Variability studies in Bitter gourd
(*Momordica charantia* L.)

A Thesis submitted to the
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Master of Sciences in Agriculture
(Vegetable Science)

By

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CERTIFICATE-I

This is to certify that the thesis entitled **"Variability studies in Bitter gourd (*Momordica charantia* L.)"** submitted in partial fulfillment of the requirements for the award of the degree of **MASTERS OF SCIENCE IN AGRICULTURE (VEGETABLE SCIENCE)** to the Orissa University of Agriculture and Technology is a faithful record of *bona fide* and original research work carried out by **Miss Subhasmita Sahoo** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the assistance and help received by him from various sources during the course of investigation has been duly acknowledged.

CHAIRMAN
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CERTIFICATE-II

This is to certify that the thesis entitled **“Variability studies in Bitter gourd (*Momordica charantia* L.)”** submitted by **Miss Subhasmita Sahoo** to the Orissa University of Agriculture and Technology, Bhubaneswar in partial fulfillment of the requirements for the degree of **MASTERS OF SCIENCE IN AGRICULTURE (VEGETABLE SCIENCE)** has been approved by the students’ advisory committee and external examiner.

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ABSTRACT

The genetic parameters were estimated for 15 quantitative characters in 23 genotypes (germplasms) of Bitter gourd at Department of Vegetable Science, College of Agriculture, Bhubaneswar, Orissa University of Agriculture and Technology following Randomized Block Design having three replications during the kharif season 2014.

The genotypes showed a wide range of variation for all the characters studied. Among the genotypes evaluated, CO-1, Phule Greengold, IIVR-2, Meghana-1 and Japani Green Kalara are identified as the ideal varieties to be grown in Bhubaneswar (Odisha) condition. High estimates of genotypic coefficient of variation (GCV), heritability (broad sense) and genetic advance as percentage of mean altogether at a glance were observed for the characters such as seed/flesh ratio, yield per plant, number of fruits per plant, fruit weight, fruit length and vine length suggesting additive gene action for expression of these characters. So, selection based on these characters will be more effective in improvement of fruit yield of bitter gourd. Correlation studies among the traits indicated that there is a strong inherent association between yield per plant with characters like leaf area, number of fruits per plant, fruit weight, fruit length and 100 seed weight both at phenotypic and genotypic levels depicting that these are important correlated characters contributing towards yield. Path analysis study of yield and its components revealed that number of fruits per plant had the maximum positive direct effect followed by leaf area and number of primary branches per plant while, vine length exhibited the highest negative direct effect on fruit yield in bitter gourd. Genotypes studied in this trial were grouped into seven different clusters by using D^2 statistics and Tocher’s methods. Cluster VI (three parents) and VII (eight parents) showed highest inter-cluster distances were the most divergent ones and hybridization involving parents from these two clusters would be result oriented. Pusa Domousumi and Thusi are the two most divergent parents. The characters such as seed/flesh ratio yield per plant and fruit weight predominantly contributed towards genetic divergence among the parents. So, selection of parents from the present set of genotypes under study differing in these quantitative characters may be useful for developing hybrids in bitter gourd.

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ABBREVIATIONS USED

% : Per cent
/ : Per
C.D. : Critical Difference
cm : Centimeter
d.f. : Degree of freedom
ESS : Error sum of square
et al. : (*et albeit*) and elsewhere
etc. : Etcetera
Even. : Evening
g : Gram
ha : Hectare
Hrs. : Hours
i.e. : (*Id est.*) that is
Kg : Kilogram
km : Kilometer
M : Meter
m^2 : Square meter
Max. : Maximum
Min. : Minimum
mm : Millimeter
MSS : Mean sum of square
No. : Number
R.H. : Relative humidity
RSS : Replication sum of square
Tss : Treatment sum of square
°C : Degree Celsius

INTRODUCTION

Bitter gourd (*Momordica charantia* L.) 2n=2x=22 belonging to family cucurbitaceae is one of the most important vegetable grown in India. Among the cucurbits, it is considered a prized vegetable because of its high nutritive value especially having ascorbic acid and iron (Behera, 2004). It is commonly known as Bitter melon, Karela, Maiden apple and Balsam pear. The origin of this crop is probably India with secondary centre of diversity in China (Grubben, 1977). It is widely cultivated in India, China, Malaysia, Africa, and South America (Minraj *et al*., 1993).

