).

Downy mildew PDI (%)

All the parents exhibited significant GCA for downy mildew disease incidence (%). Parents CS 133 (-16.65) and CS 132 (-3.25) showed negative and parent EC 709119 (11.15) and CS 130 (8.75) recorded positive GCA effects.

Parthenocarpy (%)

Positive GCA effects were found in parents CS 133 (12.72), CS 132 (9.48) and CS 130 (6.95). The parent EC 709119 (-29.15) exhibited significantly negative GCA effect for this trait (Table 4.18).

TSS (°Brix)

The parents CS 130 (0.36), CS 133 (0.24) and CS 132 (0.08) were observed with significant positive GCA effects while negative effect was found in parent EC 709119 (-0.68).

4.5.2 Estimates of SCA (Specific combining ability) effects

The SCA effects of 12 crosses (four parents full diallel) in the year, 2017 were estimated and given in Table 4.19.

Length of main vine (cm)

Out of six crosses, three crosses namely EC 709119 × CS 132 (26.56), CS 130 × CS 132 (34.41) and CS 130 × CS 133 (23.81) exhibited significant positive SCA effects for this trait (Table 4.19).

Table 4.19 : Estimates of SCA effects of crosses among four parental inbreds for quantitative traits

Crosses	Length of main vine (cm)	Branches /plant	Days to first female flower anthesis	Node at which first female flower emerged	Days to first harvest	Number of harvests	Duration of the crop	Fruits/plant
EC 709119 × CS 130	9.93	-0.47	-0.21	-0.07	11.59**	0.58**	1.52**	0.63
EC 709119 × CS 132	26.56*	1.50*	6.09**	3.68**	20.96**	-0.77**	-1.07*	-5.02**
EC 709119 × CS 133	0.01	-0.06	0.34	-0.81**	14.43**	0.25	1.26*	0.72
CS 130 × CS 132	34.41**	0.00	-0.54	-0.34**	-4.23**	0.06	0.73	4.06**
CS 130 × CS 133	23.81*	2.19**	-0.04	0.37**	-2.76**	-0.23	0.99*	0.86
CS 132 × CS 133	7.93	0.03	-0.18	-0.63**	-5.01**	0.05	-0.48	2.41**
SE (Sij) ±	11.41	0.69	0.48	0.11	0.89	0.17	0.57	0.58

*Significant at 5% level; **Significant at 1% level

Table 4.19 : Continued

Crosses	Yield/ plant (kg)	Average fruit weight (g)	Fruit length (cm)	Fruit girth (cm)	Flesh thickness (cm)	Downy mildew PDI (%)	Parthenocarpy (%)	TSS (°Brix)
EC 709119 × CS 130	0.18	60.00**	4.92**	5.55**	0.44**	-3.25	-2.76	0.56**
EC 709119 × CS 132	-0.86**	42.40**	2.01**	1.48**	0.19**	4.15*	-5.29	0.42**
EC 709119 × CS 133	0.44**	53.95**	5.91**	4.08**	0.37**	2.35	-5.37	0.72**
CS 130 × CS 132	0.95**	-10.90**	-0.61**	-1.23**	-0.12**	0.35	5.59	-0.05
CS 130 × CS 133	0.11	-23.22**	-1.61**	-2.24**	-0.16**	-7.45**	-7.46*	-0.33**
CS 132 × CS 133	0.40**	-10.73**	-0.37*	-1.31**	-0.13**	-2.45	6.45*	-0.19**
SE (Sij) ±	0.13	3.67	0.18	0.18	0.02	2.33	3.37	0.04

*Significant at 5% level; **Significant at 1% level

Branches per plant

Two crosses viz., CS 130 × CS 133 (2.19) and EC 709119 × CS 132 (1.50) exhibited positive and significant SCA effects for branches per plant.

Days to first female flower anthesis

The positive and significant SCA effect for this trait was observed only in one cross, EC 709119 × CS 132 (6.09).

Node at which first female flower emerged

Five crosses exhibited significant SCA effects for this trait. Negative effects were observed for the crosses EC 709119 × CS 133 (-0.81), CS 132 × CS 133 (-0.63) and CS 130 × CS 132 (-0.34). Crosses, EC 709119 × CS 132 (3.68) and CS 130 × CS 133 (0.37) exhibited positive SCA effects.

Days to first harvest

All the crosses showed significant SCA effects. Negative SCA effects were observed in the crosses CS 132 × CS 133 (-5.01), CS 130 × CS 132 (-4.23) and CS 130 × CS 133 (-2.76) while crosses EC 709119 × CS 132 (20.96), EC 709119 × CS 133 (14.43) and EC 709119 × CS 130 (11.59) exhibited positive SCA effects.

Number of harvests

Two crosses were observed as significant out of which cross EC 709119 × CS 130 (0.58) showed positive and cross EC 709119 × CS 132 (-0.77) showed negative SCA effects (Table 4.19).

Duration of the crop

Three crosses namely EC 709119 × CS 130 (1.52), EC 709119 × CS 133 (1.26) and CS 130 × CS 133 (0.99) exhibited significant positive SCA effects for duration of the crop while one cross EC 709119 × CS 132 (-1.07) showed negative and significant SCA effect (Table 4.19).

Fruits per plant

Positive and significant SCA effects were observed in the crosses CS 130 × CS 132 (4.06) and CS 132 × CS 133 (2.41). Cross, EC 709119 × CS 132 (-5.02) exhibited negative SCA effect.

Yield per plant (kg)

The crosses CS 130 × CS 132 (0.95), EC 709119 × CS 133 (0.44) and CS 132 × CS 133 (0.40) showed positive and significant SCA effects for yield per plant (kg). The cross EC 709119 × CS 132 (-0.86) exhibited negative and significant SCA effects for this trait.

Average fruit weight (g)

All the crosses showed significant SCA effects for average fruit weight. Three crosses *viz.*, EC 709119 × CS 130 (60.00), EC 709119 × CS 133 (53.95) and EC 709119 × CS 132 (42.40) exhibited positive while crosses CS 130 × CS 133 (-23.22), CS 130 × CS 132 (-10.90) and CS 132 × CS 133 (-10.73) showed negative SCA effects (Table 4.19).

Fruit length (cm)

All crosses exhibited significant SCA effect for fruit length (cm). Positive effects were found in the crosses EC 709119 × CS 133 (5.91), EC 709119 × CS 130 (4.92) and EC 709119 × CS 132 (2.01) whereas negative effects were observed in CS 130 × CS 133 (-1.61), CS 130 × CS 132 (-0.61) and CS 132 × CS 133 (-0.37).

Fruit girth (cm)

All crosses exhibited significant SCA for fruit girth (cm). Positive estimates for SCA were seen in the crosses EC 709119 × CS 130 (5.55), EC 709119 × CS 133 (4.08) and EC 709119 × CS 132 (1.48). The crosses, CS 130 × CS 133 (-2.24), CS 132 × CS 133 (-1.31) and CS 130 × CS 132 (-1.23) exhibited negative values of SCA effects (Table 4.19).

Flesh thickness (cm)

The positive and significant SCA effects were observed in the crosses EC 709119 × CS 130 (0.44), EC 709119 × CS 133 (0.37) and EC 709119 × CS 132 (0.19) while negative and significant SCA effects were exhibited by the crosses CS 130 × CS 133 (-0.16), CS 132 × CS 133 (-0.13) and CS 130 × CS 132 (-0.12).

Downy mildew PDI (%)

Only two crosses were found significant for this trait. One cross EC 709119 × CS 132 (4.15) showed positive and another cross CS 130 × CS 133 (-7.45) exhibited negative SCA effects.

Parthenocarpy (%)

The cross, CS 132 × CS 133 (6.45) exhibited positive and significant SCA effect. CS 130 × CS 133 (-7.46) showed negative and significant SCA effects for this trait (Table 4.19).

TSS (°Brix)

Five out of six crosses were significantly superior for SCA effects with regard to TSS (°Brix). Positive effects were exhibited by the crosses EC 709119 × CS 133 (0.72), EC 709119 × CS 130 (0.56) and EC 709119 × CS 132 (0.42) while the crosses CS 130 × CS 133 (-0.33) and CS 132 × CS 133 (-0.19) showed negative SCA effects (Table 4.19).

4.5.3 Estimates of Reciprocal effects

The estimates of reciprocal effects of crosses for 16 quantitative traits are being depicted in Table 4.20.

Length of main vine (cm)

Significant positive reciprocal effects were found in the crosses CS 133 × CS 130 (53.44) and CS 133 × CS 132 (25.31).

Table 4.20 : Estimates of Reciprocal effects of crosses among four parental inbreds for quantitative traits

Crosses	Length of main vine (cm)	Branches /plant	Days to first female flower anthesis	Node at which first female flower emerged	Days to first harvest	Number of harvests	Duration of the crop	Fruits/plant
CS 130 × EC 709119	7.81	-0.50	-0.25	-0.06	2.75*	-0.13	-0.63	-0.31
CS 132 × EC 709119	-15.94	-0.63	-10.19**	-6.19**	-4.13**	0.25	-1.00	1.50*
CS 133 × EC 709119	-18.75	-0.38	-2.25**	-0.75**	-2.00*	0.31	0.00	-0.25
CS 132 × CS 130	-19.06	1.38	-1.06*	-0.13	1.63	-0.94**	-2.81**	-6.56**
CS 133 × CS 130	53.44**	-2.38**	-0.50	0.13	-1.13	0.19	0.00	1.50*
CS 133 × CS 132	25.31*	-0.88	-1.38*	-0.13	-0.75	0.19	0.00	-1.25*
SE (Rij) ±	14.43	0.88	0.61	0.13	1.13	0.22	0.72	0.74

*Significant at 5% level; **Significant at 1% level

Table 4.20 : Continued

Crosses	Yield/ plant (kg)	Average fruit weight (g)	Fruit length (cm)	Fruit girth (cm)	Flesh thickness (cm)	Downy mildew PDI (%)	Parthenocarpy (%)	TSS (°Brix)
CS 130 × EC 709119	-0.07	-1.71	-0.85**	-0.31	-0.09**	-0.80	-6.64	-0.14**
CS 132 × EC 709119	0.17	-31.99**	-0.32	0.25	0.18**	7.40**	6.64	0.28**
CS 133 × EC 709119	-0.11	-9.12*	-2.02**	-1.41**	-0.14**	6.60*	9.81*	-0.08
CS 132 × CS 130	-1.46**	-8.77*	-0.97**	-1.08**	-0.04	3.60	-9.80*	0.20**
CS 133 × CS 130	0.13	-4.68	-0.15	-0.03	-0.08**	4.40	0.00	0.07
CS 133 × CS 132	-0.13	5.29	0.32	-0.09	0.04	-1.00	3.17	-0.05
SE (Rij) ±	0.16	4.64	0.22	0.23	0.03	2.95	4.26	0.05

*Significant at 5% level; **Significant at 1% level

Branches per plant

Significant negative reciprocal effect was exhibited by only one cross, CS 133 × CS 130 (-2.38).

Days to first female flower anthesis

The four crosses namely CS 132 × EC 709119 (-10.19), CS 133 × EC 709119 (-2.25), CS 133 × CS 132 (-1.38) and CS 132 × CS 130 (-1.06) showed significant negative reciprocal effects for this trait (Table 4.20).

Node at which first female flower emerged

The two crosses out of six, exhibited significant negative reciprocal effects namely CS 132 × EC 709119 (-6.19) and CS 133 × EC 709119 (-0.75).

Days to first harvest

Both positive and negative significant reciprocal effects were found in three crosses. Crosses CS 132 × EC 709119 (-4.13) and CS 133 × EC 709119 (-2.00) showed negative and cross CS 130 × EC 709119 (2.75) exhibited positive effects for this trait.

Number of harvests

Only one cross CS 132 × CS 130 (-0.94) was found to have significant negative reciprocal effect for this trait (Table 4.20).

Duration of crop

The significant negative reciprocal effect was shown by only one cross CS 132 × CS 130 (-2.81).

Fruits per plant

Significant positive reciprocal effect was observed in the two crosses *viz.*, CS 133 × CS 130 (1.50) and CS 132 × EC 709119 (1.50) while the cross CS 132 × CS 130 (-6.56) had shown significant negative reciprocal effect for this trait.

Yield per plant (kg)

The cross CS 132 × CS 130 (-1.46) was the only one to have significant negative reciprocal effect for yield per plant (Table 4.20).

Average fruit weight (g)

The negative and significant reciprocal effects were observed only in three crosses namely CS 132 × EC 709119 (-31.99), CS 133 × EC 709119 (-9.12) and CS 132 × CS 130 (-8.77).

Fruit length (cm)

The reciprocal estimates of SCA was found to be negative in the crosses CS 133 × EC 709119 (-2.02), CS 132 × CS 130 (-0.97) and CS 130 × EC 709119 (-0.85) for fruit length (Table 4.20).

Fruit girth (cm)

For this trait, only two crosses CS 133 × EC 709119 (-1.41) and CS 132 × CS 130 (-1.08) exhibited significant negative reciprocal effects (Table 4.20).

Flesh thickness (cm)

The estimates of reciprocal effect was found significantly positive for the cross CS 132 × EC 709119 (0.18) whereas the three crosses, CS 133 × EC 709119 (-0.14), CS 130 × EC 709119 (-0.09) and CS 133 × CS 130 (-0.08) exhibited significant negative estimates.

Downy mildew PDI (%)

Significant positive reciprocal effects were found in the two crosses CS 132 × EC 709119 (7.40) and CS 133 × EC 709119 (6.60) for downy mildew incidence.

Parthenocarpy (%)

The positive and significant reciprocal effect was seen in cross CS 133 × EC 709119 (9.81) and negative and significant reciprocal estimate was observed in CS 132 × CS 130 (-9.80) for parthenocarpy (Table 4.20).

TSS (°Brix)

The crosses CS 132 × EC 709119 (0.28) and CS 132 × CS 130 (0.20) exhibited positive reciprocal effects while the cross CS 130 × EC 709119 (-0.14) exhibited negative estimates which were significant.

4.6 Estimates of heterosis

The heterosis estimates help in identifying the best hybrid combinations for various yield contributing quantitative traits. The estimates of twelve hybrids for relative heterosis (RH), heterobeltiosis (HB) and standard heterosis (SH) for all the 16 traits are being given in the Tables 4.21 to 4.36. For estimating standard heterosis (SH), a popular parthenocarpic gynoecious hybrid 'Hilton' was included as a standard check.

Length of main vine (cm)

Length of main vine ranged from 359.38 to 497.38 cm in parents and 408.75 to 555.00 cm in hybrids (Appendix IV). Nine out of twelve hybrids exhibited significant relative heterosis (Table 4.21). Five and four crosses showed significant heterobeltiosis and standard heterosis respectively. Maximum relative heterosis and heterobeltiosis was found in the crosses CS 133 × CS 130 (30.58 %) and CS 130 × CS 132 (17.33 %) respectively. All the significant crosses for standard heterosis were in negative direction.

Branches per plant

Hybrids ranged from 8.50 to 14.25 branches per plant (Appendix IV). Four crosses showed significant standard heterosis (Table 4.22) while only one hybrid CS 130 × CS 133 (62.86 %) found significant for heterobeltiosis. Significant standard heterosis was observed in five crosses and maximum was in the hybrid CS 130 × CS 133 (62.86 %). This cross also showed maximum relative heterosis of 83.87 per cent.

Table 4.21 : Mean values of parents and F_1 hybrids and percentage heterosis for length of main vine (cm)

Parents	Length of main vine (cm)	Crosses	Length of main vine (cm)			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	497.38	EC 709119 × CS 130	539.38	11.23*	8.44	3.48
CS 130	472.50	EC 709119 × CS 132	540.00	21.40**	8.57	3.60
CS 132	392.25	EC 709119 × CS 133	481.25	12.34*	-3.24	-7.67
CS 133	359.38	CS 130 × CS 132	554.38	28.22**	17.33**	6.35
HILTON (Check)	521.25	CS 130 × CS 133	436.25	4.88	-7.67	-16.31**
		CS 132 × CS 133	408.75	8.76	4.21	-21.58**
		CS 130 × EC 709119	555.00	14.45**	11.59*	6.47
		CS 132 × EC 709119	508.13	14.23**	2.16	-2.52
		CS 133 × EC 709119	443.75	3.59	-10.78*	-14.87**
		CS 132 × CS 130	516.25	19.40**	9.26	-0.96
		CS 133 × CS 130	543.13	30.58**	14.95*	4.20
		CS 133 × CS 132	459.38	22.24**	17.11*	-11.87*
SE (±)				24.99	28.85	28.85
CD (0.05)				42.40	48.96	48.96
CD (0.01)				61.40	70.89	70.89

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Table 4.22 : Mean values of parents and F_1 hybrids and percentage heterosis for branches per plant

Parents	Branches/plant	Crosses	Branches/plant			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	13.00	EC 709119 × CS 130	12.25	12.64	-5.77	40.00*
CS 130	8.75	EC 709119 × CS 132	14.00	31.76*	7.69	60.00**
CS 132	8.25	EC 709119 × CS 133	11.75	18.99	-9.62	34.29*
CS 133	6.75	CS 130 × CS 132	8.75	2.94	0.00	0.00
HILTON (Check)	8.75	CS 130 × CS 133	14.25	83.87**	62.86**	62.86**
		CS 132 × CS 133	10.25	36.67*	24.24	17.14
		CS 130 × EC 709119	11.25	3.45	-13.46	28.57
		CS 132 × EC 709119	12.75	20.00	-1.92	45.71*
		CS 133 × EC 709119	11.00	11.39	-15.38	25.71
		CS 132 × CS 130	11.50	35.29*	31.43	31.43
		CS 133 × CS 130	9.50	22.58	8.57	8.57
		CS 133 × CS 132	8.50	13.33	3.03	-2.86
SE (±)				1.52	1.75	1.75
CD (0.05)				2.57	2.97	2.97
CD (0.01)				3.72	4.30	4.30

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Days to first female flower anthesis

Days for the first female flower anthesis varied from 32.38 to 39.63 in parent and 34.75 to 40.25 in hybrids (Appendix IV). The highest percentage of relative heterosis was found in the hybrid EC 709119 × CS 132 (65.25 %) which was one among five significant hybrids for heterosis over better parent (Table 4.23). The same cross also exhibited highest significant heterobeltiosis followed by EC 709119 × CS 133 (21.24 %). The heterosis over standard check 'Hilton' was significant for all the hybrids with negative values except the cross EC 709119 × CS 132 (25.56 %). None of the hybrids showed significant negative relative heterosis and heterobeltiosis.

Nodes at which first female flower emerged

The range of mean values for this trait varied between 4.75 to 5.88 and 4.25 to 17.63 nodes for parents and crosses, respectively (Appendix IV). The maximum significant negative relative heterosis was observed in the cross CS 133 × EC 709119 (-13.92 %). This hybrid also exhibited significant heterobeltiosis with negative values of 10.53 per cent. All the crosses except one had significant negative standard heterosis (Table 4.24). Maximum standard heterosis in negative direction was found in the cross CS 133 × EC 709119 (-47.69 %) followed by CS 133 × CS 132 (-40.00 %).

Days to first harvest

The range for days to harvest varied from 53.75 to 78.50 days in hybrids (Appendix IV). None of the hybrid exhibited significant negative value of relative heterosis (Table 4.25). For heterobeltiosis, maximum significant positive value was found for the crosses CS 130 × EC 709119 (45.96 %) followed by EC 709119 × CS 132 (43.38 %). Five out of twelve hybrids showed significant negative standard heterosis and the maximum was in the crosses CS 130 × CS 132 (-12.42 %) followed by CS 133 × CS 132 (-11.81 %).

Table 4.23 : Mean values of parents and F_1 hybrids and percentage heterosis for days to first female flower anthesis

Parents	Days to first female flower anthesis	Crosses	Days to first female flower anthesis			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	32.38	EC 709119 × CS 130	38.75	7.64**	19.69**	-12.92**
CS 130	39.63	EC 709119 × CS 132	55.88	65.25**	72.59**	25.56**
CS 132	35.25	EC 709119 × CS 133	39.25	17.16**	21.24**	-11.80**
CS 133	34.63	CS 130 × CS 132	40.25	7.51**	14.18**	-9.55**
HILTON (Check)	44.50	CS 130 × CS 133	37.25	0.34	7.58*	-16.29**
		CS 132 × CS 133	38.88	11.27**	12.27**	-12.64**
		CS 130 × EC 709119	38.25	6.25*	18.15**	-14.04**
		CS 132 × EC 709119	35.50	4.99	9.65**	-20.22**
		CS 133 × EC 709119	34.75	3.73	7.34*	-21.91**
		CS 132 × CS 130	38.13	1.84	8.16*	-14.33**
		CS 133 × CS 130	36.25	-2.36	4.69	-18.54**
		CS 133 × CS 132	36.13	3.40	4.33	-18.82**
SE (±)				1.06	1.22	1.22
CD (0.05)				1.80	2.08	2.08
CD (0.01)				2.60	3.01	3.01

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Table 4.24 : Mean values of parents and F_1 hybrids and percentage heterosis for node at which first female flower emerged

Parents	Node at which first female flower emerged	Crosses	Node at which first female flower emerged			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	5.13	EC 709119 × CS 130	6.88	25.00**	34.15**	-15.38**
CS 130	5.88	EC 709119 × CS 132	17.63	252.50**	261.54**	116.92**
CS 132	4.88	EC 709119 × CS 133	5.75	16.46**	21.05**	-29.23**
CS 133	4.75	CS 130 × CS 132	6.50	20.93**	33.33**	-20.00**
HILTON (Check)	8.13	CS 130 × CS 133	5.00	-5.88	5.26	-38.46**
		CS 132 × CS 133	5.13	6.49	7.89	-36.92**
		CS 130 × EC 709119	6.75	22.73**	31.71**	-16.92**
		CS 132 × EC 709119	5.25	5.00	7.69	-35.38**
		CS 133 × EC 709119	4.25	-13.92**	-10.53*	-47.69**
		CS 132 × CS 130	6.25	16.28**	28.21**	-23.08**
		CS 133 × CS 130	5.25	-1.18	10.53*	-35.38**
		CS 133 × CS 132	4.88	1.30	2.63	-40.00**
SE (±)				0.23	0.27	0.27
CD (0.05)				0.39	0.46	0.46
CD (0.01)				0.57	0.66	0.66

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Table 4.25 : Mean values of parents and F_1 hybrids and percentage heterosis for days to first harvest

Parents	Days to first harvest	Crosses	Days to first harvest			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	0.00	EC 709119 × CS 130	62.00	126.48**	13.24**	1.02
CS 130	54.75	EC 709119 × CS 132	78.50	226.23**	43.38**	27.90**
CS 132	48.13	EC 709119 × CS 133	69.88	162.44**	31.22**	13.85**
CS 133	53.25	CS 130 × CS 132	53.75	4.50	11.69**	-12.42**
HILTON (Check)	61.38	CS 130 × CS 133	58.00	7.41*	8.92*	-5.50
		CS 132 × CS 133	55.63	9.74**	15.58**	-9.37**
		CS 130 × EC 709119	67.50	146.58**	23.29**	9.98**
		CS 132 × EC 709119	70.25	191.95**	45.96**	14.46**
		CS 133 × EC 709119	65.88	147.42**	23.72**	7.33*
		CS 132 × CS 130	57.00	10.81**	18.44**	-7.13*
		CS 133 × CS 130	55.75	3.24	4.69	-9.16**
		CS 133 × CS 132	54.13	6.78*	12.47**	-11.81**
SE (±)				1.95	2.25	2.25
CD (0.05)				3.31	3.82	3.82
CD (0.01)				4.79	5.54	5.54

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Number of harvests

The parents showed a range of mean values from zero to 7.25 for this trait and for hybrids it varied from 2.00 to 6.88 (Appendix IV). The highest and significant relative heterosis (Table 4.26) was exhibited by the hybrids EC 709119 × CS 130 (40.54 %) followed by CS 130 × EC 709119 (29.73 %), CS 133 × EC 709119 (17.24 %) and CS 130 × CS 132 (15.56 %). None of the hybrid exhibited positive and significant value of heterobeltiosis. Positive and significant standard heterosis was achieved in the crosses CS 133 × CS 132 (71.88 %) followed by CS 132 × CS 133 (62.50 %) and CS 130 × CS 132 (62.50 %).

Duration of crop

The mean values for duration of the crop ranged from 81.50 to 91.00 days in parents and 85.38 to 91.00 days in hybrids (Appendix IV). Highest positive significant relative heterosis (Table 4.27) was exhibited by the crosses EC 709119 × CS 130 (5.56 %) followed by CS 130 × CS 132 (5.51 %), CS 130 × CS 133 (4.06 %) and CS 133 × CS 130 (4.06 %). Highest significant heterobeltiosis with positive values was shown by the cross EC 709119 × CS 130 (3.38 %) while the hybrid CS 132 × CS 130 (-6.18 %) and CS 132 × EC 709119 (-5.08 %) showed negative and significant heterobeltiosis values. All the hybrids exhibited significant positive standard heterosis and the maximum was in the crosses CS 132 × CS 133, CS 133 × CS 132 and CS 130 × CS 132 with the value of 12.35 per cent.

Fruits per plant

Mean value of hybrids for fruits per plant ranged from 2.38 to 29.75 (Appendix IV). Positive and significant relative heterosis for fruits per plant was exhibited by the crosses CS 130 × CS 132 (90.40 %) followed by CS 133 × CS 130 (43.85 %), and CS 132 × CS 133 (30.91 %). A mixed response of positive and negative significant heterobeltiosis was shown by ten crosses (Table 4.28). Highest heterobeltiosis with positive value was found in CS 130 × CS 132 (48.75 %) followed by the cross CS 132 × CS 133 (27.06 %). Highest standard heterosis

Table 4.26 : Mean values of parents and F_1 hybrids and percentage heterosis for number of harvests

Parents	Number of harvests	Crosses	Number of harvests			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	0.00	EC 709119 × CS 130	3.25	40.54**	-29.73**	-18.75*
CS 130	4.63	EC 709119 × CS 132	2.00	-39.62**	-69.81**	-50.00**
CS 132	6.63	EC 709119 × CS 133	3.63	0.00	-50.00**	-9.38
CS 133	7.25	CS 130 × CS 132	6.50	15.56*	-1.89	62.50**
HILTON (Check)	4.00	CS 130 × CS 133	5.75	-3.16	-20.69**	43.75**
		CS 132 × CS 133	6.50	-6.31	-10.34*	62.50**
		CS 130 × EC 709119	3.00	29.73*	-35.14**	-25.00*
		CS 132 × EC 709119	2.50	-24.53*	-62.26**	-37.50**
		CS 133 × EC 709119	4.25	17.24	-41.38**	6.25
		CS 132 × CS 130	4.63	-17.78**	-30.19**	15.63
		CS 133 × CS 130	6.13	3.16	-15.52**	53.13**
		CS 133 × CS 132	6.88	-0.90	-5.17	71.88**
SE (±)				0.38	0.43	0.43
CD (0.05)				0.64	0.74	0.74
CD (0.01)				0.92	1.07	1.07

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Table 4.27 : Mean values of parents and F_1 hybrids and percentage heterosis for duration of the crop

Parents	Duration of the crop	Crosses	Duration of the crop			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	85.00	EC 709119 × CS 130	87.88	5.56**	3.38*	8.49**
CS 130	81.50	EC 709119 × CS 132	88.38	0.43	-2.88*	9.10**
CS 132	91.00	EC 709119 × CS 133	91.00	3.41*	0.00	12.35**
CS 133	91.00	CS 130 × CS 132	91.00	5.51**	0.00	12.35**
HILTON (Check)	81.00	CS 130 × CS 133	89.75	4.06**	-1.37	10.80**
		CS 132 × CS 133	91.00	0.00	0.00	12.35**
		CS 130 × EC 709119	86.63	4.05**	1.91	6.94**
		CS 132 × EC 709119	86.38	-1.85	-5.08**	6.64**
		CS 133 × EC 709119	91.00	3.41*	0.00	12.35**
		CS 132 × CS 130	85.38	-1.01	-6.18**	5.40**
		CS 133 × CS 130	89.75	4.06**	-1.37	10.80**
		CS 133 × CS 132	91.00	0.00	0.00	12.35**
SE (±)				1.25	1.45	1.45
CD (0.05)				2.13	2.45	2.45
CD (0.01)				3.08	3.55	3.55

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Table 4.28 : Mean values of parents and F_1 hybrids and percentage heterosis for fruits per plant

Parents	Fruits/plant	Crosses	Fruits/plant			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	0.00	EC 709119 × CS 130	7.50	33.33	-33.33**	-48.72**
CS 130	11.25	EC 709119 × CS 132	2.38	-76.25**	-88.13**	-83.76**
CS 132	20.00	EC 709119 × CS 133	11.75	10.59	-44.71**	-19.66*
CS 133	21.25	CS 130 × CS 132	29.75	90.40**	48.75**	103.42**
HILTON (Check)	14.63	CS 130 × CS 133	20.38	25.38**	-4.12	39.32**
		CS 132 × CS 133	27.00	30.91**	27.06**	84.62**
		CS 130 × EC 709119	6.88	22.22	-38.89**	-52.99**
		CS 132 × EC 709119	5.38	-46.25**	-73.13**	-63.25**
		CS 133 × EC 709119	11.25	5.88	-47.06**	-23.08*
		CS 132 × CS 130	16.63	6.40	-16.88*	13.68
		CS 133 × CS 130	23.38	43.85**	10.00	59.83**
		CS 133 × CS 132	24.50	18.79**	15.29*	67.52**
SE (±)				1.28	1.48	1.48
CD (0.05)				2.17	2.51	2.51
CD (0.01)				3.14	3.63	3.63

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

with significant positive value was found in the crosses CS 130 × CS 132 (103.42 %) followed by CS 132 × CS 133 (84.62 %) and CS 133 × CS 132 (67.52 %).

Yield per plant (kg)

The yield varied from 0.57 to 5.91 kg in the twelve hybrids (Appendix IV). With respect to relative heterosis, the crosses CS 130 × CS 132 (124.67 %) followed by EC 709119 × CS 130 (65.33 %), CS 130 × EC 709119 (54.02 %), EC 709119 × CS 133 (52.50 %), CS 133 × CS 130 (46.26 %) and CS 132 × CS 133 (38.87 %) showed significant and positive values (Table 4.29). Highest significantly positive heterobeltiosis was exhibited by the hybrids CS 130 × CS 132 (99.62 %) followed by CS 132 × CS 133 (28.68 %), CS 133 × CS 130 (21.62 %) and CS 133 × CS 132 (21.37 %). The crosses CS 130 × CS 132 (151.04 %) followed by CS 132 × CS 133 (89.64 %), CS 133 × CS 130 (79.24 %) and CS 133 × CS 132 (78.68 %) also showed significant positive standard heterosis.

Average fruit weight (g)

Mean values with respect to average fruit weight varied between 161.13 to 257.20 g in hybrids (Appendix IV). Significant and positive relative heterosis was exhibited by the crosses which showed monoecious and gynoecious expression while for parthenocarpic hybrids maximum relative heterosis (Table 4.30) was shown by the cross CS 130 × CS 132 (11.90 %) followed by CS 133 × CS 132 (9.53 %). The maximum values for significant positive heterobeltiosis were observed in the hybrids EC 709119 × CS 132 (60.51 %) followed by EC 709119 × CS 133 (41.06) whereas the parthenocarpic gynoecious hybrids had shown significantly negative values for this trait in the crosses CS 132 × CS 130 (-12.93 %) followed by CS 133 × CS 130 (-12.60 %) and CS 130 × CS 133 (-8.12 %). Positive and significant standard heterosis was exhibited by the parthenocarpic gynoecious hybrids CS 130 × CS 132 (23.26 %) followed by CS 133 × CS 130 (12.85 %) and CS 132 × CS 130 (12.42 %).

Table 4.29 : Mean values of parents and F_1 hybrids and percentage heterosis for yield per plant (kg)

Parents	Yield/ plant (kg)	Crosses	Yield/ plant (kg)			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	0.00	EC 709119 × CS 130	1.90	65.33**	-17.34	-19.22
CS 130	2.30	EC 709119 × CS 132	0.57	-61.23**	-80.62**	-75.62**
CS 132	2.96	EC 709119 × CS 133	2.65	52.50**	-23.75**	12.37
CS 133	3.47	CS 130 × CS 132	5.91	124.67**	99.62**	151.04**
HILTON (Check)	2.35	CS 130 × CS 133	3.96	37.20**	14.09	68.14**
		CS 132 × CS 133	4.46	38.87**	28.68**	89.64**
		CS 130 × EC 709119	1.77	54.02*	-22.99	-24.75*
		CS 132 × EC 709119	0.91	-38.60*	-69.30**	-61.39**
		CS 133 × EC 709119	2.42	39.60*	-30.20**	2.87
		CS 132 × CS 130	2.99	13.55	0.89	26.87*
		CS 133 × CS 130	4.22	46.26**	21.62*	79.24**
		CS 133 × CS 132	4.21	30.97**	21.37*	78.86**
SE (±)				0.28	0.33	0.33
CD (0.05)				0.48	0.55	0.55
CD (0.01)				0.69	0.80	0.80

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Table 4.30 : Mean values of parents and F_1 hybrids and percentage heterosis for average fruit weight (g)

Parents	Average fruit weight (g)	Crosses	Average fruit weight (g)			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	0.00	EC 709119 × CS 130	257.20	146.41**	23.20**	59.08**
CS 130	208.76	EC 709119 × CS 132	236.67	221.03**	60.51**	46.38**
CS 132	147.44	EC 709119 × CS 133	234.28	182.11**	41.06**	44.90**
CS 133	166.09	CS 130 × CS 132	199.30	11.90**	-4.54	23.26**
HILTON (Check)	161.68	CS 130 × CS 133	191.82	2.34	-8.12*	18.64**
		CS 132 × CS 133	161.13	2.78	-2.99	-0.34
		CS 130 × EC 709119	253.78	143.13**	21.56**	56.96**
		CS 132 × EC 709119	172.69	134.25**	17.12**	6.81
		CS 133 × EC 709119	216.04	160.15**	30.07**	33.62**
		CS 132 × CS 130	181.76	2.05	-12.93**	12.42*
		CS 133 × CS 130	182.46	-2.65	-12.60**	12.85*
		CS 133 × CS 132	171.71	9.53*	3.38	6.20
SE (±)				8.04	9.28	9.28
CD (0.05)				13.64	15.75	15.75
CD (0.01)				19.75	22.80	22.80

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Fruit length (cm)

Fruit length in hybrids ranged from 15.54 to 25.00 cm (Appendix IV). All the hybrids except one had shown significant positive heterosis for fruit length (cm). Among parthenocarpic gynoecious hybrids, the cross CS 133 × CS 132 (16.64 %) exhibited maximum relative heterosis (Table 4.31). Some hybrid also showed maximum heterobeltiosis of 11.45 per cent for fruit length (cm). The range of heterobeltiosis varied from -8.85 to 57.34 per cent. Highest standard heterosis was seen in the hybrid EC 709119 × CS 130 (53.28 %) followed by EC 709119 × CS 133 (46.54 %) and CS 130 × EC 709119 (42.89 %). Among parthenocarpic hybrids maximum standard heterosis was shown by the hybrid CS 130 × CS 133 (28.26 %) for fruit length (cm).

Fruit girth (cm)

Fruit girth varied from 11.12 to 17.68 cm in hybrids (Appendix IV). Both positive and negative significant heterosis values were observed for different crosses. The maximum relative heterosis values were observed for the crosses showing gynoecious/monoecious sex form whereas for parthenocarpic gynoecious crosses mostly negative standard heterosis values were estimated (Table 4.32). The range of relative heterosis varied between -7.38 to 215.67 per cent. Similar trend was again showed by the crosses for heterobeltiosis. It ranged from -6.10 to 57.84 per cent. With respect to standard heterosis, parthenocarpic gynoecious cross CS 130 × CS 132 (10.85 %) showed significant standard heterosis. However, the standard heterosis for other parthenocarpic gynoecious hybrids was significantly negative.

Flesh thickness (cm)

The mean value of hybrids ranged from 1.05 to 1.72 cm (Appendix IV). Maximum relative heterosis was observed in the cross EC 709119 × CS 133 (188.29 %) and minimum relative heterosis was found in the cross CS 133 × CS 132 (-7.05 %), which were significant (Table 4.33). Cross EC 709119 × CS 133 (44.14 %) exhibited maximum significant positive heterobeltiosis. With respect to

Table 4.31: Mean values of parents and F_1 hybrids and percentage heterosis for fruit length (cm)

Parents	Fruit length (cm)	Crosses	Fruit length (cm)			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	0.00	EC 709119 × CS 130	25.00	117.86**	8.93**	53.28**
CS 130	22.95	EC 709119 × CS 132	16.18	133.74**	16.87**	-0.83
CS 132	13.84	EC 709119 × CS 133	23.90	214.68**	57.34**	46.54**
CS 133	15.19	CS 130 × CS 132	20.61	12.04**	-10.20**	26.36**
HILTON (Check)	16.31	CS 130 × CS 133	20.92	9.70**	-8.85**	28.26**
		CS 132 × CS 133	16.30	12.30**	7.31**	-0.06
		CS 130 × EC 709119	23.31	103.09**	1.55	42.89**
		CS 132 × EC 709119	15.54	124.53**	12.27**	-4.74*
		CS 133 × EC 709119	19.86	161.49**	30.74**	21.77**
		CS 132 × CS 130	18.67	1.49	-18.65**	14.47**
		CS 133 × CS 130	20.62	8.13**	-10.15**	26.43**
		CS 133 × CS 132	16.93	16.64**	11.45**	3.80
SE (±)				0.39	0.45	0.45
CD (0.05)				0.66	0.76	0.76
CD (0.01)				0.95	1.10	1.10

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Table 4.32 : Mean values of parents and F_1 hybrids and percentage heterosis for fruit girth (cm)

Parents	Fruit girth (cm)	Crosses	Fruit girth (cm)			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	0.00	EC 709119 × CS 130	18.23	215.67**	57.84**	52.17**
CS 130	11.55	EC 709119 × CS 132	13.40	87.81**	-6.10*	11.85**
CS 132	14.27	EC 709119 × CS 133	17.68	177.91**	38.95**	47.54**
CS 133	12.72	CS 130 × CS 132	13.28	2.87	-6.94*	10.85**
HILTON (Check)	11.98	CS 130 × CS 133	11.24	-7.38*	-11.64**	-6.18
		CS 132 × CS 133	12.01	-11.00**	-15.84**	0.25
		CS 130 × EC 709119	17.62	205.02**	52.51**	47.04**
		CS 132 × EC 709119	13.89	94.64**	-2.68	15.92**
		CS 133 × EC 709119	14.86	133.65**	16.82**	24.04**
		CS 132 × CS 130	11.12	-13.87**	-22.07**	-7.18*
		CS 133 × CS 130	11.18	-7.87*	-12.11**	-6.68*
		CS 133 × CS 132	11.84	-12.26**	-17.03**	-1.17
SE (±)				0.39	0.45	0.45
CD (0.05)				0.67	0.77	0.77
CD (0.01)				0.97	1.12	1.12

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Table 4.33 : Mean values of parents and F_1 hybrids and percentage heterosis for flesh thickness (cm)

Parents	Flesh thickness (cm)	Crosses	Flesh thickness (cm)			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	0.00	EC 709119 × CS 130	1.72	177.42**	38.71**	81.05**
CS 130	1.24	EC 709119 × CS 132	1.13	73.08**	-13.46**	18.42**
CS 132	1.30	EC 709119 × CS 133	1.60	188.29**	44.14**	68.42**
CS 133	1.11	CS 130 × CS 132	1.24	-2.36	-4.62	30.53**
HILTON (Check)	0.95	CS 130 × CS 133	1.21	2.98	-2.42	27.37**
		CS 132 × CS 133	1.05	-12.86**	-19.23**	10.53*
		CS 130 × EC 709119	1.55	150.00**	25.00**	63.16**
		CS 132 × EC 709119	1.49	128.85**	14.42**	56.58**
		CS 133 × EC 709119	1.33	139.64**	19.82**	40.00**
		CS 132 × CS 130	1.16	-8.66*	-10.77*	22.11**
		CS 133 × CS 130	1.05	-10.43*	-15.12**	10.79*
		CS 133 × CS 132	1.12	-7.05*	-13.85**	17.89**
SE (±)				0.05	0.06	0.06
CD (0.05)				0.08	0.10	0.10
CD (0.01)				0.12	0.14	0.14

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

standard heterosis all the hybrids recorded positive significant values ranging from 10.53 (CS 132 × CS 133) to 81.05 (EC 709119 × CS 130) per cent.

Downy mildew PDI (%)

Three out of 12 hybrids recorded significant relative heterosis namely CS 130 × CS 133 (-59.09 %), CS 133 × CS 130 (-34.09 %) with negative values and CS 132 × EC 709119 (36.04 %) with positive value (Table 4.34). None of the hybrid showed negative and significant heterobeltiosis. All the hybrids except three recorded significant and negative standard heterosis. Maximum was in the cross CS 133 × CS 132 (-81.51 %).

Parthenocarpy (%)

Parthenocarpy ranged from 13.28 to 76.69 per cent in hybrids (Appendix IV). Highest relative heterosis for this trait was observed in the cross CS 130 × CS 132 (27.29 %). All crosses showed significant negative heterobeltiosis values (Table 4.35). The highest positive and significant standard heterosis (34.35 %) was recorded for the crosses CS 133 × CS 132 and CS 130 × CS 132.

TSS (°Brix)

The mean values for hybrids ranged between 2.60 and 3.64 °Brix (Appendix IV). The highest relative heterosis with positive figure was found in the cross CS 132 × EC 709119 (108.61 %) followed by EC 709119 × CS 133 (104.82 %) as depicted in table 4.36. Significant negative relative heterosis was also observed for the cross CS 130 × CS 133 (-6.09 %). With respect heterobeltiosis, all the six significant crosses recorded negative values. Maximum and positive significant standard heterosis was observed in the cross CS 132 × CS 130 (13.75 %).