It is adapted to a wide range of environments and can be grown in tropical and subtropical climates (Lim, 1998). This vegetable is a different nature's bountiful gifts to mankind, which does not only have fabulous digestional properties; it is a storehouse of remedies for many common ailments.

The fruits and few other parts of bitter gourd were reported to have cooling effect, stomaechic, appetising, carminative, antipyretic, antithelamintic, aphrodisiac and vermifuge properties. It is also well known for its anti-diabetic properties due to its potent, oxygen free radical scavenging activity of the fruit juice. The bitter principle in bitter gourd is cucurbitacin, a bitter glucoside which prevents the spoilage of cooked vegetable and keeps fit for consumption even for two to three days.

In India, bitter gourd covers an area of 83,000 hectare with the production of 940430 MT (NHB, 2014). Further, among the cultivated cucurbits, it has been identified as one of the potent vegetables for export by Agricultural Processed Food Products and Export Development Authority (APEDA) next to onion and okra. As a monoecious crop, it is highly cross pollinated and thus, there exists a wide genetic variability in nature. But there are few released varieties of this popular vegetable as per its requirements.

In India *M. charantia* have relatively broad phenotypic species variation (i.e., sex expression, growth habit, maturity, and fruit shape, size, colour and surface texture (Behera *et al*. 2006). In spite of the potential economic and medicinal properties in bitter gourd, due attention has not been given about the nature and magnitude of genetic divergence towards a need based crop improvement programme. However, recently the cultivation of bitter gourd becomes increasingly popular, because of the growing awareness of its antidiabetic property and nutritive value among consumers. Nevertheless, there is a long way to go with bitter gourd improvement work. Therefore, the improvement work should be focused on selection of genotypes for better yield, superior quality and resistant to biotic stresses. Before aiming at an improvement in yield, it is necessary to have information on genetic variability and heritability, in respect of important characters associated with yield. Therefore, the present study entitled "Variability studies in Bitter gourd (*Momordica charantia* L.)" has been designed to be carried out with a set of genotypes with the following objectives.

Objective:

1. To study the magnitude of genetic variation in the collection,
2. To assess the nature and extent of variability and heritability of character and their expected genetic gain by selection,
3. To investigate the amount and nature of association among different characters with yield through co-relation analysis,
4. To determine the direct and indirect association among yield components through path co-efficient analysis and
5. To compare and contrast the genotypes for component of yield and assess genetic divergence among them based on genetic distance.

REVIEW OF LITERATURES

Bitter gourd (*Momordica charantia* L.) is an important vegetable crop and grown extensively all over the India and also throughout the world. It is a cross pollinated crop and therefore, the selection breeding is a most important technique for its improvement. So for plant breeding programme for high yield and selection of desirable line, the information and knowledge on the nature of magnitude of genetic variability present in the breeding materials, nature of character association and genetic divergence and external environmental influence on the traits is highly essential.

A brief review of information available on the above aspects under study in bitter gourd as well as related cucurbits has been grouped into the following heads.

2.1 Variability of quantitative traits

2.2 Coefficient of variation

2.3 Heritability

2.4 Genetic Advance

2.5 Correlation coefficient

2.6 Path coefficient analysis.

2.7 Genetic diversity

2.1 Variability of quantitative traits

Selection of superior genotypes is the most important aspect in a crop improvement programme and the effectiveness of the selection is dependent upon the existence of genetic variability within or among the population subjected to selection (Dixit *et al*., 1971; Swamy Rao, 1972; Tikka *et al*., 1974). Therefore, genetic variability is of great importance to begin with planning of crop improvement research programme.