4.7 Performance of parents, hybrids and standard check for qualitative traits

The data for 11 qualitative traits (density of prickles at harvestable maturity; sex form; colour of prickles at emergence; colour of prickles at senescence; stem pubescence; colour of rind at tender harvestable maturity; colour

Table 4.34 : Mean values of parents and F_1 hybrids and percentage heterosis for downy mildew PDI (%)

Parents	Downy mildew PDI (%)	Crosses	Downy mildew PDI (%)			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	53.20	EC 709119 × CS 130	51.60	-10.42	-3.01	-11.64
CS 130	62.00	EC 709119 × CS 132	38.80	-1.52	51.56*	-33.56**
CS 132	25.60	EC 709119 × CS 133	24.40	-20.78	190.48**	-58.22**
CS 133	8.40	CS 130 × CS 132	36.40	-16.89	42.19*	-37.67**
HILTON (Check)	58.40	CS 130 × CS 133	14.40	-59.09**	71.43	-75.34**
		CS 132 × CS 133	12.80	-24.71	52.38	-78.08**
		CS 130 × EC 709119	50.00	-13.19	-6.02	-14.38
		CS 132 × EC 709119	53.60	36.04**	109.38**	-8.22
		CS 133 × EC 709119	37.60	22.08	347.62**	-35.62**
		CS 132 × CS 130	43.60	-0.46	70.31**	-25.34**
		CS 133 × CS 130	23.20	-34.09*	176.19**	-60.27**
		CS 133 × CS 132	10.80	-36.47	28.57	-81.51**
SE (±)				5.10	5.89	5.89
CD (0.05)				8.66	9.99	9.99
CD (0.01)				12.53	14.47	14.47

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

Table 4.35 : Mean values of parents and F_1 hybrids and percentage heterosis for parthenocarpy (%)

Parents	Parthenocarpy (%)#	Crosses	Parthenocarpy (%)#			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	0.00	EC 709119 × CS 130	26.55	-16.24	-58.12**	-53.48**
CS 130	63.41	EC 709119 × CS 132	13.28	-53.48*	-76.74**	-76.74**
CS 132	57.08	EC 709119 × CS 133	13.28	-65.37**	-82.69**	-76.74**
CS 133	76.69	CS 130 × CS 132	76.69	27.29*	20.94	34.35*
HILTON (Check)	57.08	CS 130 × CS 133	57.08	-18.51*	-25.57*	0.00
		CS 132 × CS 133	70.36	5.19	-8.26	23.26
		CS 130 × EC 709119	13.28	-58.12**	-79.06**	-76.74**
		CS 132 × EC 709119	26.55	-6.96	-53.48**	-53.48**
		CS 133 × EC 709119	32.89	-14.24	-57.12**	-42.39**
		CS 132 × CS 130	57.08	-5.25	-9.98	0.00
		CS 133 × CS 130	57.08	-18.51*	-25.57*	0.00
		CS 133 × CS 132	76.69	14.66	0.00	34.35*
SE (±)				7.38	8.52	8.52
CD (0.05)				12.52	14.46	14.46
CD (0.01)				18.13	20.93	20.93

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis
values are Arc sine transformed

Table 4.36 : Mean values of parents and F_1 hybrids and percentage heterosis for TSS (°Brix)

Parents	TSS (°Brix)	Crosses	TSS (°Brix)			
	Mean		Mean	RH (%)	HB (%)	SH (%)
EC 709119	0.00	EC 709119 × CS 130	3.42	91.06**	-4.47	6.87*
CS 130	3.58	EC 709119 × CS 132	2.60	72.19**	-13.91**	-18.75**
CS 132	3.02	EC 709119 × CS 133	3.40	104.82**	2.41	6.25*
CS 133	3.32	CS 130 × CS 132	3.24	-1.82	-9.50**	1.25
HILTON (Check)	3.20	CS 130 × CS 133	3.24	-6.09**	-9.50**	1.25
		CS 132 × CS 133	3.22	1.58	-3.01	0.62
		CS 130 × EC 709119	3.15	75.98**	-12.01**	-1.56
		CS 132 × EC 709119	3.15	108.61**	4.30	-1.56
		CS 133 × EC 709119	3.24	95.18**	-2.41	1.25
		CS 132 × CS 130	3.64	10.30**	1.68	13.75**
		CS 133 × CS 130	3.38	-2.03	-5.59*	5.62*
		CS 133 × CS 132	3.12	-1.58	-6.02*	-2.50
SE (±)				0.08	0.10	0.10
CD (0.05)				0.14	0.16	0.16
CD (0.01)				0.21	0.24	0.24

*Significant at 5% level; **Significant at 1% level; RH – Relative heterosis; HB – Heterobeltiosis; SH – Standard heterosis

of rind at mature stage; presence/absence of cavity; bitterness; crispness/texture) was recorded for all the parents, crosses and standard check (Tables 4.37; 4.38).

The parents varied widely for most of the qualitative traits. The parents EC 709119 and CS 130 were having sparse density of prickles at harvestable maturity whereas the parents CS 132 and CS 133 were observed with no prickles (Table 4.37). At the initial growth of the plants, the colour of prickles at emergence was white for the parents EC 709119, CS 130 and CS 133 while prickles at emergence were not observed for the parent CS 132. The brown and white colour prickles were exhibited by the parents EC 709119 and CS 130 respectively at senescence whereas no prickles were observed for the parents CS 132 and CS 133 at senescence.

The stems were pubescent in all the parents. Light green and greenish yellow colour rinds were noticed in the parent EC 709119 at tender harvestable maturity and mature stage, respectively. The parents CS 130, CS 132 and CS 133 exhibited green and cream colour rinds at tender harvestable maturity and mature stage, respectively. Seed cavity was present in all the parents. All the parents were bitter free (Table 4.37). Parents CS 130, CS 132 and CS 133 obtained sensory evaluation values for crispness/texture of 6.33±0.40, 5.92±0.34 and 5.75±0.22 based on 0-9 hedonic scale (Table 4.38). All the parents were parthenocarpic gynoecious in nature except the parent EC 709119 which was showing only gynoecious nature.

The crosses and standard check-Hilton also exhibited wide variation for qualitative traits (Table 4.37). Sparsely dense prickles at harvestable maturity were recorded for the crosses EC 709119 × CS 133, CS 130 × CS 133, CS 133 × EC 709119 and CS 132 × CS 130 while medium density of prickles at harvestable maturity was observed in the crosses EC 709119 × CS 130, EC 709119 × CS 132, CS 130 × EC 709119 and CS 132 × EC 709119. The prickles were absent in the other crosses and standard check-Hilton (Table 4.37).

The crosses CS 130 × CS 132, CS 130 × CS 133, CS 132 × CS 133, CS 132 × CS 130, CS 133 × CS 130, CS 133 × CS 132 and standard check Hilton

Table 4.37 : Qualitative characters of cucumber parental lines, their all possible crosses and check in 2017

Genotypes	Density of prickles at harvestable maturity	Sex form	Colour of prickles at		Stem pubescence	Colour of rind at tender harvestable maturity	Colour of rind at mature stage	Cavity	Bitterness
			emergence	senescence					
EC 709119	Sparse	G	White	Brown	P	Light Green	Greenish Yellow	P	A
CS 130	Sparse	PG	White	White	P	Green	Cream	P	A
CS 132	Absent	PG	Absent	Absent	P	Green	Cream	P	A
CS 133	Absent	PG	White	Absent	P	Green	Cream	P	A
EC 709119 × CS 130	Medium	M	White	Brown	P	Light Green	Greenish Yellow	P	A
EC 709119 × CS 132	Medium	M	White	Brown	P	Cream	Greenish Yellow	P	A
EC 709119 × CS 133	Sparse	M	White	Brown	P	Cream	Greenish Yellow	P	A
CS 130 × CS 132	Absent	PG	White	Absent	P	Green	Cream	P	A
CS 130 × CS 133	Sparse	PG	White	White	P	Green	Cream	P	A
CS 132 × CS 133	Absent	PG	Absent	Absent	P	Green	Cream	P	A
CS 130 × EC 709119	Medium	G	White	Brown	P	Light Green	Greenish Yellow	P	A
CS 132 × EC 709119	Medium	M	White	Brown	P	Cream	Greenish Yellow	P	A
CS 133 × EC 709119	Sparse	G	White	Brown	P	Light Green	Greenish Yellow	P	A
CS 132 × CS 130	Sparse	PG	White	White	P	Green	Cream	P	A
CS 133 × CS 130	Absent	PG	Absent	Absent	P	Green	Cream	P	A
CS 133 × CS 132	Absent	PG	Absent	Absent	P	Green	Cream	P	A
HILTON (Check)	Absent	PG	Absent	Absent	P	Green	Cream	P	A

G-Gynoecious, PG-Parthenocarpic gynoecious, M- Monoecious; A-Absent; P-Present

Table 4.38 : Mean values for crispness/texture as per 0-9 hedonic scale in parthenocarpic parents, crosses (hybrids) and standard check in 2017

Genotype	Crispness/texture*
CS 130	6.33±0.40
CS 132	5.92±0.34
CS 133	5.75±0.22
CS 130 × CS 132	6.00±0.28
CS 130 × CS 133	5.92±0.34
CS 132 × CS 133	7.33±0.40
CS 132 × CS 130	6.67±0.26
CS 133 × CS 130	7.50±0.38
CS 133 × CS 132	8.00±0.33
Hilton	7.08±0.38

'*' Data are mean ± standard error, n=12

Table 4.39 : Incidence of pest and diseases in parents, F_1 hybrids and standard check

Parents	Serpentine leaf miner	Red spider mite	Aphids	White flies
EC 709119	Mild	Mild	Mild	Mild
CS 130	Mild	Mild	Mild	Mild
CS 132	Mild	Mild	Mild	Mild
CS 133	Mild	Mild	Mild	Mild
EC 709119 × CS 130	Mild	Mild	Mild	Mild
EC 709119 × CS 132	Mild	Mild	Mild	Mild
EC 709119 × CS 133	Mild	Mild	Mild	Mild
CS 130 × CS 132	Mild	Mild	Mild	Mild
CS 130 × CS 133	Mild	Mild	Mild	Mild
CS 132 × CS 133	Mild	Mild	Mild	Mild
CS 130 × EC 709119	Mild	Mild	Mild	Mild
CS 132 × EC 709119	Mild	Mild	Mild	Mild
CS 133 × EC 709119	Mild	Mild	Mild	Mild
CS 132 × CS 130	Mild	Mild	Mild	Mild
CS 133 × CS 130	Mild	Mild	Mild	Mild
CS 133 × CS 132	Mild	Mild	Mild	Mild
Hilton (Check)	Mild	Mild	Mild	Mild

were parthenocarpic gynoecious in nature. Four crosses namely EC 709119 × CS 130, EC 709119 × CS 132, EC 709119 × CS 133 and CS 132 × EC 709119 were monoecious in nature. The cross CS 133 × EC 709119 exhibited gynoecious nature. The colour of prickles at emergence and senescence varied from white to brown, respectively for the crosses EC 709119 × CS 130, EC 709119 × CS 132, EC 709119 × CS 133, CS 130 × EC 709119, CS 132 × EC 709119 and CS 133 × EC 709119. At emergence of fruits, cross CS 130 × CS 132 showed white prickles but these were absent at senescence stage. The white colour prickles at emergence and senescence were observed in the crosses CS 130 × CS 133 and CS 132 × CS 130.

All the hybrids and standard check Hilton were pubescent, with seed cavity and were free from bitterness (Table 4.37). With respect to colour of rind at tender harvestable maturity and at mature stage, the crosses EC 709119 × CS 130, CS 130 × EC 709119 and CS 133 × EC 709119 were light green and greenish yellow, respectively. The cream and greenish yellow rinds at tender harvestable maturity and at mature stages, respectively were observed for the crosses EC 709119 × CS 132, EC 709119 × CS 133 and CS 132 × EC 709119. Rest of the crosses and Hilton exhibited green and cream colour rind at tender harvestable maturity and at mature stages, respectively.

The 0-9 hedonic scale sensory evaluation values for crispness/texture for the parthenocarpic gynoecious hybrids and standard check (Table 4.38) were highest for CS 133 × CS 132 (8.00±0.33) followed by CS 133 × CS 130 (7.50±0.38), CS 132 × CS 133 (7.33±0.40), Hilton (7.08±0.38), CS 130 × CS 132 (6.00±0.28) and CS 130 × CS 133 (5.92±0.34).

4.8 Incidence of pest and disease in parents, hybrids and standard check

Mild attack of serpentine leaf miner, red spider mite, aphids and whiteflies was recorded in all the genotypes (Table 4.39). None of the genotype was observed with any serious incidence of pest and disease.

Discussion

5. DISCUSSION

Parthenocarpy along with gynoecious sex expression is an asset for protected cultivation of cucumber. The development of hybrids exhibiting these traits along with various useful yield attributing characters is a tedious and very risky affair because if a generation is missed for inducing male flowers or failed under *in vitro* regeneration for seed production, it will result in complete loss of genetic material. Keeping all these risks aside, parthenocarpic gynoecious hybrids with high yield and fruit quality were developed in this study. Various experiments regarding the development of these hybrids are discussed under following headings:

5.1 Maintenance of parthenocarpic lines of cucumber through tissue culture

Standardization of micro-propagation protocol for cucumber could be used for reducing the cost (approx. 30 %) of hybrid seed production (Alam *et al.*, 2015) and moreover, to cope up the risk of maintenance of parthenocarpic and gynoecious cucumber due to their innate seedless nature.

Seed germination of two parthenocarpic (CS 130 and CS 131), one gynoecious (EC 709119) and one monoecious (L-04) genotype was observed *in vitro* with half strength MS (Murashige and Skoog, 1962) basal medium and 100 percent germination was achieved. Precocious germination was shown by the gynoecious genotype (EC 709119) followed by parthenocarpic genotypes (CS 130 and CS 131) and monoecious cultivar (L-04). *In vitro* germination of cucumber cultivar was also reported by Margaret *et al.* (2014) and Alam *et al.* (2015).

Maximum shoot initiation and its response (100 %) from seedling excised cotyledonary leaf explants was obtained with the media composition of half strength MS medium supplemented with 0.50 mg/l IAA and 2 mg/l BAP. This was achieved due to the high concentration of cytokinin which initiated early shooting. The remaining treatments varied in shoot initiation response for the different genotypes. Similar type of varied shoot initiation response for different genotypes were also

observed by Wehner and Locy (1981), Rhonda and William (1990), Hooymons *et al.* (1994), Mohiuddin *et al.* (2005) and Ugandhar *et al.* (2011).

The half strength MS medium supplemented with 0.25 mg/l IAA followed by half MS + 0.50 mg/l IAA were found best for rooting and the half MS media fortified with 0.25 mg/l IAA and 2 mg/l BAP for callusing in all the genotypes. The half strength MS medium, supplemented with 0.25 mg/l IAA followed by 0.50 mg/l IAA, were better for rooting in cotyledonary leaf explants of parthenocarpic and gynoecious cucumber. With regard to callusing from cotyledonary leaf explants in parthenocarpic cucumber, the half MS medium supplemented with 0.25 mg/l IAA and 2 mg/l BAP was found to be best with cent per cent response in parthenocarpic and gynoecious cucumber genotypes. *In vitro* rooting using various auxin and cytokinin concentrations was also achieved by Handley and Chambliss (1979), Cade *et al.* (1990), Misra and Bhatnagar (1995), Chovelon *et al.* (2011) and Ugandhar *et al.* (2011).

Micro-propagation from stem nodal cuttings is always preferable over cotyledonary explants. Shoot initiation from stem nodal explants was achieved in A_2 (Full MS + 1.50 mg/l IAA + 2 mg/l BAP) media whereas half strength MS media without any hormones resulted in rooting of various parthenocarpic, gynoecious and monoecious cucumber genotypes in the present study. The shoot and root regeneration from stem nodal explants were also observed by Custers and Verstappen (1989), Sarowar *et al.* (2003), Vasudevan *et al.* (2007), Pakarla (2013), Margaret *et al.* (2014) and Alam *et al.* (2015).

In vitro development of male and female flowers was noticed in all genotypes. Fertile male flowers based on pollen fertility test using acetocarmine stain (1 %) were found in the medium supplemented with BAP in the cotyledonary leaf and stem nodal explants of parthenocarpic and gynoecious genotypes. This might have happened due to high concentration of cytokinin hormone used in the media. It had been earlier reported that flowering of cucumber in tissue culture depends on the type of explants,

media composition, type and concentration of plant growth regulators (Kielkowska and Havey, 2011). *In vitro* male flower production in cucumber was also reported by various researchers namely Rajasekaran *et al.* (1983), Msikita *et al.* (1990) and Kielkowska and Havey (2011).

While evaluating tissue cultured regenerated plants in the polyhouse, 87.50 per cent survival was found in monoecious genotype (L-04) and least (44.44 %) in parthenocarpic gynoecious line, CS 130. Out of five survived plants of parthenocarpic genotype (CS 131), three plants showed monoecious sex expression whereas two had shown parthenocarpic gynoecious sex expression. The change in sex expression was probably due to the presence of high concentration of growth hormone. This can be studied further for finding concrete results. Variation in survival percentage was also recorded by Vasudevan *et al.* (2004) and Ugandhar *et al.* (2011).

5.2 Induction of male flower in parthenocarpic lines

Maintenance of parthenocarpic and gynoecious cucumber genetic stocks, through induction of male flowers phenotypically using various growth regulators is an important step in breeding parthenocarpic cucumber hybrids (Peterson and Andher, 1960; Robinson, 1999).

Out of four treatments of silver thiosulphate (STS) with different concentrations varying from 150 to 600 ppm, two sprays of STS at 300 ppm treatment was found best. This treatment took minimum days for male flower induction and nodes up to which male flower appeared at 2 to 6 leaf stage in parthenocarpic and gynoecious cucumber genotypes. The lowest node at which male flower induced was achieved with the treatment of STS at 600 ppm concentration. The results achieved in this experiment are in close conformity with the results obtained by Nijs and Visser (1980), Milotay (1983), Scrutu and Scrutu (1995), Chaudhary *et al.* (2001) and Nagar *et al.* (2014; 2015).

5.3 Evaluation of inbred lines for isolation of improved parthenocarpic lines

The inbreds derived from self pollination were developed using single seed descent method (SSD) as proposed by Brim (1966) for up to I_5 generations. Oviedo *et al.* (2008) also developed cucumber inbred lines up to five generations using SSD method. The four inbred lines (CS 130, CS 131, CS 132 and CS 133) exhibited variation in ranges for all the characters across generations. These inbreds differed for various traits namely node for the first female flower emergence, days to harvest, fruit length (cm), fruit girth (cm), average fruit weight (g) and parthenocarpy (%) in I_0, I_1, I_2 and I_3 generations. Parthenocarpic expression which is the most important trait in inbred development exhibited less variation in advanced generations.

During evaluation of these inbreds in I_4 and I_5 generation for various quantitative and qualitative traits, significant mean squares were observed based on analysis of various estimates in both generations. Significant values of mean square due to genotypes against G × E interactions in pooled ANOVA were also recorded for all the traits. The significant G × E interaction was also observed for all the traits except flesh thickness (cm). Sharma (2010) also found significant values of mean squares due to genotype and G × E interactions for all the traits. The test of homogeneity was significant for the traits namely, days to first female flower appearance, node of first female flower emergence, days to harvest, TSS (°Brix), parthenocarpy (%) and average fruit weight (g) indicating that results obtained for these traits would not provide clear estimates on the basis of pooling of data alone. Solanki and Seth (1980), Kumar *et al.* (2008), Yadav *et al.* (2009), Bisht *et al.* (2010), Gaikwad *et al.* (2011) and Dogra (2012) also reported significant variations for various traits in protected cultivation during the evaluation of cucumber germplasm. On the basis of mean performance, the genotypes CS 133 followed by CS 130, CS 132 and CS 131 were found superior for majority of the required quantitative traits, thereby indicating variability in the two generations when compared with the commercial hybrids.

The genetic variability can be partitioned into phenotypic, genotypic and environmental components to know its nature and magnitude in the genotypes used. PCV and GCV estimates predict the amount of genetic variability in the observed genetic stock and helps in deciding an efficient breeding programme. The estimates of PCV were higher in magnitude than corresponding GCV estimates for all the traits and over the generations. These higher estimates of PCV gave clue for influence of environment. Hence, caution is necessary while going for selection on the basis of only phenotypic prediction. In various studies at respective places, Afangideh and Uyoh (2007), Kumar *et al.* (2008), Yadav *et al.* (2009), Bisht *et al.* (2010), Dogra (2012) and Karthika (2016) also reported higher PCV values than corresponding GCV values for different traits in cucumber thereby substantiating the present findings.

High GCV and PCV estimates were observed for downy mildew PDI (%) in I_4, I_5 and pooled over generations, and node of first female flower appearance, flesh thickness (cm) and parthenocarpy (%) in pooled over generations which suggested improvement through selection for these traits. Gaikwad *et al.* (2011) and Hossain *et al.* (2010) also reported similar results for PDI and node numbers of first female flower, akin to the present findings. Moderate GCV and PCV effects were exhibited by the traits namely average fruit weight (g), fruits per plant, and flesh thickness (cm) in I_4 generation, node of first female flower appearance, days to harvest, flesh thickness (cm), fruits per plant and yield per plant (kg) in I_5 generation and days to first female flower emergence in pooled over generations. In consonance with present finding, Dogra (2012) also reported moderate GCV and PCV estimates for days taken to first fruit harvest and fruits per plant.

Moderate GCV coupled with high PCV values were obtained in the traits, node of first female flower appearance, parthenocarpy (%) and yield per plant (kg) in I_4 generation, days to first harvest, average fruit weight (g), fruits per plant and yield per plant (kg) in pooled over generations and parthenocarpy (%) in I_5 generation.

Similar GCV and PCV estimates were also observed by Basavarajeshwari *et al.* (2014) for fruits per plant and fruit yield per vine in their respective genetic stock. The traits, days to first female flower emergence, days to first harvest, fruit length (cm), fruit girth (cm) and TSS (°Brix) in I_4 and I_5 generation except days to first harvest showed lower estimates of PCV and GCV, which indicated lower variability in genotypes for these traits. In support of these results, earlier workers Solanki and Seth (1980), Saikia *et al.* (1995) and Ranjan *et al.* (2015) also observed lower estimates of GCV and PCV. Moderate GCV and low PCV values for fruit length (cm), fruit girth (cm) and TSS (°Brix) in pooled over generations and lower GCV with moderate PCV for average fruit weight (g) in I_5 generation indicated moderate and low genetic variability among the genotypes for these traits. Kumar *et al.* (2013) also observed moderate GCV for TSS (°Brix) in their study.

The magnitude of heritability in board sense directs the reliability of a genotype for phenotypic performance (Lush, 1949). It is a measure of heritable variations (Burton and De Vane, 1953). The usefulness of genetic advance along with heritability for measuring the real effects is of utmost importance (Johnson *et al.*, 1955). High heritability with high genetic advance estimates were evidenced for characters namely node of first female flower emergence, flesh thickness (cm), downy mildew PDI (%) and yield per plant (kg) in I_4 generation, flesh thickness (cm) and downy mildew PDI (%) in I_5 and pooled over generations. These high estimates revealed that these traits are amenable for selection. High heritability and genetic advance estimates were also observed for various traits by Kumar *et al.* (2008), Mehdi and Khan (2009), Yadav *et al.* (2009) and Veena *et al.* (2012).

The non-additive effects were exhibited due to the high heritability coupled with low genotypic advance values for days to first female flowers appearance, fruit length (cm) and fruit girth (cm) in I_4, I_5 and pooled over generations, and days to first harvest in I_4 and I_5 generation, and TSS (°Brix) in I_4 generation. Similar findings were also recorded for days to first female flower and fruit length by Chaudhary *et al.*

(1985) which substantiate the results in this study. High heritability with moderate genetic advance was observed for average fruit weight (g) and fruits per plant in I_4 generation; node of first female flower emergence, fruits per plant and yield per plant (kg) in I_5 generation; and days to first harvest in pooled over generations. Moderate heritability and genetic advance was obtained for parthenocarpy (%) in I_4 generation and three traits *viz.*, average fruit weight (g), fruits per plant and yield per plant (kg) in pooled over generations. These results were in concordance with the findings of Kumar *et al.* (2008) and Kumar *et al.* (2013). In I_5 generation, the characters TSS (°Brix) and average fruit weight (g) recorded moderate heritability and low genetic advance, while in pooled over generations lower estimates of heritability and genetic advance were observed. Chaudhary *et al.* (1985), Prasad and Singh (1992) and Dutta (2013) also got low genetic advance for various traits.

For the qualitative traits, all the four inbreds and commercial hybrids in both the generations showed parthenocarpic gynoecious sex expression. The prickles on harvestable maturity were sparsely dense on the genotype CS 130 and CS 131 in all the generations while they were absent in the genotypes CS 132, CS 133, Isatis, Asma, Aviva and Hilton. The colour of prickles at emergence and senescence was white in the genotype CS 130 and CS 131 while it was absent in the genotypes CS 132, Isatis, Asma, Aviva and Hilton. White colour prickles at emergence and senescence were observed for the genotype CS 133. All the genotypes were pubescent and the seed cavity was present in all. The colour of rind at mature stage was cream and it was green at harvestable maturity in all the genotypes. No bitter fruits were found over the generations in all the genotypes. Brown colour prickles were also observed by Pyzhenkov (1986) in cucumber genotypes.

Mild incidence of serpentine leaf miner, red spider mite and aphids was recorded in all the genotypes irrespective of seasons, the spread of these pests was found very common. Moderate incidence of tobacco caterpillar was also observed in all inbreds and commercial hybrids for both the seasons. In protected cultivation,

these pests can be managed by following proper guidelines and various sanitation measures.

Based on the qualitative and important quantitative characters, mean performance of the inbreds and parameters of variability estimates, three parthenocarpic (CS 130, CS 132 and CS 133) inbreds were chosen for full diallel mating along with stable gynoecious (EC 709119) inbred.

5.4 Combining ability analysis

The diallel set of four parents and their consequent six reciprocal and six direct crosses was subjected to combining ability analysis by following the approach of Griffing (1956) - Method I and Model I.

The 'F test' for both GCA and SCA was significant for all the traits. It indicated that sufficient differences were available between parents and crosses, respectively, which further signify the importance of both additive and non additive type of gene action in the inheritance of all the 16 quantitative traits observed under the study. The 'F test' for reciprocal effect was also significant for all the traits except branches per plant. Reciprocal effects is an important criteria to examine the *per se* performance of crosses by following Griffing (1956) approach for estimating general and specific combining ability.

The influence of additive genes, intra or inter allelic interactions and the rate of cytoplasmic genes in the expressions of the traits was evident as the significant values of 'F test' were achieved for GCA, SCA and reciprocal effects (except branches per plant) in the present study for all the traits. Similar significant results for GCA and SCA were also observed by Kanobdee *et al.* (1990), Golabadi *et al.* (2015), and Kaur *et al.* (2016).

Our finding regarding significant reciprocal effects were corroborated by earlier researcher's as well. Golabadi *et al.* (2015) while investigating the combining ability in a full 9 × 9 diallel population of cucumber found significant reciprocal

effects for all the traits studied and Shen *et al.* (2015) also found significant reciprocal effects for all the traits in doubled haploids of cucumber.

5.4.1 General Combining Ability (GCA) estimates

Genetically superior parents and tested breeding methods are needed for the development of superior hybrids. GCA effects are very much valuable in cucumber breeding program for the development of superior hybrids. The experimental results pertaining to 4 × 4 full diallel mating design for estimation of combining ability revealed that all the parents showed variable and significant results of GCA for one or another trait.

Parent EC 709119 was a good general combiner for length of main vine (cm), branches per plant and days to first harvest and exhibited desirable significant GCA effects for these traits (Table 5.1). Another parent CS 130 showed significant and desirable GCA effects for length of main vine (cm), node of first female flower emergence, number of harvests, fruits per plant, yield per plant (kg), average fruit weight (g), fruit length (cm), fruit girth (cm), flesh thickness (cm), parthenocarpy (%) and TSS (°Brix). Desirable and significant GCA effects for the traits *viz.*, number of harvests, duration of the crop, fruits per plant, yield per plant (kg), fruit girth (cm), downy mildew PDI (%), parthenocarpy (%) and TSS (°Brix) were exhibited by the parent CS 132 (Table 5.1). With respect to the traits namely days to first female flower emergence, node of first female flower emergence, number of harvests, duration of the crop, fruits per plant, yield per plant (kg), fruit length (cm), fruit girth (cm), downy mildew PDI (%), parthenocarpy (%) and TSS (°Brix), significant desirable GCA effects were observed for the parent CS 133.

Significant negative and desirable GCA effects were also reported earlier for days to first female flower appearance (Abhang, 1987; Lopez-Sese and Staub, 2002; Vidhya and Kumar, 2014), node of first female flower (Mule *et al.,* 2012; Kaur and Dhall, 2017), days to first harvest (Hanchinamani, 2006; Dogra and Kanwar, 2011;

Table 5.1 : Best performing parents based on GCA effects

Characters	Parents
Length of main vine (cm)	CS 130, EC 709119
Branches per plant	EC 709119
Days to first female flower emergence	CS 133
Node of first female flower appearance	CS 133, CS 130
Days to first harvest	EC 709119
Number of harvests	CS 133, CS 132, CS 130
Duration of crop	CS 133, CS 132
Fruits per plant	CS 133, CS 132, CS 130
Yield per plant (kg)	CS 133, CS 130, CS 132
Average fruit weight (g)	CS 130
Fruit length (cm)	CS 130, CS 133
Fruit girth (cm)	CS 130, CS 133, CS 132
Flesh thickness (cm)	CS 130
Downy mildew PDI (%)	CS 133, CS 132
Parthenocarpy (%)	CS 133, CS 132, CS 130
TSS (°Brix)	CS 130, CS 133, CS 132

Kumar, 2013; Tiwari, 2015) and incidence of downy mildew (Kumar, 2013) at different locations with different genetic materials. The desirable and significantly positive GCA effects for the traits *viz.*, length of main vine (cm), branches per plant, number of harvests, duration of the crop, fruits per plant, yield per plant (kg), average fruit weight (g), fruit length (cm), fruit girth (cm), flesh thickness (cm), parthenocarpy (%) and TSS (°Brix) were also in conformity with the results of El-Shawaf and Baker (1981), Guseva and Mospan (1984), Abhang (1987), Lopez-Sese and Staub (2002), Hanchinamani (2006), Singh *et al.* (2010), Dogra and Kanwar (2011), Mule *et al.* (2012), Kumar (2013), Vidhya and Kumar (2014), Tiwari (2015), Golabadi *et al.* (2015) and Kaur *et al.* (2016).

The best parthenocarpic gynoecious general combiners for yield and related traits were the parents CS 133 and CS 130 (Table 5.1), which showed overall better performance and desirable GCA effects. Different parents expressing high GCA (desirable) for yield and related traits have been reported by Abhang (1987), Hanchinamani (2006), Singh *et al.* (2010), Dogra and Kanwar (2011), Mule *et al.* (2012), Tiwari (2015) and Kaur and Dhall (2017).

5.4.2 Specific Combining Ability (SCA) estimates

Relatedness of non-additive gene interactions with SCA effects helps in choosing the best F_1 hybrids / cross combinations. In the present study, the cross CS 130 × CS 132 (Table 5.2) exhibited better and desirable SCA performance for the traits namely length of main vine (cm), node of first female flower emergence, days to first harvest, fruits per plant, yield per plant (kg) and undesirable but significant SCA effects for average fruit weight (g), fruit length (cm), fruit girth (cm) and flesh thickness (cm). The desirable SCA effects pointed towards the non-additive gene action for manifestation of these traits.

The hybrid CS 130 × CS 133 exhibited significant desirable values of SCA for length of main vine (cm), branches per plant, days to first harvest, duration of the

Table 5.2 : Best performing hybrids based on SCA effects

Characters	Hybrids
Length of main vine (cm)	CS 130 × CS 132, EC 709119× CS 132, CS 130 × CS 133
Branches per plant	CS 130 × CS 133, EC 709119 × CS 132
Days to first female flower emergence	None
Node of first female flower appearance	EC 709119 ×CS 133, CS 132 × CS 133, CS 130 ×CS 132
Days to first harvest	CS 132 ×CS 133, CS 130 × CS 132, CS 130 × CS 133
Number of harvest	EC 709119 ×CS 130
Duration of crop	EC 709119 ×CS 130, EC 709119 ×CS 133, CS 130 × CS 133
Fruits per plant	CS 130 ×CS 132, CS 132 ×CS 133
Yield per plant (kg)	CS 130 ×CS 132, EC 709119 ×CS 133, CS 132 × CS 133
Average fruit weight (g)	EC 709119 × CS 130, EC 709119 ×CS 133, EC 709119 ×CS 132
Fruit length (cm)	EC 709119 × CS 133, EC 709119 ×CS 130, EC 709119×CS 132
Fruit girth (cm)	EC 709119 × CS 130, EC 709119 ×CS 133, EC 709119 ×CS 132
Flesh thickness (cm)	EC 709119 × CS 130, EC 709119 ×CS 133, EC 709119 ×CS 132
Downy mildew PDI (%)	CS 130 × CS 133
Parthenocarpy (%)	CS 132 × CS 133
TSS (°Brix)	EC 709119 × CS 133, EC 709119 × CS 130, EC 709119 × CS 132

crop and downy mildew PDI (%), however this hybrid showed undesirable SCA estimates for node at which first female flower emerged, all fruit related traits, parthenocarpy (%) and TSS (°Brix). High desirable SCA effects were also observed for the characters namely node at which first female flower emerged, days to first harvest, fruits per plant, yield per plant (kg) and parthenocarpy (%) for the best performing hybrid CS 132 × CS 133 (Table 5.2).

All the hybrids derived from the cross involving gynoecious parent (EC 709119) exhibited significant desirable SCA estimates (Table 5.2) for the days to first harvest, number of harvests, duration of the crop, average fruit weight (g), fruit length (cm), fruit girth (cm), flesh thickness (cm) and TSS (°Brix). This might have happened due to the higher *per se* performance of hybrids over their parent (EC 709119), which got zero values for these traits.

Significant and desirable SCA effects for cucumber germplasm and crosses were also reported by Hanchinamani (2006) and Mule *et al.* (2012) for length of main vine; Lopez-Sese and Staub (2002) and Singh *et al.* (2010) for number of primary branches; Abhang (1987), Hanchinamani (2006), Dogra and Kanwar (2011) and Tiwari (2015) for days to first female flowering, node of first female flower and days for harvesting, fruits per vine and yield per vine (kg); Kumar (2013) and Tiwari (2015) for days to last harvest and crop duration; Dogra and Kanwar (2011), Vidhya and Kumar (2014) and Kaur and Dhall (2017) for fruit weight (g), fruit length (cm) and fruit girth (cm); Abhang (1987) and Hanchinamani (2006) for flesh thickness (cm); Kumar (2013) for incidence of downy mildew disease (%); Guseva and Mospan (1984) for parthenocarpy (%); Kaur *et al.* (2016) for TSS (°Brix), which supported the present findings showing non additive gene effects for these traits.

5.4.3 Estimates of reciprocal effects

The best cross combinations showing desirable reciprocal effects (Table 5.3) were CS 133 × CS 132 for length of main vine (cm) and days to first female flower

anthesis; CS 133 × CS 130 for length of main vine (cm) and fruits per plant; CS 132 × CS 130 for days to first female flower anthesis and TSS; CS 132 × EC 709119 for all earliness related traits, fruits per plant, flesh thickness (cm) and TSS (°Brix); CS 133 × EC 709119 for all earliness related traits and parthenocarpy (%). Similar findings were reported in cucumber by Vidhya and Kumar (2014) showing significant reciprocal effects in various hybrids for days to first female flowering, number of fruits per vine and fruit pulp thickness (cm).

It is interesting and clearly evident that wherever the parents CS 132 and CS 133 were used as a maternal parent, their crosses exhibited significant reciprocal effects. Such reciprocal differences are manifested by either maternal or cytoplasmic effects. So, care should be exercised while using such parents for expression of traits as suggested by Chezhian *et al.* (2000).

5.5 Estimation of Heterosis

The twelve F_1 hybrids for 16 quantitative traits were subjected to heterosis studies (relative heterosis, heterobeltiosis and standard heterosis) in the present experiment. All the characters showed significant heterosis.

High vegetative growth is an asset in polyhouse cultivation of cucumber for exploring the vertical space and maximizing the yield potential. Desirable relative heterosis and heterobeltiosis values were exhibited by the hybrids CS 133 × CS 132, CS 130 × CS 132 and CS 133 × CS 130 (Table 5.4) for longer vine length (cm) due to high SCA and reciprocal effects for this trait. Similar results for high heterosis were also reported by Vijayakumari *et al.* (1993), Bairagi *et al.* (2005), Yadav *et al.* (2008), Hanchinamani and Patil (2009), Singh *et al.* (2010), Batakurki *et al.* (2011), Airina (2013) and Sharma *et al.* (2016) for vine length (cm) in cucumber.

Another trait which is also an essential part of high vegetative growth is branches per plant. For this trait the hybrids CS 130 × CS 133, CS 132 × CS 133 and CS 132 × CS 130 showed high relative heterosis; CS 130 × CS 133 showed desirable

Table 5.3 : Best performing hybrids based on Reciprocal effects

Characters	Hybrids
Length of main vine (cm)	CS 133 × CS 130, CS 133 × CS 132
Branches per plant	Non significant
Days to first female flower emergence	CS 132 × EC 709119, CS 133 × EC 709119, CS 133 × CS 132
Node of first female flower appearance	CS 132 × EC 709119, CS 133 × EC 709119
Days to first harvest	CS 132 × EC 709119, CS 133 × EC 709119
Number of harvest	None
Duration of crop	None
Fruits per plant	CS 133 × CS 130, CS 132 × EC 709119
Yield per plant (kg)	None
Average fruit weight (g)	None
Fruit length (cm)	None
Fruit girth (cm)	None
Flesh thickness (cm)	CS 132 ×EC 709119
Downy mildew PDI (%)	None
Parthenocarpy (%)	CS 133 × EC 709119
TSS (°Brix)	CS 132 × EC 709119, CS 132 × CS 130

heterobeltiosis and the crosses CS 130 × CS 133, EC 709119 × CS 132 and CS 132 × EC 709119 exhibited desirable standard heterosis values (Table 5.4). These results can be attributed due to high GCA effects of the parent EC 709119 and high SCA effects of the cross CS 130 × CS 133. Wide range of heterosis for this trait was also reported by Gayathri (1997), Bairagi *et al.* (2005), Pandey *et al.* (2005), Yadav *et al.* (2008), Singh *et al.* (2010), Airina (2013) and Sharma *et al.* (2016).

Significant negative heterosis estimates are an indication for earliness. For earning good returns from the produce, earliness is the most important trait and holds its primary position among the breeding objectives for improvement of the crop. Days to first female flower anthesis, node of first female flower emergence and days to first harvest are such traits which imparts earliness for achieving early yields. The desirable standard heterosis for days to first female flower appearance was shown by the hybrids CS 133 × EC 709119, CS 132 × EC 709119 and CS 133 × CS 132 (Table 5.4). The hybrid CS 133 × EC 709119 was the best for node of first female flower appearance by showing desirable relative heterosis and heterobeltiosis values. For days to first harvest the hybrids CS 130 × CS 132, CS 133 × CS 132 and CS 132 × CS 133 were better based on standard heterosis values (Figure 5.1). Hormuzdi and More (1989), Vijayakumari *et al.* (1993), Gayathri (1997), Dogra *et al.* (1997), Bairagi *et al.* (2005), Kumbhar *et al.* (2005), Pandey *et al.* (2005), Dogra *et al.* (2007), Singh and Ram (2009), Kushwaha *et al.* (2011), Airina (2013), Kumar (2013), Arya and Singh (2014) and Sharma *et al.* (2016) also observed significant desirable heterosis values for earliness in their study at respective places.

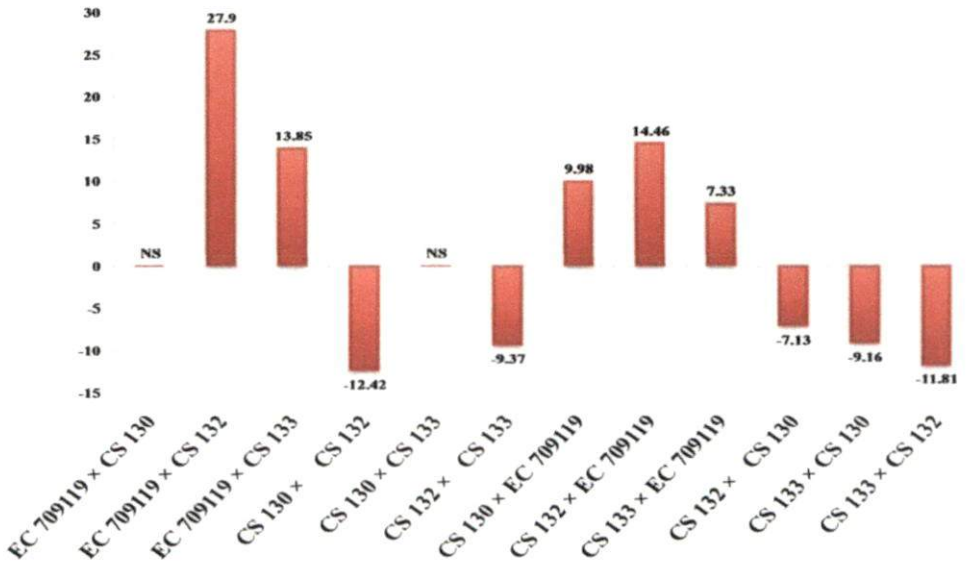
Number of harvests and crop duration are important traits in parthenocarpic cucumber cultivation in poly houses as they ensure prolonged supply of produce in the market. For number of harvests, the hybrids EC 709119 × CS 130, CS 130 × EC 709119 and CS 130 × CS 132 recorded significant positive and desirable relative heterosis values. The best performing hybrids based on significant desirable heterosis over mid parent were EC 709119 × CS 130 followed by CS 130 × CS 132 and CS

Table 5.4 : Best performing hybrids based on percentage heterosis

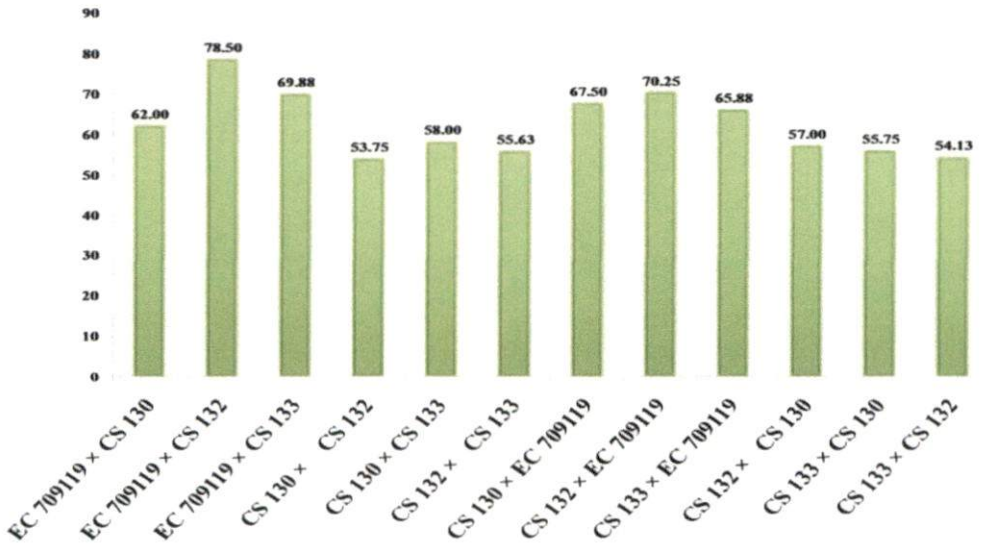
Characters	Relative heterosis (%)	Heterobeltiosis (%)	Standard heterosis (%)
Length of main vine (cm)	CS 133 × CS 130	CS 130 × CS 132	None
	CS 130 × CS 132	CS 133 × CS 132	
	CS 133 × CS 132	CS 133 × CS 130	
Branches/plant	CS 130 × CS 133	CS 130 × CS 133	CS 130 × CS 133
	CS 132 × CS 133		EC 709119 × CS 132
	CS 132 × CS 130		CS 132 × EC 709119
Days to first female flower anthesis	None	None	CS 133 × EC 709119
			CS 132 × EC 709119
			CS 133 × CS 132
Node at which first female flower emerged	CS 133 × EC 709119	CS 133 × EC 709119	None
Days to first harvest	None	None	CS 130 × CS 132
			CS 133 × CS 132
			CS 132 × CS 133
Number of harvests	EC 709119 × CS 130	None	CS 133 × CS 132
	CS 130 × EC 709119		CS 132 × CS 133
	CS 130 × CS 132		CS 130 × CS 132
Duration of the crop	EC 709119 × CS 130	EC 709119 × CS 130	CS 133 × CS 132
	CS 130 × CS 132		CS 132 × CS 133
	CS 133 × CS 130		CS 130 ×CS 132
Fruits/plant	CS 130 × CS 132	CS 130 × CS 132	CS 130 × CS 132
	CS 133 ×CS 130	CS 133 × CS 130	CS 132 ×CS 133
	CS 132 × CS 133	CS 133 × CS 132	CS 133 × CS 132