The variability observed for any character is due to differences in genetic constitution of the population as well as due to the environmental conditions. The observable quantitative trait is only the phenotype which can be easily assessed but for purpose of selection, it is inadequate since plant is the resultant of the interaction of genotype and environment which creates difficulty to ascertain whether variability is heritable or non-heritable (environmental). This requires the partitioning of total variation or phenotypic variation into two groups such as heritable and non-heritable components as follows:

A) Heritable or genotypic variation:

  a) Additive genetic variance (V_A), which results from additive or average effect of genes and it is heritable

  b) Dominance vaiance (V_D), which arises from intra-allelic interaction and it is also heritable

B) Non-heritable or non-genotypic variation:

  a) Epistatic variance (V_I) which results from the interaction of non-allelic and is referred as inter-allelic interaction

  b) Environmental variance (V_E) which results from non genetic factor such as environmental fluctuations, sampling error and difference in cultural practices

Apart from this classification, statistical methods are now available for partitioning of phenotypic variation into genetic and environment components which permit a quantitative assessment of genetic variability and the relative importance of heredity and environment in the expression of quantitative traits.

2.2. Coefficient of variation

It is the measure of variation and is independent of unit of measurement which is used for comparing different populations. It is provided by the standard deviation expressed as percentage of mean (Panse and Sukhatme, 1954).

Phenotypic coefficient of variation is the phenotypic standard deviation expressed as percentage of mean and genotypic coefficient of variation is the genotypic standard deviation expressed as percentage of mean. A slight difference between phenotypic and genotypic standard deviation suggested negligible influence of environment on that particular character (Choudhary *et al.*, 1973)**.**

2.3. Heritability

The degree to which variability of a character may be transmitted to the progeny is referred to as its heritability. Heritability is a useful measure to determine the amount of genetic variance over total variance. Lush (1949) defined heritability as "portion of observed variance for which differences in heritability is responsible". Robinson *et al.* (1966) defined heritability in broad sense as "the ratio of total genotypic variance to total phenotypic variance". Higher magnitude of heritability suggested the major role of the genetic factors in the expression of the characters. It is generally expressed in percentage. Thus the heritability is the heritable of phenotypic variance which is good index of the transmission of characters from parents to their offspring. Johnson *et al.* (1955) hypothesized that heritability estimates, when studied in conjunction with genetic advance would provide more appropriate information than the study of heritability. Allard (1960) viewed that characters, which had low heritability are, not dependable because their genotypic expression is superimposed by the environmental influences.

Heritability in other words is an index to measure transmissibility of characters in a population. Heritability always emphasizes about the selection in relation to the genetic traits. Heritability in broad sense reflects the functioning of genotypes as a whole. In narrow sense it is that part of observed variance which is caused by additive genetic variance. It guides the plant breeder with respect of selecting the individual from segregating generations for effective improvement. Therefore, it is pre-requisite for planning of any breeding programme based on selection technique.

2.4 Genetic Advance

Genetic advance or genetic gain is still more useful tools to estimate the nature of the crop. Genetic advance is directly related with the heritability as it gives an idea about the expected genetic changes on account of selection applied for a particular trait. Heritability often fails to provide the estimates of absolute variability. The estimate of the genetic advance in per cent of mean provides more reliable information regarding the effectiveness of selection in improving a trait because its estimate is derived by involving heritability, phenotypic standard deviation and selection intensity thus, the estimate of heritability and genetic advance are of a great significance to plant breeders in developing suitable selection strategies.

Genetic advance is the improvement in the mean genotypic value of selected plants over the parental population. It is the measure of genetic gain under selection. The success of genetic advance under selection depends on three factors; (i) genetic variability (ii) heritability and (iii) selection intensity. The genetic advance is generally high with the characters having high heritability.

Estimates of genetic advance help in understanding the type of gene action involved in the expression of various polygenic characters. High values of genetic advance are indicative of additive gene action and low values are indicative of non-additive gene action.