Table 5.4 : Continued

Characters	Relative heterosis (%)	Heterobeltiosis (%)	Standard heterosis (%)
Yield/ plant (kg)	CS 130 × CS 132	CS 130 × CS 132	CS 130 × CS 132
	EC 709119 × CS 130	CS 132 × CS 133	CS 132 × CS 133
	CS 130 × EC 709119	CS 133 × CS 130	CS 133 × CS 130
Average fruit weight (g)	EC 709119 × CS 132	EC 709119 × CS 132	EC 709119 × CS 130
	EC 709119 × CS 133	EC 709119 × CS 133	CS 130 × EC 709119
	CS 133 × EC 709119	CS 133 × EC 709119	EC 709119 × CS 132
Fruit length (cm)	EC 709119 × CS 133	EC 709119 × CS 133	EC 709119 × CS 130
	CS 133 × EC 709119	CS 133 × EC 709119	EC 709119 × CS 133
	EC 709119 × CS 132	EC 709119 × CS 132	CS 130 × EC 709119
Fruit girth (cm)	EC 709119 × CS 130	EC 709119 × CS 130	EC 709119 × CS 130
	CS 130 × EC 709119	CS 130 × EC 709119	EC 709119 × CS 133
	EC 709119 × CS 133	EC 709119 × CS 133	CS 130 × EC 709119
Flesh thickness (cm)	EC 709119 × CS 133	EC 709119 × CS 133	EC 709119 × CS 130
	EC 709119 × CS 130	EC 709119 × CS 130	EC 709119 × CS 133
	CS 130 × EC 709119	CS 130 × EC 709119	CS 130 × CS 133
Downy mildew PDI (%)	CS 130 × CS 133	None	CS 133 × CS 132
	CS 133 × CS 130		CS 132 × CS 133
			CS 130 × CS 133
Parthenocarpy (%)	CS 130 × CS 132	None	CS 133 × CS 132
			CS 130 × CS 132
TSS (°Brix)	CS 132 × EC 709119	None	CS 132 × CS 130
	EC 709119 × CS 133		EC 709119 × CS 130
	CS 133 × EC 709119		EC 709119 × CS 133



5.1a. Standard heterosis (%) of cucumber F_1 hybrids for days to first harvest

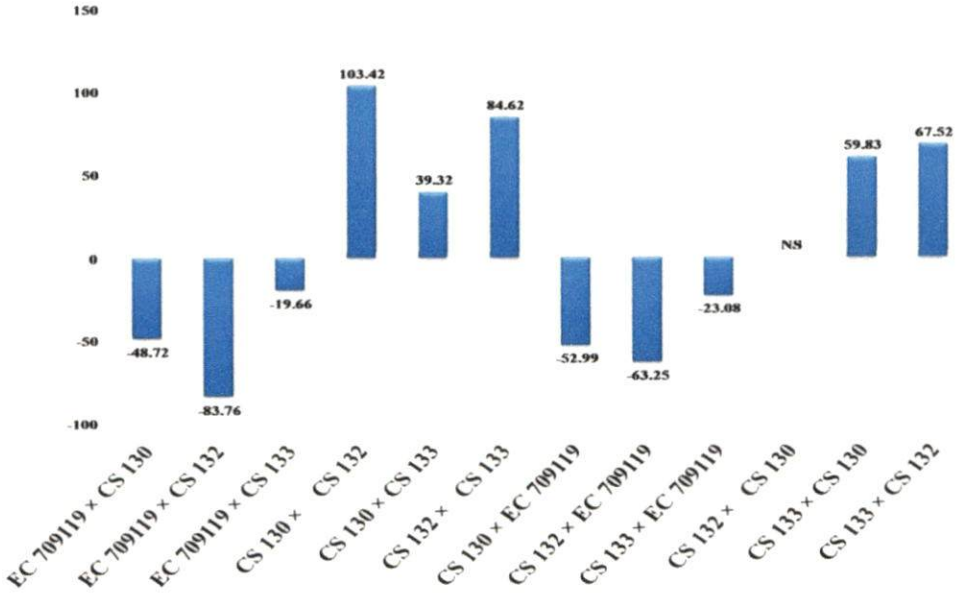


5.1b. Mean values of cucumber F_1 hybrids for days to first harvest

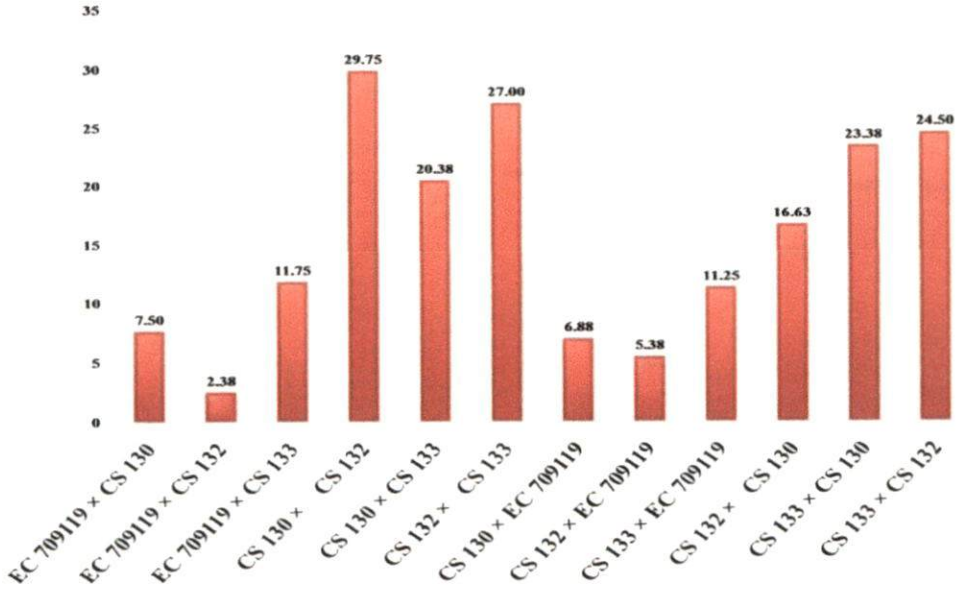
Figure 5.1 : Standard heterosis (%) and mean values of cucumber F_1 hybrids for days to first harvest

133 × CS 130 for duration of the crop (Table 5.4). The desirable better parent heterosis was found in only one cross EC 709119 × CS 130 for duration of the crop while no hybrid showed significant positive heterosis for number of harvest which is evident from heterobeltiosis. The best performing hybrid with desirable and high heterosis over standard check were CS 133 × CS 132 followed by CS 132 × CS 133 and CS 130 × CS 132 for both the characters (Table 5.4). These estimates of high mid, better and standard heterosis were achieved due to the significant GCA effects of the parent CS 133, CS 132 and CS 130 for number of harvest, duration of crop and further high SCA and *per se* performance of the cross EC 709119 × CS 130. Airina (2013) and Sharma *et al.* (2016) also observed significant heterosis values over mid, better and standard check for these two (number of harvests and duration of crop) traits while working with gynoecious lines in cucumber.

Fruits per plant and plant yield (kg) are the important traits on which every breeder and farmer shows excessive concern as these contributes directly for productivity and income. The highest estimates of relative heterosis were evident in the hybrids namely CS 130 × CS 132, CS 133 × CS 130 and CS 132 × CS 133 for fruits per plant and crosses CS 130 × CS 132, EC 709119 × CS 130 and its reciprocal for yield per plant (kg). The significant heterotic hybrids for fruit per plant over better parent and standard parent were CS 130 × CS 132, CS 133 × CS 130, CS 133 × CS 132 exhibiting heterobeltiosis and CS 130 × CS 132, CS 132 × CS 133, CS 133 × CS 132 for standard heterosis (Table 5.4; Figure 5.2). With regard to yield per plant (kg), the better performing heterotic hybrids over better parent and standard check were CS 130 × CS 132, CS 132 × CS 133 and CS 133 × CS 130 (Table 5.4; Figure 5.3). Wide range of heterosis for fruits per plant and yield per plant (kg) have been reported by various workers Hormuzdi and More (1983), Cramer and Wehner (1999), More (2002), Munshi *et al.* (2005), Bairagi *et al.* (2005), Pandey *et al.* (2005), Dogra *et al.* (2007), Hanchinamani and Patil (2009), Mule *et al.* (2012), Airina (2013), Kumar (2013) and Arya and Singh (2014). While evaluating gynoecious hybrids, Sharma *et*

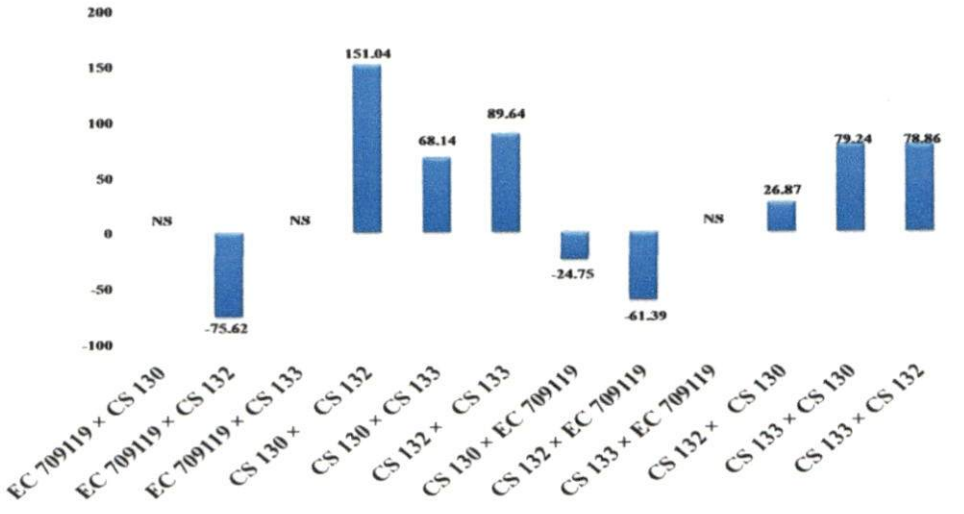


5.2a. Standard heterosis (%) of cucumber F_1 hybrids for fruits per plant

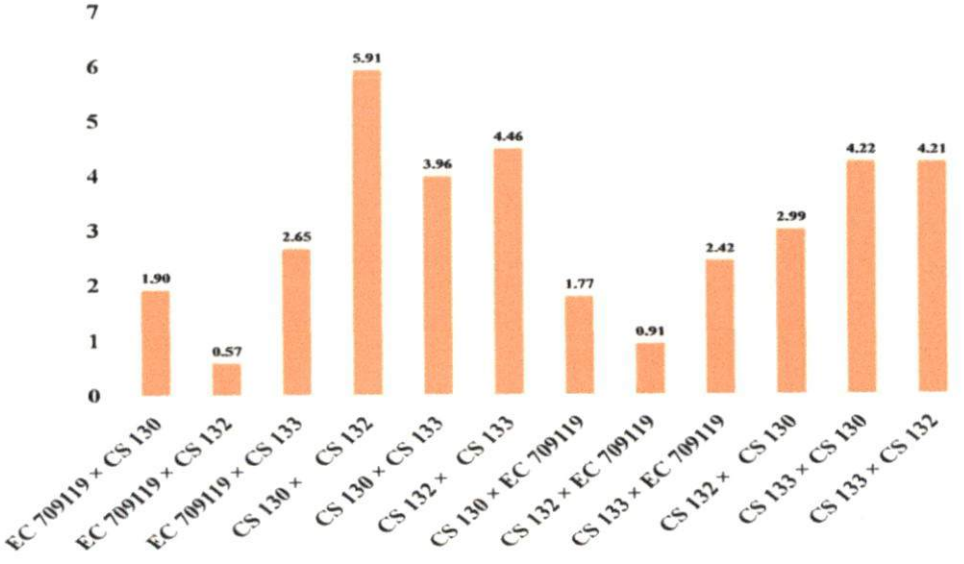


5.2b. Mean values of cucumber F_1 hybrids for fruits per plant

Figure 5.2 : Standard heterosis (%) and mean values of cucumber F_1 hybrids for fruits per plant



5.3a. Standard heterosis (%) of cucumber F_1 hybrids for yield per plant (kg)



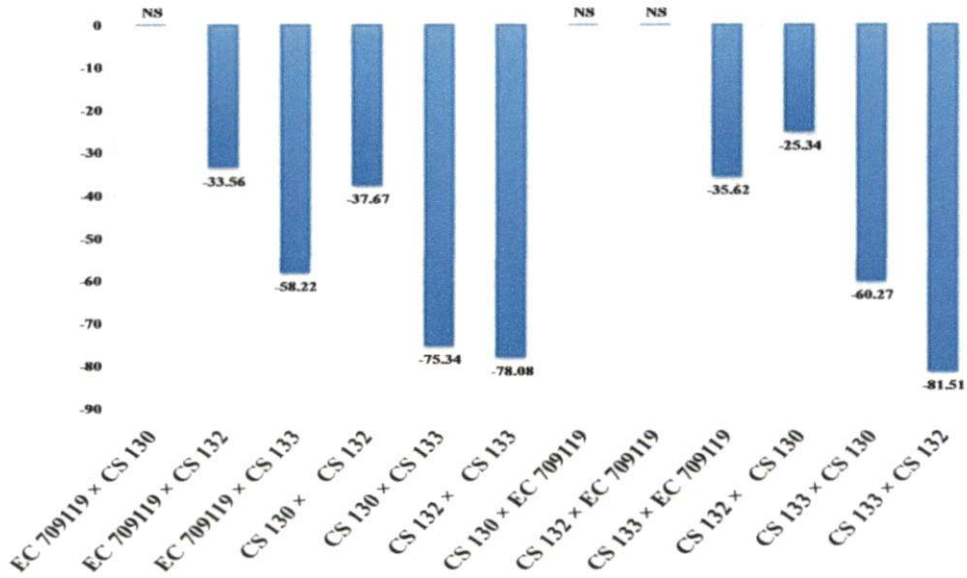
5.3b. Mean values of cucumber F_1 hybrids for yield per plant (kg)

Figure 5.3 : Standard heterosis (%) and mean values of cucumber F_1 hybrids for yield per plant (kg)

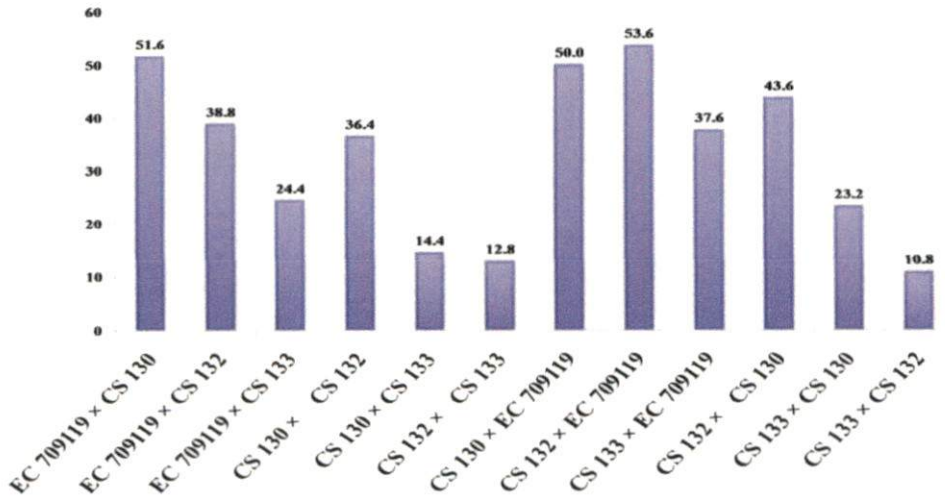
al. (2016) and for parthenocarpic hybrids, Tiwari (2015), also reported similar findings of significant heterotic cross combinations for fruits per plant and yield per plant (kg) as evident from heterobeltiosis and standard heterosis estimates.

Fruit based characters like average fruit weight (g), fruit girth (cm) and flesh thickness (cm) contributes in overall liking and yield of the plants. Gynoecious parent, EC 709119 in crosses with parthenocarpic inbred parents exhibited significant desirable heterosis estimates. The best heterotic combinations among them were EC 709119 × CS 132 for average fruit weight (g), EC 709119 × CS 133 for fruit length (cm) and flesh thickness (cm) and EC 709119 × CS 130 for fruit girth (cm) based on relative heterosis and standard heterosis (Table 5.4). While the cross EC 709119 × CS 130 was most heterotic for average fruit weight (g), fruit length (cm), fruit girth (cm) and flesh thickness (cm) as evidenced *via* highest desirable standard heterosis values. This kind of response was achieved probably due to the specific *per se* performance of these crosses involving gynoecious parent and high SCA estimates. High heterosis for these kind of traits were also observed by Gayathri (1997), Bairagi *et al.* (2005), Dogra *et al.* (2007), Airina (2013) and Sharma *et al.* (2016) for fruit length (cm) and girth (cm); Pandey *et al.* (2005), Hanchinamani and Patil (2009), Kumar (2013) and Sharma *et al.* (2016) for fruit weight (g); and Dogra *et al.* (2007), Batakurki *et al.* (2011) and Airina (2013) for flesh thickness (cm).

Downy mildew is a serious disease of cucurbits and very prominent in cucumber. It is more devastating in the polyhouse because of the favourable environment for its instant spread. The high estimates of heterosis for downy mildew resistance were observed in the hybrids CS 130 × CS 133 over mid parent, CS 130 × CS 132 over better parent and CS 133 × CS 132 over standard check (Table 5.4; Figure 5.4). These crosses exhibited resistance attributing to high GCA of parent CS 133 and high SCA of the cross CS 130 × CS 133. Similarly resistant crosses were also reported by Kumar (2013).



5.4a. Standard heterosis (%) of cucumber F_1 hybrids for downy mildew PDI (%)



5.4b. Mean values of cucumber F_1 hybrids for downy mildew PDI (%)

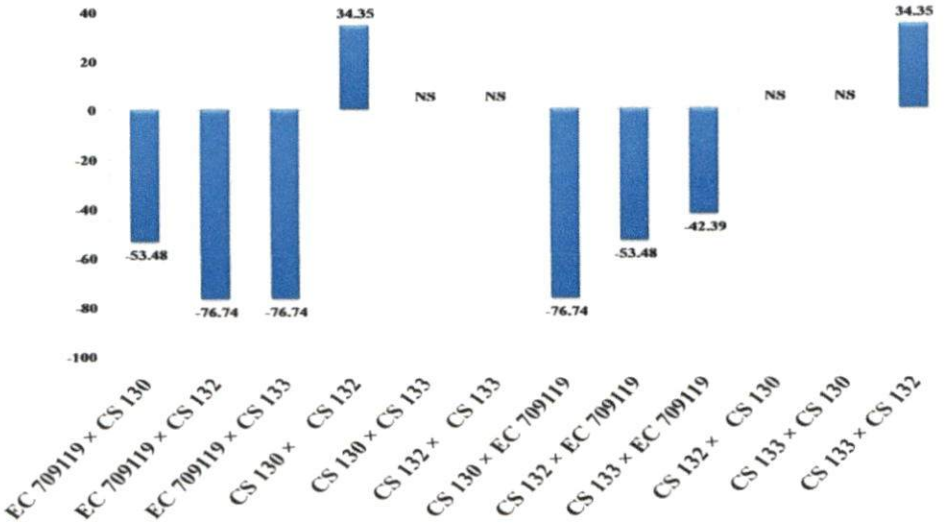
Figure 5.4 : Standard heterosis (%) and mean values of cucumber F_1 hybrids for downy mildew PDI (%)

High estimate of heterobeltiosis and standard heterosis for parthenocarpy (%) was exhibited by the hybrid CS 133 × CS 132 over mid parent and standard check, respectively (Table 5.4; Figure 5.5) due to the *per se* performance of these crosses for this trait and significant GCA values of the parents. Parthenocarpy (%) is an inherent character needed to obtain higher yield of cucumber in polyhouse as fruiting occurs without any pollination and fertilization. Arya and Singh (2014) also observed good extent of heterosis in parthenocarpic × parthenocarpic crosses for parthenocarpic fruit yield. Among the qualitative traits, TSS (°Brix), the crosses CS 132 × CS 130 over standard check and CS 132 × EC 709119 over mid parent revealed high heterosis. High and desirable heterotic combinations based on heterosis estimates were also reported by Kumar (2013) and Sharma *et al.* (2016) for this trait.

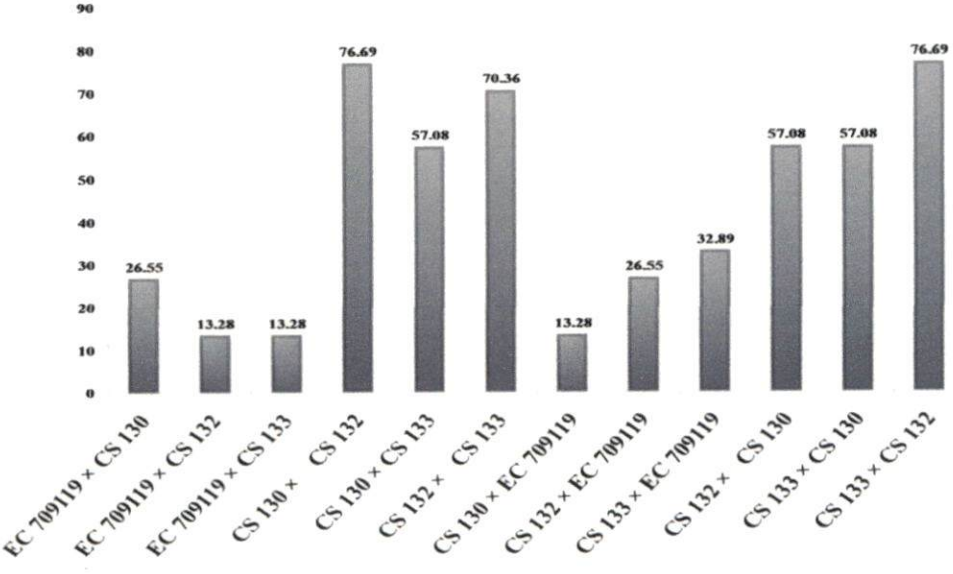
5.6 Performance of parents, hybrids and standard check for qualitative traits

Qualitative traits depicts the commercial importance of fruit and exhibited by various characters like density of prickles at harvestable maturity, sex form, colour of prickles at emergence and senescence, stem pubescence, colour of rind, crispness, bitterness and presence/absence of seed cavity etc.

Two parents (including gynoecious) showed sparse spines on fruits and in the other two parents exhibited spineless fruits. The crosses with sparse spine × sparse spine resulted in medium/sparse density of spines on fruits and the combination of sparse × no spine resulted in fruits with sparse spines indicating dominance behavior of sparse spines over no spines. The gynoecious parent, EC 709119 exhibited white spines at emergence and brown spines at senescence stage. Because the gynoecious parent, EC 709119 had brown spines, all the hybrids involving that parent showed brown spines except the crosses CS 130 × CS 133 and CS 132 × CS 130. It revealed that brown spine colour is a dominant trait over white in cucumber as also observed by Pyzhenkov (1986).



5.5a. Standard heterosis (%) of cucumber F_1 hybrids for parthenocarpy (%)



5.5b. Mean values of cucumber F_1 hybrids for parthenocarpy (%)

Figure 5.5 : Standard heterosis (%) and mean values of cucumber F_1 hybrids for parthenocarpy (%)

The primary differences, appears among the cucumber fruits are related to shape and colour (Shetty and Wehner, 1998). The colour of rind at harvestable maturity among the parents ranged from light green to green. The gynoecious parent was observed with light green rind colour. When hybridized with light green gynoecious parent, the combination of light green × green reproduced light green fruits in EC 709119 × CS 130 and CS 130 × EC 709119 and CS 133 × EC 709119. But rest of the crosses with EC 709119 exhibited cream fruits. The crosses involving green fruits yielded green colour fruits only. After maturity fruits with light green and cream colour rind changed to greenish yellow colour and fruits with green colour rind turned to cream in colour at mature stage.

Bitterness in cucumber is a major drawback for fresh consumption. Bitterness is due to presence of cucurbitacin-C (Balkema-Boomstra *et al.*, 2003) and also depends on genetic character of the cultivars as well as the growing conditions (Pitchaimuthu *et al.,* 2012). All the parents and hybrids were bitter free. Stem pubescence and seed cavity was present in all the genotypes.

Sex form in cucurbits is a major area of research as it is governed by three genes. The crosses with gynoecious and parthenocarpic parents exhibited variation for its inheritance as compared with the crosses of parthenocarpic parents. Four (EC 709119 × CS 130, EC 709119 × CS 132, EC 709119 × CS 133 and CS 132 × EC 709119) out of six crosses involving gynoecious and parthenocarpic gynoecious parents produced monoecious types, only two crosses (CS 130 × EC 709119 and CS 133 × EC 709119) exhibited gynoecious sex form, which might be due to the strong parthenocarpic expression of the maternal parents.

The crispness/texture's sensory evaluation values of parthenocarpic gynoecious parents and hybrids varied between CS 133 (5.75) to CS 133 × CS 132 (8.00) based on 0-9 hedonic scale. All the genotypes were tender and soft. Significant variation for texture of cucumber cultivars was also observed by Dhall *et al.* (2012) and Shimomura *et al.* (2012).

5.7 Incidence of pest and disease in parents, hybrids and standard check

Incidence of pest and diseases was also observed in parents and hybrids during the growing period but none of them were serious. Important pests recorded were serpentine leaf miner, red spider mite, aphids and white flies. Pest infestation was mild among the parents and hybrids which can be managed in controlled environment conditions.

The best three hybrids based on their performance for quantitative and qualitative characters, high GCA estimates of their parents, high SCA and reciprocal estimates and pioneer heterotic performance than standard check were found to be, CS 133 × CS-132, CS 130 × CS 132 and CS 132 × CS 133. The overall estimates of these crosses are summarized in Table 5.5. These hybrids should be tested at different agro-climatic conditions for making a recommendation.

Table 5.5 : Overall performance of best three hybrids for selected qualitative and quantitative traits

Characters	CS 133 × CS 132				CS 130 × CS 132				CS 132 × CS 133			
	Mean	SCA ®	HB (%)	SH (%)	Mean	SCA	HB (%)	SH (%)	Mean	SCA	HB (%)	SH (%)
Days to first harvest	54.13	-0.75	12.47	-11.81	53.75	-4.23	11.69	-12.42	55.63	-5.01	15.58	-9.37
Fruits/plant	24.50	-1.25	15.29	67.52	29.75	4.06	48.75	103.42	27.00	2.41	27.06	84.62
Yield/plant (kg)	4.21	-0.13	21.37	78.86	5.91	0.95	99.62	151.04	4.46	0.40	28.68	89.64
Parthenocarpy (%)	76.69	3.17	0.00	34.35	76.69	5.59	20.94	34.35	70.36	6.45	-8.26	23.26
Downy mildew PDI (%)	10.80	-1.00	28.57	-81.51	36.40	0.35	42.19	-37.67	12.80	-2.45	52.38	-78.08
Crispness/texture	8.00 ± 0.33				6.00 ± 0.28				7.33 ± 0.40			
Sex form	Parthenocarpic gynoecious				Parthenocarpic gynoecious				Parthenocarpic gynoecious			

SCA®-Reciprocal effect, SCA-Specific combining ability, HB (%)-Heterobeltiosis, SH (%)-Standard heterosis

Summary

6. SUMMARY

Though protected cultivation was introduced to India in 80s, technology is still in infancy due to the lack of suitable germplasm for utilization owing to varied response and prevailing agro-climatic conditions. Parthenocarpic gynoecious cucumber is one such technology in protected cultivation which need prime attention. Cultivation of parthenocarpic gynoecious hybrids is gaining attention of the growers as it is a reliable and profitable venture. But still, the growers are left with the option of choosing from the private sector hybrids which costs very high (Rs. 4 to 7 per seed) or from very limited public sector hybrids which are yet to be tested at various places.

Realizing the need and challenge, the present work 'Development of parthenocarpic gynoecious hybrids in cucumber (*Cucumis sativus* L.) for protected cultivation was carried out at Department of Olericulture, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur during the period of 2012 - 2017 to develop the parthenocarpic gynoecious lines and then F_1 hybrids for protected cultivation at Kerala.

Germplasm including parthenocarpic and gynoecious lines (inbred EC 709119 from USA) were procured from various places. Then the work was divided into various parts and initial work was to maintain these lines/germplasm through tissue culture. Seed germination of two parthenocarpic (CS 130 and CS 131), one gynoecious (EC 709119) and one monoecious (L-04) genotype was observed *in vitro* with half strength MS basal medium with 100 per cent germination. Maximum shoot initiation (100 %) from seedling excised cotyledonary leaf explants was obtained with the media composition of half strength MS medium supplemented with 0.50 mg/l IAA and 2 mg/l BAP. The half strength MS medium supplemented with 0.25 mg/L IAA followed by half MS + 0.50 mg/l IAA were found best for rooting and the half MS media accompanying 0.25 mg/l IAA and 2 mg/l BAP for callusing in all the

genotypes. Shoot initiation from stem nodal explants was achieved in A_2 (Full MS + 1.50 mg/l IAA + 2 mg/l BAP) media whereas half strength MS media without any hormones resulted in rooting. *In vitro* development of fertile male and female flowers was also noticed in all genotypes. While evaluating, tissue cultured regenerated plants in the polyhouse, 87.50 per cent survival was found in monoecious genotype (L-04) and least (44.44 %) in parthenocarpic gynoecious line, CS 130.

The second part performed was the experiment on induction of male flowers in the gynoecious and parthenocarpic lines through use of growth regulators. For this, four treatments of silver thiosulphate (STS) varying from 150 to 600 ppm concentration were sprayed. The twice STS spray at 300 ppm treatment was found best. This treatment took minimum days for male flower induction and prolonged male phase.

The third and important part was to develop parthenocarpic gynoecious inbreds. Four inbreds were developed by single seed descent method for up to I_5 generations. The four inbred lines (CS 130, CS 131, CS 132 and CS 133) exhibited sufficient variation for all the characters across generations. Parthenocarpic expression exhibited less variation in advanced generations.

In the next (fourth) part, these inbreds along with four commercial hybrids (Hilton, Aviva, Asma and Isatis) were evaluated in two generations in Randomized Block Design for 12 quantitative and nine qualitative traits. During evaluation, significant mean squares were observed based on analysis of various estimates in both generations suggesting the presence of sufficient variability for all the traits. Pooled ANOVA was also performed and it revealed significant G × E interaction for all the traits except flesh thickness (cm). On the basis of mean performance, the genotypes CS 133 followed by CS 130, CS 132 and CS 131 were found superior for majority of the required quantitative traits, thereby indicating variability in the two generations when compared with the commercial hybrids.

High GCV and PCV estimates were observed for downy mildew PDI (%) in all the generations, and node of first female flower appearance, flesh thickness (cm) and parthenocarpy (%) in pooled over generations. Moderate GCV and PCV effects were exhibited by the traits namely average fruit weight (g), fruits per plant, and flesh thickness (cm) in generation I_4, node of first female flower appearance, days to harvest, flesh thickness (cm), fruits per plant and yield per plant (kg) in I_5 generation and days to first female flower emergence in pooled over generations.

High heritability with high genetic advance estimates were evidenced in the characters namely node of first female flower emergence, flesh thickness (cm), downy mildew PDI (%) and yield per plant (kg) in I_4 generation, flesh thickness (cm) and downy mildew PDI (%) in I_5 and pooled over generations. High heritability with moderate genetic advance was observed for average fruit weight (g) and fruits per plant in I_4 generation, node of first female flower emergence, fruits per plant and yield per plant (kg) in I_5 generation and days to first harvest in pooled over generations. However, the trait parthenocarpy (%) in generation I_4 and three traits *viz.*, average fruit weight (g), fruits per plant and yield per plant (kg) in pooled over generations exhibited moderate heritability and genetic advance values.

For the qualitative traits, all the four inbreds and commercial hybrids in both the generations exhibited parthenocarpic gynoecious sex expression. The prickles on harvestable maturity were sparsely dense with white colored spines at senescence and emergence in the genotypes CS 130 and CS 131 in all the generations while they were absent in the other genotypes. No bitter fruits were noticed over the generations in all the genotypes. Mild incidence of serpentine leaf miner, red spider mite and aphids was recorded in all the genotypes irrespective of seasons.

Based on the qualitative and important quantitative characters, mean performance of the inbreds, and parameters of variability estimates, three parthenocarpic (CS 130, CS 132 and CS 133) inbreds were chosen for full diallel mating along with stable gynoecious (EC 709119) inbred for accomplishing fifth and

sixth parts of the study. The full diallel set developed by crossing of four parents and their consequent six reciprocals and six direct crosses was subjected to RBD for combining ability analysis. All the treatments exhibited significant variation as revealed through ANOVA for RBD. For combining ability ANOVA, the 'F test' for both GCA and SCA was significant for all the traits. The 'F test' for reciprocal effect was also significant for all the traits except branches per plant.

With respect to the traits namely days to first female flower emergence, node of first female flower emergence, number of harvest, duration of the crop, fruits per plant, yield per plant (kg), fruit length (cm), fruit girth (cm), downy mildew PDI (%), parthenocarpy (%) and TSS (°brix), significant desirable GCA effects were observed for the parent CS 133. The best parthenocarpic gynoecious general combiners for yield and related traits were the parents CS 133 and CS 130, which showed better overall performance and desirable GCA effects.

The cross CS 130 × CS 132 exhibited better and desirable SCA performance for the traits namely length of main vine (cm), node of first female flower emergence, days to first harvest, fruits per plant and yield per plant (kg). High desirable SCA effects were observed for the characters namely node at which first female flower emerged, days to first harvest, fruits per plant, yield per plant (kg) and parthenocarpy (%) for the best performing hybrid, CS 132 × CS 133. The best cross combinations showing desirable reciprocal effects were CS 133 × CS 132 for length of main vine (cm) and days to first female flower anthesis; CS 133 × CS 130 for length of main vine (cm) and fruits per plant; CS 132 × CS 130 for days to first female flower anthesis

These twelve F_1 hybrids were subjected to heterosis studies (relative heterosis, heterobeltiosis and standard heterosis) for 16 quantitative traits in the present experiment. The popular F_1 hybrid 'Hilton' was used to estimate standard heterosis. The significant heterotic hybrids for fruit per plant over better parent and standard check were CS 130 × CS 132, CS 133 × CS 130, CS 133 × CS 132

exhibiting heterobeltiosis and CS 130 × CS 132, CS 132 × CS 133, CS 133 × CS 132 for standard heterosis, respectively. With regard to yield per plant (kg), the better performing heterotic hybrids over better parent and standard check were CS 130 × CS 132, CS 132 × CS 133 and CS 133 × CS 130. For days to first harvest, the hybrids CS 130 × CS 132, CS 133 × CS 132 and CS 132 × CS 133 were better based on standard heterosis values. The high estimates of heterosis for downy mildew resistance were observed in the hybrids CS 130 × CS 133 over mid parent, CS 130 × CS 132 over better parent and CS 133 × CS 132 over standard check. High estimate of heterobeltiosis for parthenocarpy (%) was exhibited by the hybrid CS 133 × CS 132 over mid parent.

While evaluation for qualitative traits in parents and hybrids, all the parents and hybrids were found bitter free. Stems were pubescent and seed cavity was present in all the genotypes. Four (EC 709119 × CS 130, EC 709119 × CS 132, EC 709119 × CS 133 and CS 132 × EC 709119) out of six crosses involving gynoecious and parthenocarpic gynoecious parents produced monoecious types, while only two crosses (CS 130 × EC 709119 and CS 133 × EC 709119) exhibited gynoecious sex form. Based on the crispness/texture's sensory evaluation values of parthenocarpic gynoecious parents and hybrids, high acceptability was found in the hybrid CS 133 × CS 132 (8.00) based on 0-9 hedonic scale. All the genotypes were found tender and soft. Incidence of pest and diseases was also observed in parents and hybrids during the growing period but none of them were serious. Important pests occurred were serpentine leaf miner, red spider mite, aphids and white flies.

The best three hybrids based on their performance for quantitative and qualitative characters, high GCA estimates of their parents, high SCA and reciprocal estimates and pioneer heterotic performance than standard check were found to be, CS 133 × CS 132, CS 130 × CS 132 and CS 132 × CS 133. These hybrids should be tested at different agro-climatic conditions for making a recommendation. Package of practices for hybrid seed production should be standardized to economize cost of seed

production. Inheritance pattern for parthenocarpic expression should be studied further to make conclusive reference as varying response for parthenocarpy was evidenced in the present study. In this line, studies on development of markers linked to parthenocarpy for facilitating marker assisted selection should be explored. Another derived task for further study will be to explore the sources for incorporating downy mildew disease resistance in promising parents and hybrids.

References

REFERENCES

Abhang, A. G. 1987. Heterosis and combining ability in cucumber (*Cucumis sativus* L.). M.Sc. (Ag) thesis, Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, India, 128p.

Afangideh, U. and Uyoh, E. A. 2007. Genetic variability and correlation studies in some varieties of cucumber (*Cucumis sativus* L.). *Jordan J. Agric. Sci.* 3(4): 376-384.

Airina, C. K. 2013. Heterosis breeding exploiting gynoecy in cucumber (*Cucumis sativus* L.). M.Sc. (Hort.) thesis, Kerala Agricultural University, Thrissur, 132p.

Alam, F. M., Amin, R., Ekhlas, U. M., Biswas, S. K. and Monirul, I. M. 2015. Regeneration of shoot from nodal explants of *Cucumis sativus* considering different hormonal concentration. *Int. Res. J. Biol. Sci.* 4(7): 48-52.

Alcazar, E. J. T. and Gulick, P. J. 1983. *Genetic Resources of Cucurbitaceae-A Global Report.* International Board for Plant Genetic Resources, Rome, 101p.

Allard, R. W. 1960. *Principles of Plant Breeding*. John Wiley and Sons, New York, 485p.

Amerine, M. A., Pangborn, R. M. and Roessler, E. B. 1965. *Principles of Sensory Evaluation of Food.* Academic Press, New York, 602p.

Arya, K. and Singh, D. K. 2014. Exploitation of heterosis among parthenocarpic and monoecious genotypes of cucumber (*Cucumus Sativus* L.) under polyhouse. *Int. J. Basic Appl. Agric. Res.* 12(1): 68-71.

Bairagi, S. K., Ram, H. H., Singh, D. K. and Maurya, S. K. 2005. Exploitation of hybrid vigour for yield and attributing traits in cucumber. *Indian J. Hortic.* 62(1): 41-45.

Balkema-Boomstra, A. G., Zijlstra, S., Verstappen, F. W. A., Inggamer, H. and Mercke, P. 2003. Role of cucurbitacin C in resistance to spider mite (*Tetranychus urticae*) in cucumber (*Cucumis sativus* L.). *J. Chem. Ecol.* 29: 225-235.

Basavarajeshwari, M. R., Nagaraja, K. S., Srikanth, L. G., Raveendra, Y. C., Toufeeq, M., Husain, N. and Gowda, H. V. 2014. Genetic variability, heritability and genetic advance for yield and yield parameters and fruit and seed quality parameters in cucumber (*Cucumis sativus* L.). *Trends Biosci.* 7(15): 1965-1967.

Batakurki, I., Mulge, R., Aradiguddi, M. K. and Ghasti, V. D. 2011. Heterosis and combining ability studies for growth and quality parameters in cucumber (*Cucumis sativus* L.). *Green Farming* 2(5): 521-523.

Beyer, E. M. J. 1976. Silver ion: A potent anti-ethylene agent in cucumber and tomato. *Hortic. Sci.* 11: 195-196.

Bisht, B., Singh, M. P., Srivastava, B. K., Singh, Y. V. and Singh, P. K. 2010. Evaluation of open-pollinated varieties and hybrids of cucumber for off-season production under naturally ventilated polyhouse. *Indian J. Hortic.* 67(2): 202-205.

Bitzer, M. J., Fonesca, S., Papathanosion, G. and Patterson, F. L. 1968. Hybrid vigour in a seven parent diallel crosses in common wheat (*Triticum aestivum* L.). *Crop Sci.* 8: 85-88.

Briggle, L. M. 1963. Heterosis in wheat- a review. *Crop Sci.* 3: 407-412.

Brim, C. A. 1966. A modified pedigree method of selection in soybeans. *Crop Sci.* 6: 220.

Brummell, D. A. 2006. Cell wall disassembly in ripening fruit. *Funct. Plant Biol.* 33: 103-119.

Burley, N. and Willson, M. F. 1983. *Mate Choice in Plants*. Princeton University Press, Princeton, N.J. 264p.

Burton, G. W. 1952. Quantitative inheritance in grasses. In: *Proceedings 6th International Grassland Congress,* pp. 277-283.

Burton, G. W. and De Vane, E. H. 1953. Estimating heritability in tall fescue (*Festuca arundinacea*) from replicated clonal material. *Agron. J.* 54(10): 478-481.

Cade, M. R., Wehner, C. T. and Blazich, A. F. 1990. Somatic embryos derived from cotyledons of cucumber. *J. Am. Soc. Hortic*. 115(4): 691-696.

Chaudhary, B. N., Piluek, K., Taychasinpitak, T. and Sagwansupyakorn, C. 2001. Development and maintenance of gynoecious lines of cucumber (*Cucumis sativus* L.). *Kasetsart J. Nat. Sci.* 35: 242-250.

Chen, H. X. and Cao, P. S. 1994. Parthenocarpy of cucumber. *China Veg.* 3: 56-59.

Chezhian, P., Babu, S. and Ganesan, J. 2000. Combining ability studies in eggplant (*Solanum melongena* L.). *Trop. Agric. Res.* 12: 394-397.

Choudhary, M. L., Joshi, S. and Singh, A. 1985. Genetic studies in cucumber (*Cucumis sativus* L.). *Progressive Hortic.* 17(3): 236-240.

Chovelon, V., Restier, V., Giovinazzo, N., Dogimont, C. and Aarrouf, J. 2011. Histological study of organogenesis in *Cucumis melo* L. after genetic transformation: why is it difficult to obtain transgenic plants? *Plant Cell Rep.* 30: 2001–2011.

Cramer, C. S. and Wehner, T. C. 1999. Little heterosis for yield and yield components in hybrid of six cucumber inbreds. *Euphytica* 110(2): 99-108.

Custers, J. B. M. and Verstappen, E. C. P. 1989. Improvements of *in vitro* growth of cucumber. *Cucurbit Genet. Coop. Rep*. 12: 20-22.

Dalal, M., Dani, R. G. and Kumar, P. A. 2006. Current trends in genetic engineering of vegetable crops. *Sci. Hortic.* 107: 215-225.

de Candolle, A. 1886. *Origin of Cultivated Plants* (2nd Ed.). Hafner Publishing Company, New York, 268p.

Dhall, R. K., Sharma, S. R. and Mahajan, B. V. C. (2012). Effect of shrink wrap packaging for maintaining quality of cucumber during storage. *J. Food Sci. Technol.* 49(4): 495–499.

Dhatt, A. S. and Kaur, G. 2016. Parthenocarpy: A potential trait to exploit in vegetable crops-A review. *Agric. Rev.* 37(4): 300-308.

Dogra, B. S. and Kanwar, M. S. 2011. Exploitation of combining ability in cucumber (*Cucumis sativus* L.). *Res. J. Agri. Sci.* 2(1): 55-59.

Dogra, B. S., Kanwar, M. S. and Bhardwaj, R. K. 2007. Heterosis for yield and horticultural traits in cucumber (*Cucumis sativus* L.). *Haryana J. Hortic. Sci.* 36: 92-94.

Dogra, B. S., Rastogi, K. B., Kala, B. N. and Sharma, H. R. 1997. Heterosis and combining ability studies for yield and quality characters in cucumber (*Cucumis sativus* L.). *J. Hill Res.* 10(1): 39-42.

Dogra, L. K. 2012. Genetic evaluation of some hybrids of cucumber under modified naturally ventilated greenhouse in mid hills of western Himalayas. M.Sc.(Ag) thesis, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh , India, 92p.

Dutta, R. K. 2013. Study on genetic variability, heritability, genetic advance, correlation and path coefficient analysis in diverse genotypes of cucumber (*Cucumis sativus* L.). M.Sc. (Ag) thesis, Banaras Hindu University, Varanasi, 74p.

El-Shawaf, I. I. S. and Baker, L. R. 1981. Combining ability and genetic variances of G × HF1 hybrids for parthenocarpic yield in gynoecious cucumber for once over mechanical harvest. *J. Am. Soc. Hortic. Sci.* 106(3): 365-370.

FAO [Food and Agriculture Organization]. 2014. FAO home page [on line]. Available: http://www.fao.org/faostat/en/#data/QC. [10 Aug. 2017].

Fonesca, S. and Patterson, F. L. 1968. Hybrid vigour in a seven parent diallel crosses in common wheat (*Triticum aestivum* L.). *Crop Sci.* 8: 85-88.