Genetic variability and heritability in bitter gourd

Variability studies were made in ten lines of bitter gourd (*Momordica charantia* L.) by Srivastava *et al.* (1976). Of the ten characters studied, they reported genotypic coefficient of variation, heritability per cent in broad sense and genetic advance as per cent of mean were highest for number of fruits per plant and lowest for number of male flowers per plant. High heritability value in conjunction with high genetic advance as per cent of mean was observed for number of fruits per plant, weight of fruit and yield per plant.

In a variability study in twenty-one cultivars of bitter gourd, Mangal *et al.* (1983) found high estimates of heritability along with high genetic advance and genetic coefficient of variation for yield, number of fruits weight of fruit, number of branches per plant and plant height. Number of days to first female flower and number of lobings per leaf showed lower values of these estimates.

Bhave *et al.* (2003) studied the variability in 17 families of 5 crosses of bitter gourd in the F_2 generation. They reported that in the phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) for all the characters studied (vine length, branch number per vine, flowering duration, harvesting span, fruit length, average fruit weight, seed number per fruit, fruit number per vine, dry matter per vine, biological yield per vine and total fruit yield per vine). Highest GCV and PCV were for branch number per vine, total fruit yield per vine and vine length.

Narayan *et al.* (2006) from a variability study in bitter gourd reported that the highest values for most of the yield contributing traits such as the highest fruit yield (2.89 kg) with the maximum fruit number per plant (16.00) and maximum fruit diameter (5.50 cm) in bitter gourd was found in Preethi. Maximum fruit length and average fruit weight was observed in BGR-1. All the characters were highly heritable and showed high phenotypic and genotypic coefficients of variation. High genetic coefficient of variation and heritability estimates was associated with high genetic advance was observed for branch number per plant, average fruit length, average fruit diameter, fruit number per plant and fruit yield per plant**.**

A field study in bitter gourd conducted by Ram *et al.* (2006) and found highly significant difference for all the characters under study in the evaluated genotypes. The coefficients of variation were maximum for days to male flower emergence followed by seed weight/fruit, yield/plant, fruit weight and fruit length in order.

A study was undertaken with 46 genotypes of bitter gourd to assess the variability under zero irrigation condition by Raja *et al*.(2007).They reported that the highest PCV and GCV were observed for number of female flowers per plant followed by fruit weight and number of primary branches per plant indicating the extent of variability based in these characters. High heritability coupled with greater genetic gain was observed for number of female flowers per plant followed by fruit weight, number of primary branches per plant and yield per plot. Fruit girth showed moderate heritability with low genetic gain.

Agasimani *et al.* (2008) evaluated twelve genotypes of bitter gourd and observed that the genotypic variation for fruit yield, numbers of fruit per vine and fruit length was significant for all the three traits.

A variability study conducted by Yadav *et al.* (2008) recorded maximum vine length in IC-85635A followed by MC-84, JMC-4, CO-1 and lowest in TZA. Maximum number of primary branches per vine was noted in IC-85639 (37.67) followed by MC-84, improved Jaunpuri and S-17 whereas lowest number of primary branches per vine was recorded in DVBT-G-5. Maximum numbers of days were recorded for first appearance of male flower in IC-85612, Pusa Do Mousumi, VRBT-14 and minimum days in MC-84, TZA1, JMC-22 and S-17. Maximum days were recorded to first appearance of female flower in CO-1 followed by Pusa Do Mousumi, Preethi and minimum days in TZAI, VRBT-6-9, JMC-22 and Gy-I. Maximum fruit yield per vine was recorded in MC-84 followed by S-17, VRBT-6-4 and NDBT-15. The lower fruit yield per vine was recorded in CO-1, TZA, TZA1 and DVBT-G-5 of bitter gourd.