Fos, M., Proano, K., Nuez, F. and Garcia- Martinez, J. L. 2001. Role of gibberellins in parthenocarpic fruit development induced by the genetic system *pat-3/pat-4* in tomato. *Physiol. Plant* 111: 545-550.

Gaikwad, A. G., Sonawane, H. G., Dhumal, S. S. and Musmade, A. M. 2011. Variability studies in cucumber (*Cucumis sativus* L.). *Asian J. Hortic.* 6(1): 148-150.

Gayathri, K. 1997. Genetic variability and heterosis in cucumber (*Cucumis sativus* L.). M.Sc. (Hort.) thesis, Kerala Agricultural University, Thrissur, 94p.

Gill, H. S, Singh, J. P. and Pachauri, D. C. 1973. Pusa Sanyog outyields other cucumbers. *Indian Hortic.* 18(2): 11-13.

Gillaspy, G., Ben-David, H. and Gruissem, W. 1993. Fruits: a developmental perspective. *Plant Cell* 5: 1439-1451.

Golabadi, M., Golkar, P. and Eghtedary, A. R. 2012. Assessment of genetic variation in cucumber (*Cucumis sativus* L.) genotypes. *Eur. J. Exp. Biol.* 2(3): 826-831.

Golabadi, M., Golkar, P. and Eghtedary, A. R. 2015. Combining ability analysis of fruit yield and morphological traits in greenhouse cucumber (*Cucumis sativus* L.). *Can. J. Plant Sci.* 95(2): 377-385.

Griffing, J. B. 1956. Concept of general and specific combining ability in relation to diallel crossing system. *Aus. J. Biol. Sci.* 9: 463-493.

Grubben, G. J. H. and Denton, O. A. 2004. *Plant Resources of Tropical Africa: Vol.2. Vegetable*. PROTA Foundation, Wageningen, 668p.

Gulam-ud-Din, Ahmed, N., Narayan, R., Nazir, G. and Hussain, K. 2006. Variability studies in cucumber. *Haryana J. Hortic. Sci.* 35(3-4): 297-298.

Guseva, L. I. and Mospan, M. V. 1984. Study of combining ability in the production of cucumber hybrids [abstract]. In: *Abstracts, Geneticheskie osnovy selektsii sel'skokhozyaĭstvennykh rasteniĭ i zhivotnykh;* 25, April, 1984, Moldavian, SSR, Russia, pp. 28-29.

Hallidri, M. 2004. Effect of silver nitrate on induction of staminate flowers in gynoecious cucumber line (*Cucumis sativus* L.). *Acta Hortic.* 637: 149-154.

Hanchinamani, C. N. 2006. Genetic variability, divergence, heterosis and combining ability studies in cucumber (*Cucumis sativus* L.). Ph.D. (Hort.) thesis, University of Agricultural Sciences, Dharwad, 131p.

Hanchinamani, C. N. and Patil, M. G. 2009. Heterosis in cucumber (*Cucumis sativus* L.) *Asian J. Hortic.* 4(1): 21-24.

Handley, L. W. and Chambliss, O. L. 1979. *In vitro* propagation of *Cucumis sativus* L. *Hortic. Sci.* 14: 22-23.

Harlan, J. R. 1975. *Crops and Man* (2nd Ed.). American Society of Agronomy-Crop Science Society of America, Madison, WI. 284p.

Hayes, H. K. and Jones, D. F. 1916. First generation crosses in cucumber. *Ann. Rep. Conn. Agric. Expt. Sta.* 319-322.

Hayes, H. K., Immer, F. R. and Smith, D. C. 1965. *Methods of Plant Breeding.* McGraw-Hill Book Company, New York, 329p.

Hooymans, C. M., Hakkert, J. C., Jansen, J. and Custers, J. B. M. 1994. Competence for regeneration of cucumber cotyledons is restricted to specific developmental stages. *Plant Cell Tissue Org. Cult.* 39: 211-217.

Hormuzdi, S. J. and More, T. A. 1989. Heterosis studies in cucumber (*Cucumis sativus* L.). *Indian J. Hortic.* 46: 73-79.

Hossain, M. F., Rabbani, M. G., Hakim, M. A. and Ahsanullah, A. S. M. 2010. Study on variability character association and yield performance of cucumber (*Cucumis sativus* L.). *Bangladesh Res. Publ. J.* 4(3): 297-311.

Hutchins, A. E. 1938. Some examples of heterosis in cucumber. *Proc. Am. Soc. Hortic. Sci.* 36: 660-664.

IIHR [Indian Institute of Horticultural Research]. 2012. IIHR home page [on line]. Available: http://www.iihr.ernet.in. [01 Nov. 2012].

Jeffrey, C. 1980. A review of the Cucurbitaceae. *Bot. J. Linn.Soc.* 81(3): 23-247.

Johnson, H. W., Robinson, H. F. and Comstock, R. E. 1955. Estimates of genetic and environmental variability in soybean. *J. Agron.* 47: 314-318

Kalloo, G., Banerjee, M. K., Kumar, S. and Prakash, C. 2000. Hybrid vegetable technology in India-An overview. In: Kalloo, G. and Singh, K. (eds.), *Emerging Scenario in Vegetable Research and Development.* Research Periodicals and Book Publishing House, India, pp.11-31.

Kanobdee, J., Lavapaurya, T., Subhadrabandu, S. and Srinivas, P. 1990. Combining ability of yield and yield components in pickling cucumber. *Kasetsart J. (Nat. Sci.)* 24: 102-107.

Karthika, A. K. 2016. Development of tropical gynoecious lines in cucumber (*Cucumis sativus* L.). M.Sc. (Hort.) thesis, Kerala Agricultural University, Thrissur, 88p.

KAU [Kerala Agricultural University]. 2011. Package of Practices Recommendations: Crops (14th Ed.). Kerala Agricultural University, Thrissur, 360p.

Kaur, K. and Dhall, R. K. 2017. Heterosis and combining ability for yield and yield attributes in cucumber (*Cucumis sativus* L.). *SABRAO J. Breed. Genet.* 49(1): 94-103.

Kaur, K., Dhall, R. K. and Chawala, N. 2016. Heterosis and combining ability for quality attributing traits in cucumber (*Cucumis sativus* L.). *Agric. Res. J.* 53(4): 475-479.

Kiełkowska, A. and Havey, M. J. 2011. *In vitro* flowering and production of viable pollen of cucumber. *Plant Cell Tissue Org. Cult.* 109:73–82.

Kumar, A., Kumar, S. and Pal, A. K. 2008. Genetic variability and characters association for fruit yield and yield traits in cucumber. *Indian J. Hortic.* 65(4): 423-428.

Kumar, J., Munshi, A. D., Kumar, R. and Sureja, A. K. 2010. Studies on heterosis in slicing cucumber. *Indian J. Hortic.* 67(2): 197-201.

Kumar, S. 2013. Genetic studies on yield and quality traits in cucumber (*Cucumis sativus* L.). Ph.D. (Hort.) thesis, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Solan, 224p.

Kumar, S., Kumar, D., Kumar, R., Thakur, K. S. and Dogra, B. S. 2013. Estimation of genetic variability and divergence for fruit yield and quality traits in cucumber (*Cucumis sativus* L.) in North-Western Himalays. *Univers. J. Plant Sci.* 1(2): 27-36.

Kumar, S., Kumar, R., Kumar, D., Gautam, N., Dogra, R. K., Mehta, D. K., Sharma, H. D. and Kansal, S. 2016. Parthenocarpic gynoecious parental lines of

cucumber introduced from Netherlands for developing high-yielding, quality hybrids. *J. Crop Improv.* 30(3): 352-369.

Kumbhar, H. C., Dimbre, A. D. and Patil, H. E. 2005. Heterosis and combining ability studies in cucumber (*Cucumis sativus* L.). *J. Maharastra Agric. Univ.* 30(3): 272-275.

Kushwaha, M., Yadav, L. B. and Maurya, R. P. 2011. Heterobeltiosis and combining ability in cucumber (*Cucumis sativus* L.) under mid hilly area of Uttarakhand. *Progressive Agric.* 11(1): 103-107.

Lopez-Sese, A. I. and Staub, J. 2002. Combining ability analysis of yield components in cucumber. *J. Am. Soc. Hortic. Sci.* 127: 931- 937.

Lush, J. L.1949. Inter size correlation, regression of offspring on dams as method of estimating heritability of characters. *Proc. Am. Soc. Animal Prod.* 33: 293-301.

Margaret, S., Maheswari, U., Ambethkar, V. and Selvaraj. S. 2014. Direct regeneration of multiple shoots from nodal explants of West Indian Gherkin (*Cucumis anguria* L.) *Int. J. Innovative Res. Sci. Eng. and Technol.* 3(6): 13876-13881.

Mckinney, H. H. 1923. A new system of grading of plant diseases. *J. Agric. Res.* 26: 195-218.

Mehdi, M. and Khan, F. A. S. 2009. Variability and character association analysis in cucumber germplasm. *J. Agril. Biol. Res.* 25(2): 87-91.

Milotay, P. 1983. Possibilities of field seed production by gynoecious cucumbers. *Zöldségtermesztési Kutató Intézet Bulletinje* 16: 17-22.

Misra, A. K. and Bhatnagar, S. P. 1995. Direct shoots regeneration from the leaf explant of cucumber. *Phytomorphol.* 45: 47-55.

Mohiuddin, A. K. M., Abdullah, Z. C., Chowdhury, M. K. U. and Napis, S. 2005. Enhancement of adventitious shoot regeneration in *Cucumis sativus* L. using $AgNO_3$. *Plant Tissue Cult.* 15: 15-23.

More, T. A. 2002. Development and exploitation of tropical gynoecious lines in F_1 hybrid of cucumber. *Acta Hortic.* 588: 261-267.

More, T. A. and Budgujar, C. D. 2002. Isolation of parthenocarpic tropical gynoecious lines in cucumber (*Cucumis sativus* L.). *Acta Hortic.* 588: 255-260.

More, T. A. and Seshadri, V. S. 1988. Development of tropical gynoecious lines in cucumber. *Cucurbit Genet. Coop. Rep.* 11: 17-18.

More, T. A., and Munger, H. M. 1986. Gynoecious sex expression and stability in cucumber (*Cucumis sativus*). *Euphytica* 35: 899-903.

Msikita, W., Skirvin, R. M., Juvik, J. A., Splittstoesser, W. E. and Ali, N. 1990. Regeneration and flowering *in vitro* of burpless hybrid cucumber cultured from excised seed. *HortSci.* 25: 474-477.

Mule, P. N., Khandelwal, V., Lodam, V. A., Shinde, D. A., Patil, P. P. and Patil, A. B. 2012. Heterosis and combining ability in cucumber (*Cucumis sativus* L.). *Madras Agric. J.* 99(7-9): 420-423.

Munshi, A. D., Kumar, R. and Panda, B. 2005. Heterosis for yield and its component in cucumber (*Cucumis sativus* L.). *Veg. Sci.* 32(2): 133-135.

Murashige, T. and Skoog, F. 1962. A revised medium for rapid growth and bioassays with tobacco tissue cultures. *Physiol. Plant* 15: 473- 487.

Nagar, S., Maurya, I. B., Aravindakshan, K., Singh, B. and Singh, J. 2014. Production of staminate flower through silver ion containing compounds in gynoecious cucumber. *Progressive Hortic.* 46(2): 335-338.

Nagar, S., Mauyra, I. B. and Hatwal, P. K. 2015. Maintenance of gynoecious line of cucumber, *Cucumis sativus* L. through induction of staminate flower using silver nitrate and silver thiosulphate. *Int. J. Farm Sci.* 5(3): 67-73.

Nancy, D. 2015. Scrutiny of strategies in developing parthenocarpic tomato (*Solanum lycopersicum* L.). *Indian J. Appl. Res.* 5: 71-74.

Nijs, A. P. M. den. and Visser, D. L. 1980. Induction of male flowering in gynoecious cucumbers (*Cucumis sativus* L.) by silver ions. *Euphytica* 29(2): 273-280.

Noll, F. 1902. Fruchtbilding ohne vorausgegangene bestaubung (parthenokarpie) bei der gurke. *Gesellschaft fur Natur-u. Heilkunde zu Bonn.* 106: 149-162.

Oviedo, V. R. S., Godoy, A. R. and Cardoso, A. I. I. 2008. Performance of advanced generation from a hybrid Japanese cucumber. *Sci. Agric.* 65(5): 553-556.

Ozga, J. A., Huizen, V. R. and Reinecke, D. M. 2002. Hormone and seed-specific regulation of pea fruit growth. *Plant Physiol.* 128: 1379-1389.

Pakarla, R. 2013. Direct shoot regeneration and transformation of cucumber (*Cucumis sativus* L.) with *gus* gene. M.Sc. (Ag) thesis, University of Agricultural Sciences, Bangalore, 79p.

Pandey, P., Singh, B., Singh, M. and Rai, M. 2005. Heterosis in cucumber (*Cucumis sativus* L.). *Veg. Sci.* 32(2): 143-145.

Pandolfini, T., Molesini, B. and Spena, A. 2009. Parthenocarpy in crop plants. *Ann. Plant Rev.* 38: 326–345.

Panse, V. G. and Sukhatme, P. V. 1957. *Statistical Methods for Agricultural Workers.* ICAR, New Delhi, 359p.

Patil, R. M. and Patil, A. A. 1985. Studies in relative performance of different gentoyeps of cucumber, vegetative and reproductive characters. *South Indian Hortic.* 33: 225-229.

Peterson, C. E. and Anhder, L. D. 1960. Inducation of staminate flowers on gynoecious cucumber with gibberellin GA_3. *Science* 131: 1673-1674.

Phillips, R. L. 1999. Research needs in heterosis. In: Coors, J. G. and Pandey, S. (eds.), *Genetics and Exploitation of Heterosis in Crops.* American Society of Agronomy-Crop Science Society of America, pp. 501-507.

Pitchaimuthu, M., Dutta, O. P., Swamy, K. R. M. and Souravi, K. 2012. Mode of inheritance of bitterness and spine colour in cucumber fruits (*Cucumis sativus* L.). In: Sari, S. and Aras (eds.), *Proceedings of the Xth EUCARPIA Meeting on Genetics and Breeding of Cucurbitaceae*, 15-18th October 2012, Antalya (Turkey), pp. 70-74.

Prasad, V. S. R. K. and Singh, D. P. 1992. Estimates of heritability, genetic advance and association between yield and its components in cucumber (*Cucumis sativus* L.). *Indian J. Hortic.* 49(1):62-69.

Pyzhenkov, V. I. 1986. Inheritance of spine colour and type of fruit surface in cucumber. *Sbornik Nauchnykh Trudov po Prikladnoĭ Botanike, Genetike i Selektsii.* 101: 33-38.

Raghavan, V. 2003. Some reflections on double fertilization, from its discovery to the present. *New Phytol.* 159: 565-583.

Rajasekaran, K., Mullins, M. G. and Nair, Y. 1983. Flower formation *in vitro* by hypocotyls explants of cucumber (*Cucumis sativus* L.). *Ann. Bot.* 52: 417-420.

Ranjan, P., Gangopadhyay, K. K., Kumar, M. B., Roy, A., Srivastava, R., Bhardwaj, R. and Dutta, M. 2015. Evaluation of cucumber (*Cucumis sativus* L.) germplasm for agronomic traits and disease resistance and estimation of genetic variability. *Indian J. Agric. Sci.* 85(2): 234–239.

Rawat, T. S. 2002. Studies on heterosis and combining ability in cucumber (*Cucumis sativus* L.). Ph.D. (Hort.) thesis, Maharana Pratap University of Agriculture and Technology, Udaipur, 133p.

Reuveni, R. 1983. Resistance reaction of *Cucumis melo* to inoculation with *Pseudoperonospora cubensis*. *Ann. Appl. Biol.* 102: 533-537.

Rhonda, L. G. and William, A. D. 1990. An *in vitro* technique for the production of multiple shoots in cotyledon explants of cucumber (*Cucumis sativus* L.). *Plant Cell Tissue Org. Cult.* 20: 177-183.

Richey, J. L. 1922. Estimation of components of heterosis. *Genetics* 43: 233-234.

Robinson, R. W. 1999. Rationale and methods for producing hybrid cucurbit seed. *J. New Seeds* 1(3/4): 1-47.

Robinson, R. W. and Whitaker, T. W. 1974. *Cucumis*. In: King, R.C. (ed.), *Handbook of Genetics,* Vol.2, Plenum, New York, pp. 145-150.

Saikia, J., Shadeque, A. and Bora, G. C. 1995. Genetic studies in cucumber. *Haryana J. Hortic. Sci.* 24(1): 73-76.

Sarowar, S., Oh, H. Y., Hyung, N. I., Min, B. W., Harn, C. H., Yang, S. K., Ok, S. H. and Shin, J. S. 2003. *In vitro* micropropagation of a *cucurbita* interspecific hybrid cultivar – a root stock plant. *Plant Cell Tissue Org. Cult.* 75: 179-182.

Schwabe, W. W. and Mills, J. J. 1981. Hormones and parthenocarpic fruit set: A literature survey. *Hortic. Abstr.* 51: 661-698.

Scurtu, M. and Scurtu, I. 1995. Utilization of sex expression in cucumber for the production of F_1 hybrids. *Acta Hortic.* 13: 59-66.

Serquan, F. C., Bachar, J. and Staub, J. E. 1997. Genetic analysis of yield components in cucumber at low plant density. *J. Am. Soc. Hortic. Sci.* 12(4): 522-528.

Sharma, J. R. 1988. *Statistical and Biometrical Techniques in Plant Breeding*. New Age International Ltd., New Delhi, 430p.

Sharma, M. 2010. Gene action and heterosis studies involving gynoecious lines in cucumber (*Cucumis sativus* L.). Ph.D. (Ag) thesis, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, 192p.

Sharma, M., Singh, Y., Singh, S. K. and Dhangrah, V. K. 2016. Exploitation of gynoecious lines in cucumber (*Cucumis Sativus* L.) for heterosis breeding. *Int. J. Bioresour. Stress Manag.* 7(2): 184-190.

Sharma, R. K., Pathania, N. and Joshi, A. K. 2004. Studies on hybrid seed production in cucumber. *Seed Res*. 32: 103-104.

Shen, J., Dirks, R. and Havey, M. J. 2015. Diallel crossing among doubled haploids of cucumber reveals significant reciprocal-cross differences. *J. Am. Soc. Hortic. Sci.* 140(2): 178-182.

Sheshadri, V. S. and More, T. A. 2009. *Cucurbit Vegetables [Biology, Production and Utilization]*. Studium Press Pvt. Ltd., New Delhi, 482p.

Shetty, N. V. and Wehner, T. C. 1998. Evaluation of oriental trellis cucumbers for production in North Carolina. *Hortic. Sci.* 33: 891-896.

Shimomura, K., Yoshioka, Y. and Sugiyama, M. 2012. Fruit texture variation among beit Alpha, European greenhouse and Japanese cucumbers (*Cucumis sativus*). In: Sari, S. and Aras (eds.), *Proceedings of the Xth EUCARPIA Meeting on Genetics and Breeding of Cucurbitaceae*, 15-18th October 2012, Antalya (Turkey), pp. 571-574.

Shull, G. H. 1914. Duplicate gene for capsul-form in Bursa pastoris. *Zeitschrift Ind. Abst. V. Verebsgl*. 12: 97-149.

Singh, A. and Ram, H. H. 2009. Standard heterosis for yield and its attributing characters in cucumber (*Cucumis sativus* L.). *Pantnagar J. Res.* 7(1): 81-84.

Singh, A. K., Gautam, N. C. and Singh. R. D. 1999a. Heterosis in cucumber (*Cucumis sativus* L.). *Veg. Sci.* 26: 126-128.

Singh, D. K. 2012. Polyhouse vegetable crop breeding in India. In: *Proceedings of National Seminar on Protected Cultivation of Vegetables and Flowers-A Value Chain Approach,* 11-12 January 2012, CoA, GBPUAT, Pant Nagar, India, pp. 27-32.

Singh, D. K., Singh, A., Punetha, S. and Singh, B. 2012. Performance of some cucumber (*Cucumis sativus* L.) genotypes under protected condition in Uttarakhand-mid hills. In: *Proceedings of National Seminar on Protected Cultivation of Vegetables and Flowers-A Value Chain Approach,* 11-12 January 2012, CoA, GBPUAT, Pant Nagar, India, pp. 33-37.

Singh, H. K., Pandey, S., Tiwari, A. and Singh, M. C. 2010. Heterosis and combining ability for yield and contributing traits in cucumber (*Cucumis Sativus* L.). *Veg. Sci.* 37(1): 64-66.

Singh, H. P. and Malhotra, S. K. 2012. Current scenario and policy issues for protected cultivation of horticultural crops in India. In: *Proceedings of National Seminar on Protected Cultivation of Vegetables and Flowers-A Value Chain Approach,* 11-12 January 2012, CoA, GBPUAT, Pant Nagar, India, pp. 9-20.

Singh, R. V., Verma, T. S. and Thakur, P. C. 1999b. Relative heterosis in cucumber in temperate region. *Himachal J. Agric. Res.* 24: 49-54.

Singh, R., Singh, A. K., Kumar, S. and Singh, B. K. 2012. Heterosis and inbreeding depression for fruit characters in cucumber. *Indian J. Hort.* 69: 200-204.

Snedecor, G. W. and Cocharan, W. G. 1968. *Statistical Methods*. Oxford and IBH publishing Co., 593p.

Solanki, S. S. and Seth, J. N. 1980. Studies on genetic variability in cucumber. *South Indian Hortic.* 28: 43-49.

Sprague, G. F. and Tatum, L. A. 1942. General versus specific combining ability in single cross of corn. *J. Am. Soc. Agron.* 34: 923-932.

Staub, J. E., Crubaugh, L. K. and Fazio, G. 2002. Cucumber recombinant inbred lines. *Cucurbit Genet. Coop. Rep.* 25: 1-2.

Stephenson, A. G. 1981. Flower and seed abortion: proximate causes and ultimate functions. *Annu. Rev. Ecol. Syst.* 12: 253-279.

Sturtevant, E. L. 1890. Seedless fruits. *Mem. Torrey Bot. Club* 1: 141-185.

Swarup, V. and Chaughale, D. S. 1962. Studies on genetic variability in sorghum-I. Phenotypic variation and its heritability components in important characters towards yield. *Indian J. Genet. Breed.* 22: 31-33.

Takei, S. and Ono, M. 1939. Leaf alcohol. III. Fragrance of cucumber. *J. Agric. Chem. Soc. Jpn.* 15: 193.

Tasdighi, M. and Baker, L. R. 1981. Combining ability for femaleness and yield in single and 3-way crosses of pickling cucumbers intended for once-over harvest. *Euphytica* 30(1): 183-192.

Tatlioglu, T. 1993. Cucumber: *Cucumis sativus* L. In: Kalloo, G. and Bergh, B. O. (eds.), *Genetic Improvement of Vegetable Crops*. Pergamon Press, New Delhi, pp. 197-234.

Tiwari, R. 2015. Molecular characterization and genetical studies in cucumber (*Cucumis sativus* L.). Ph.D. (Ag) thesis, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India, 129p.

Tiwari, R. and Singh, D. K. 2016. Study of heterosis and combining ability for earliness and vegetative traits in cucumber (*Cucumis sativus* L.). *J. Appl. Nat. Sci.* 8(2): 999-1005.

Traveset, A. 1993. Deceptive fruits reduce insect seed predation in *Pistacia terebinthus* L. *Evol. Ecol.* 7: 357-361.

Tysdal, H. M., Kiesselback, T. A. and Westover, H. L. 1942. Alfalfa breeding. *Nebr. Agric. Exp. Sta. Res. Bull.* 124.

Ugandhar, T., Venkateshwarrlu, M., Gousia, B., Srilatha, T. and Jaganmohan, R. K. 2011. *In vitro* plant regeneration of cucumber (*Cucumis sativum* L.) from cotyledon and hypocotyl explants. *Sci. Res. Rep.* 1(3): 164-169.

Ullah, M. Z., Hasan, M. J., Chowdhury, A. Z. M. K. A., Saki, A. I. and Rahman, A. H. M. A. 2012. Genetic variability and correlation in exotic cucumber (*Cucumis sativus* L.) varieties. *Bangladesh J. Plant Breed. Genet.* 25(1): 17-23.

Varoquaux, F., Blanvillain, R., Delseny, M. and Gallois, P. 2000. Less is better: New approaches for seedless fruit production. *Trends Biotechnol.* 18: 233-242.

Vashista, P. C. 1974. *Taxonomy of Angiosperms*. P. B. M. Press, New Delhi, 599p.

Vasudevan, A., Selvaraj, N., Ganapathi, A., Choi, C. W., Manickavasagam, M. and Kasthurirengan, S. 2007. Direct plant regeneration from cucumber embryonal axis. *Biol. Plant.* 51: 521-524.

Vasudevan, A., Selvaraj, N., Ganapathi, A., Kasthurirengan, S., Anbazhagan, V. R. and Manickavasagam, M. 2004. Glutamine: a suitable nitrogen source for enhanced shoot multiplication in *Cucumis sativus* L. *Biol. Plant.* 48: 125-128.

Veena, R., Sidhu, A. S., Pitchaimuthu, M. and Souravi, K. 2012. Genetic evaluation of cucumber (*Cucumis sativus* L.) genotypes for some yield and related traits. *Electr. J. Plant Breed.* 3(3): 945-948.

Verdu, M. and Garcia-Fayos, P. 1998. Ecological causes, function, and evolution of abortion and parthenocarpy in *Pistacia lentiscus* (Anacardiaceae). *Can. J. Bot.* 76: 134-141.

Verma, M. M., Gill, K. S. and Virk, D. S. 1987. Genotype × environment interaction, its measurement and significance in plant breeding. In: Gill, K. S., Khehra, A. S., Verma, M. M. and Virk, D. S. (eds.), *Proceedings of first Symposium on*

Crop Improvment, 23-27 February 1987, Punjab Agricultural University, Ludhiana. Crop improvement society of India, Ludhiana, pp. 3-10.

Vidhya, C. and Kumar, S. 2014. Studies on combining ability in cucumber (*Cucumis sativus* L.). *Trends Biosci.* 7(15): 1891-1892.

Vijayakumari, P., More, T. A. and Sehsadri, V. S. 1993. Heterosis in tropical and temperate gynoecious hybrids in cucumber. *Veg. Sci.* 20(2): 152-157.

Wehner, T. C. and Locy, R. D. 1981. *In vitro* adventitious shoot and root formation of cultivars and lines of *Cucumis sativus* L. *HortSci.* 16: 759-760.

Wehner, T. C., Lower, R. L., Staub, J. E. and Jolla, G. E. 1989. Convergent divergent selection for cucumber fruit yield. *HortSci.* 24: 667-669.

Yadav, J. R., Singh, S. P., Singh, N. and Singh, P. B. 2008. Heterosis in cucumber (*Cucumis sativus* L.). *Progressive Res.* 3(1): 87-88.

Yadav, Y. C., Kumar, S., Brijpal, B. and Dixit, S. K. 2009. Genetic variability, heritability and genetic advance for some traits in cucumber. *Indian J. Hortic.* 66(4): 488-491.

Yan, L. Y., Lou, L. N., Lou, Q. F. and Chen, J. F. 2008. Inheritance of parthenocarpy in gynoecious cucumber. *Acta Hortic. Sinica* 35: 1441-1446.

Yan, L. Y., Lou, L. N., Li, X. L., Feng, Z. H., Lou, Q. F. and Chen, J. F. 2012. Inheritance of parthenocarpy in cucumber under the same background. *Acta Hortic.* 935: 55-59.

Yawalkar, K. S. 1985. *Vegetable Crops of India.* Agri-Horticultural Publishing House, Nagpur, 300p.

Yin, Z., Malinowski, R., Ziolkowska, A., Sommer, H., Plcader, W. and Malepszy, S. 2006. The DefH9-iaaM-containing construct efficiently induces parthenocarpy in cucumber. *Cell Mol. Biol.* 11: 279-290.

Zhang, C. P., Ping, H., Qu, Z. C., Zhou, X. Y., Zhang, Z. Y., Ji, H. C., Gaio, S. and Li, J. H. 2007. Male flower- inducing effects of silver nitrate in a cucumber (*Cucumis sativus* L.) gynoecious line. *J. Southwest Agric. Univ*. 29: 49-52.

Appendices

Appendix I : Mean performance of cucumber inbred lines and commercial hybrids in I_4 generation

Entry	Days to first female flower anthesis	Node at which first female flower emerged	Days to harvest	Fruit length (cm)	Fruit girth (cm)	Flesh thickness (cm)
CS 132	22.00	4.40	39.67	17.67	13.84	1.40
CS 133	22.25	3.08	34.67	19.92	13.16	1.83
CS 130	24.08	4.50	43.33	18.17	14.25	1.25
CS 131	22.75	3.75	42.33	17.59	11.30	1.06
ISATIS	23.93	3.53	45.33	17.99	13.64	1.31
ASMA	25.50	2.63	44.67	15.59	13.48	1.08
AVIVA	27.00	2.90	44.33	17.79	14.12	1.38
HILTON	26.73	3.70	41.33	16.78	13.13	1.50
C.D. ($P \leq 0.05$)	1.01	0.58	1.56	0.66	0.43	0.18
SE_m (±)	0.33	0.19	0.51	0.22	0.14	0.06
SE_d (±)	0.47	0.27	0.73	0.31	0.20	0.08
C.V. ($P \leq 0.05$)	2.36	9.10	2.11	2.11	1.77	5.67

Appendix I : Continued

Entry	TSS (°Brix)	Parthenocarpy (%)#	Average fruit weight (g)	Fruits per plant	Downy mildew PDI (%)#	Yield/ plant (kg)
CS 132	2.65	72.26	193.38	11.11	55.43	2.24
CS 133	3.03	81.11	235.51	14.11	0.85	3.62
CS 130	3.38	54.97	222.41	11.61	64.59	2.95
CS 131	3.10	46.91	172.22	11.89	47.66	2.13
ISATIS	3.48	50.75	190.55	12.88	45.65	2.46
ASMA	3.15	59.19	180.98	12.13	42.59	2.20
AVIVA	3.07	68.04	175.45	13.49	49.98	2.37
HILTON	3.13	63.41	158.67	16.26	51.73	2.58
C.D. ($P \leq 0.05$)	0.25	18.02	5.16	0.88	3.51	0.25
SE_m (±)	0.08	5.94	1.70	0.29	1.16	0.08
SE_d (±)	0.12	8.40	2.41	0.41	1.64	0.12
C.V. ($P \leq 0.05$)	4.11	16.57	1.54	3.89	4.47	5.69

#Values are Arc Sine transformed

Appendix II : Mean performance of cucumber inbred lines and commercial hybrids in I_5 generation

Entry	Days to first female flower anthesis	Node at which first female flower emerged	Days to harvest	Fruit length (cm)	Fruit girth (cm)	Flesh thickness (cm)
CS 132	24.03	3.97	34.33	18.32	13.90	1.42
CS 133	24.20	2.48	32.33	19.29	13.71	1.90
CS 130	27.30	3.33	38.33	18.29	14.59	1.34
CS 131	27.00	3.77	41.33	17.46	12.39	1.13
ISATIS	24.60	3.13	37.33	18.08	13.09	1.29
ASMA	26.70	2.87	42.33	16.55	13.69	1.23
AVIVA	28.20	3.47	43.00	17.28	13.75	1.38
HILTON	27.53	3.73	33.67	17.01	13.16	1.50
C.D. ($P \leq 0.05$)	1.73	0.39	3.46	0.55	0.43	0.18
SE_m (±)	0.57	0.13	1.14	0.18	0.14	0.06
SE_d (±)	0.81	0.18	1.61	0.26	0.20	0.08
C.V. ($P \leq 0.05$)	3.78	6.43	5.22	1.80	1.83	6.11

Appendix II : Continued

Entry	TSS (˚Brix)	Parthenocarpy (%)#	Average fruit weight (g)	Fruits per plant	Downy mildew PDI (%)#	Yield/ plant (kg)
CS 132	3.07	59.19	209.38	16.26	37.25	3.40
CS 133	3.36	72.26	253.16	16.13	0.43	4.08
CS 130	3.08	46.91	228.32	13.69	59.03	3.12
CS 131	3.16	43.06	245.73	14.10	60.71	3.45
ISATIS	3.06	50.75	236.91	12.47	42.50	2.95
ASMA	3.25	54.97	224.63	14.93	38.79	3.35
AVIVA	3.18	46.91	201.28	13.94	41.63	2.80
HILTON	3.38	63.41	205.04	18.96	47.08	3.89
C.D. ($P \leq 0.05$)	0.18	13.65	27.31	1.05	3.59	0.30
SE_m (±)	0.06	4.50	9.00	0.35	1.18	0.10
SE_d (±)	0.08	6.36	12.73	0.49	1.67	0.14
C.V. ($P \leq 0.05$)	2.81	14.25	6.91	3.97	5.01	5.40

#Values are Arc Sine transformed

Appendix III : Mean performance of cucumber inbred lines and commercial hybrids in pooled over generations

Entry	Days to first female flower anthesis	Node at which first female flower emerged	Days to harvest	Fruit length (cm)	Fruit girth (cm)	Flesh thickness (cm)
CS 132	23.02	4.19	37.00	18.00	13.88	1.41
CS 133	23.23	2.79	33.50	19.60	13.44	1.87
CS 130	25.69	3.92	40.83	18.23	14.42	1.30
CS 131	24.88	3.76	41.83	17.53	11.84	1.10
ISATIS	24.27	3.33	41.33	18.04	13.37	1.30
ASMA	26.10	2.75	43.50	16.07	13.59	1.16
AVIVA	27.60	3.18	43.67	17.54	13.94	1.38
HILTON	27.13	3.72	37.50	16.90	13.14	1.50
C.D. ($P \leq 0.05$)	0.96	0.33	1.81	0.41	0.29	0.12
SE_m (±)	0.33	0.12	0.63	0.14	0.10	0.04
SE_d (±)	0.47	0.16	0.88	0.20	0.14	0.06
C.V. ($P \leq 0.05$)	3.21	8.20	3.84	1.95	1.82	7.25

Appendix III : Continued

Entry	TSS (˚Brix)	Parthenocarpy (%)#	Average fruit weight (g)	Fruits per plant	Downy mildew PDI (%)#	Yield/ plant (kg)
CS 132	2.86	65.73	201.38	13.69	46.34	2.82
CS 133	3.20	76.69	244.33	15.12	0.64	3.85
CS 130	3.23	50.94	225.37	12.65	61.81	3.04
CS 131	3.13	44.98	208.98	13.00	54.18	2.79
ISATIS	3.27	50.75	213.73	12.68	44.07	2.71
ASMA	3.20	57.08	202.81	13.53	40.69	2.78
AVIVA	3.12	57.47	188.37	13.71	45.80	2.59
HILTON	3.26	63.41	181.85	17.61	49.41	3.24
C.D. ($P \leq 0.05$)	0.14	10.79	13.27	0.65	2.40	0.19
SE_m (±)	0.05	3.73	4.58	0.23	0.83	0.06
SE_d (±)	0.07	5.27	6.48	0.32	1.17	0.09
C.V. ($P \leq 0.05$)	3.88	15.63	5.39	3.94	4.73	5.31

#Values are Arc Sine transformed

Appendix IV : Mean performance of cucumber parental lines, their all possible crosses and check in 2017

Genotype	Length of main vine (cm)	Branches/ plant	Days to first female flower anthesis	Node at which first female flower emerged	Days to first harvest	Number of harvests	Duration of the crop	Fruits/ plant
EC 709119	497.38	13.00	32.38	5.13	0.00	0.00	85.00	0.00
CS 130	472.50	8.75	39.63	5.88	54.75	4.63	81.50	11.25
CS 132	392.25	8.25	35.25	4.88	48.13	6.63	91.00	20.00
CS 133	359.38	6.75	34.63	4.75	53.25	7.25	91.00	21.25
EC 709119 × CS 130	539.38	12.25	38.75	6.88	62.00	3.25	87.88	7.50
EC 709119 × CS 132	540.00	14.00	55.88	17.63	78.50	2.00	88.38	2.38
EC 709119 × CS 133	481.25	11.75	39.25	5.75	69.88	3.63	91.00	11.75
CS 130 × CS 132	554.38	8.75	40.25	6.50	53.75	6.50	91.00	29.75
CS 130 × CS 133	436.25	14.25	37.25	5.00	58.00	5.75	89.75	20.38
CS 132 × CS 133	408.75	10.25	38.88	5.13	55.63	6.50	91.00	27.00
CS 130 × EC 709119	555.00	11.25	38.25	6.75	67.50	3.00	86.63	6.88
CS 132 × EC 709119	508.13	12.75	35.50	5.25	70.25	2.50	86.38	5.38
CS 133 × EC 709119	443.75	11.00	34.75	4.25	65.88	4.25	91.00	11.25
CS 132 × CS 130	516.25	11.50	38.13	6.25	57.00	4.63	85.38	16.63
CS 133 × CS 130	543.13	9.50	36.25	5.25	55.75	6.13	89.75	23.38
CS 133 × CS 132	459.38	8.50	36.13	4.88	54.13	6.88	91.00	24.50
HILTON (Check)	521.25	8.75	44.50	8.13	61.38	4.00	81.00	14.63
C.D. ($P \leq 0.05$)	59.93	3.47	2.43	0.60	4.49	0.86	2.92	2.94
SE_m (±)	20.71	1.20	0.84	0.21	1.55	0.30	1.01	1.02
SE_d (±)	29.29	1.69	1.19	0.29	2.20	0.42	1.43	1.44
C.V. ($P \leq 0.05$)	7.41	19.46	3.77	5.63	4.73	11.31	1.98	11.78

Appendix IV : Continued

Genotype	Yield/ plant (kg)	Average fruit weight (g)	Fruit length (cm)	Fruit girth (cm)	Flesh thickness (cm)	Downy mildew PDI (%)	Parthenocarpy (%)#	TSS (°Brix)
EC 709119	0.00	0.00	0.00	0.00	0.00	53.20	0.00	0.00
CS 130	2.30	208.76	22.95	11.55	1.24	62.00	63.41	3.58
CS 132	2.96	147.44	13.84	14.27	1.30	25.60	57.08	3.02
CS 133	3.47	166.09	15.19	12.72	1.11	8.40	76.69	3.32
EC 709119 × CS 130	1.90	257.20	25.00	18.23	1.72	51.60	26.55	3.42
EC 709119 × CS 132	0.57	236.67	16.18	13.40	1.13	38.80	13.28	2.60
EC 709119 × CS 133	2.65	234.28	23.90	17.68	1.60	24.40	13.28	3.40
CS 130 × CS 132	5.91	199.30	20.61	13.28	1.24	36.40	76.69	3.24
CS 130 × CS 133	3.96	191.82	20.92	11.24	1.21	14.40	57.08	3.24
CS 132 × CS 133	4.46	161.13	16.30	12.01	1.05	12.80	70.36	3.22
CS 130 × EC 709119	1.77	253.78	23.31	17.62	1.55	50.00	13.28	3.15
CS 132 × EC 709119	0.91	172.69	15.54	13.89	1.49	53.60	26.55	3.15
CS 133 × EC 709119	2.42	216.04	19.86	14.86	1.33	37.60	32.89	3.24
CS 132 × CS 130	2.99	181.76	18.67	11.12	1.16	43.60	57.08	3.64
CS 133 × CS 130	4.22	182.46	20.62	11.18	1.05	23.20	57.08	3.38
CS 133 × CS 132	4.21	171.71	16.93	11.84	1.12	10.80	76.69	3.12
HILTON (Check)	2.35	161.68	16.31	11.98	0.95	58.40	57.08	3.20
C.D. ($P \leq 0.05$)	0.65	18.46	0.97	0.91	0.11	12.12	17.12	0.20
SE_m (±)	0.23	6.38	0.33	0.32	0.04	4.19	5.92	0.07
SE_d (±)	0.32	9.02	0.47	0.45	0.06	5.92	8.37	0.10
C.V. ($P \leq 0.05$)	14.06	5.98	3.21	4.27	5.68	20.38	22.48	3.97

values are Arc sine transformed

Abstract

DEVELOPMENT OF PARTHENOCARPIC GYNOECIOUS HYBRIDS IN CUCUMBER (*Cucumis sativus* L.) FOR PROTECTED CULTIVATION

by

Ajay Bhardwaj
(2012-22-106)

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY IN HORTICULTURE
(Olericulture)

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF OLERICULTURE
COLLEGE OF HORTICULTURE
KERALA AGRICULTURAL UNIVERSITY
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA
2017

ABSTRACT

Parthenocarpy along with gynoecious sex expression is an asset for protected cultivation of cucumber (*Cucumis sativus* L.). Cultivation of parthenocarpic gynoecious hybrids is gaining attention of the growers as it is a reliable and profitable venture. But still, the growers are left with the option of choosing from the private sector hybrids which costs very high (Rs. 4 to 7 per seed) or from very limited public sector hybrids which are yet to be tested at various places. Realizing the need and challenge, the present work 'Development of parthenocarpic gynoecious hybrids in cucumber (*Cucumis sativus* L.) for protected cultivation' was carried out at Department of Olericulture, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur during the period of 2012 - 2017 to develop the parthenocarpic gynoecious lines and then F_1 hybrids for protected cultivation at Kerala.

For maintaining the germplasm, *in vitro* seed germination protocol of two parthenocarpic (CS 130 and CS 131), one gynoecious (EC 709119) and one monoecious (L-04) genotype was standardized. Maximum shoot initiation (100 %) from seedling excised cotyledonary leaf explants was obtained with the half strength MS medium supplemented with 0.5 mg/l IAA and 2 mg/l BAP. Shoot initiation from stem nodal explants was achieved in A_2 (Full MS + 1.5 mg/l IAA + 2 mg/l BAP) media whereas half strength MS media without any hormones resulted in rooting. *In vitro* development of fertile male and female flowers was also noticed in all genotypes. Field evaluation of regenerated plants was also carried out and reduced expression of parthenocarpy was observed.

Silver thiosulphate (STS) solution varying from 150 to 600 ppm concentrations was used for inducing male flowers in the gynoecious and parthenocarpic lines. The STS spray (twice) at 300 ppm was found best for early male flower induction and longer duration of male phase.

Development of inbreds and evaluation of genetic variation helps to provide valuable information about improved and new sources of genes. Four

inbreds were developed by selfing and following single seed descent method for up to I_5 generations. The four inbred lines (CS 130, CS 131, CS 132 and CS 133) exhibited variation in ranges for all the selected characters across generations. Parthenocarpic expression exhibited less variation in advanced generations. The I_4 and I_5 generation inbreds were evaluated under RBD with three replications for 12 quantitative and nine qualitative traits.

Cucumber germplasm exhibited presence of significant differences among inbreds for majority of characters. On the basis of mean performance, the genotypes CS 133 was found superior for majority of the preferred quantitative and qualitative traits. High GCV and PCV estimates were observed for downy mildew PDI (%) in all the seasons, and parthenocarpy in pooled over seasons. High heritability with high genetic advance estimates were observed for downy mildew PDI (%) and yield per plant (kg) in I_4 generation, downy mildew PDI (%) in I_5 and pooled over generations. Based on the performance for quantitative and qualitative traits in both the generations, three genotypes were selected for the crossing programme. Gynoecious inbred (EC 709119) was also utilized for full diallel mating programme (4 × 4) including reciprocals for combining ability and heterosis studies.

Evaluation of 12 hybrid combinations developed through full diallel mating design and their parents along with standard check 'Hilton' for 16 quantitative and 10 qualitative traits indicated presence of significant difference for GCA, SCA and reciprocal effects. Among the parental genotypes, CS 133 exhibited significantly high GCA effects for majority of the desirable traits followed by CS 130. The hybrids, CS 132 × CS 133 and CS 130 × CS 132 showed significant SCA effects for desirable traits *viz.*, days to first harvest, fruits per plant, yield per plant (kg), downy mildew PDI (%) and parthenocarpy (%). CS 133 × CS 132, CS 130 × CS 132 and CS 132 × CS 133 were exhibiting significant standard heterosis estimates for majority of the desirable quantitative traits.

CS 133 × CS 132 was the most promising hybrid based on SCA effects, heterosis and *per se* performance for desirable quantitative and qualitative traits (crispness/texture).