Dey *et al.* (2009) recorded high phenotypic coefficient of variations (PCV) and genotypic coefficient of variation (GCV) for characters average fruit weight (g), average fruit diameter (cm), average flesh thickness (cm) and fruit yield per plant (g) in bitter gourd. Phenotypic coefficient of variation was higher than genotypic coefficient of variation for all the characters studied indicating influence of environment in the expression of characters. Heritability recorded moderate to high for all the traits. High heritability along with high genetic advance was revealed for traits like average fruit weight (g), average flesh thickness (cm), fruit yield per plant (g) and node to first female flower**.**

A field experiment was conducted by Islam *et al*. (2009) using twenty genotypes of bitter gourd. The study revealed wide genetic variation for branches per vine, yield per plant and number of fruit per plant. High genotypic co-efficient of variation (GCV) was observed for branches per vine, yield per plant and number of fruit per plant whereas low genotypic co-efficient of variation was observed days to first male and female flowering. High heritability with low genetic advance in percent of mean was observed days to first female flowering. High heritability with high genetic advance in percent of mean was observed for yield per plant and vine length.

Devmore *et al.* (2010) suggested that based on the nature and magnitude of genetic variability, heritability accompanied with genetic advance as percentage of mean, fruit length, vine length, fruit number per vine, days to first fruit harvest, node number per vine, primary branches per vine would offer scope for selection in breeding for high fruit yield in bitter gourd.

A field study conducted by Pornsuriya *et al.* (2011) showed that high phenotypic coefficient of variation in fruit weight and seeds per fruit and low variation in several traits like petiole length, petal width of both staminate and pistilate flower, fruit width, fruit length and fruit petiole length in bitter gourd.

A genetic variability study in bitter gourd by Singh *et al.* (2012), exhibited maximum phenotypic coefficient of variability in number of fruits per plant. All the characters showed high heritability except average fruit weight which indicated moderate heritability. Fruit length followed by fruit diameter showed high heritability in broad sense as well as genetic advance in per cent of mean.

Ullah e*t al.* (2012) reported that genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were high for yield per plant, fruits per plant, fruit weight and fruit length. Broad sense heritability estimates for various traits ranged from 42.26 to 89.55%.

Chakraborty *et al.* (2013) observed that, high genotypic coefficient of variations and phenotypic coefficient of variations values for characters like fruit yield per vine, fruit weight, number of seeds per fruit, fruit length, seed weight per fruit and number of fruits per vine in bitter gourd. High heritability coupled with high genetic advance was observed for total fruit yield per vine.

According to Dalamu and Behera (2013), the higher genotypic coefficient of variance along with high heritability and genetic advance for number of fruits per plant and fruit weight would also be of great use for indirect selection for improvement in fruit yield per plant in bitter gourd, which they reported from a field experiment.

In a genetic variability study in 26 accessions of bitter gourd genotypes, Gupta *et al*. (2013) found that the estimates of heritability was highest (97.0%) for number of branches per plant and lowest (21.0%) for number of days to first picking. High heritability value was associated with the value of high genetic gain for number of branches per plant followed by fruit size. High expected genetic advance were recorded for characters fruit yield per hectare (47.82), fruit size (34.12) and average fruit weight (20.56). The genotypic coefficient of variation was highest for number of branches per plant (35.91%) followed by fruit size (28.93%). The phenotypic coefficient of variation was highest (36.46%) for number of branches per plant followed by fruit yield per plant (36.06%). However, the lowest phenotypic coefficient of variation was exhibited by number of days to first picking (5.64%).

Radharani *et al*. (2013) reported the moderate heritability for number of fruits per vine, average fruit weight, fruit girth, number of seeds per fruit, days to first male and female flower appearance suggesting selection methods for improvement of these characters and low heritability for fruit length, plant height, number of laterals per vine, node number at first male and female flower appearance, sex ratio, pulp thickness and fruit length in bitter gourd indicated that these characters were more prone to environmental fluctuations.

Genetic variability study in bitter gourd by Yadav *et al*. (2013) revealed that the highest range of variation was recorded for yield/ha, followed by fruit weight, number of nodes per vine, days to first appearance of female flower, days to first appearance of male flower, fruit length and minimum variation was observed for the trait yield per vine. Further the study indicated high heritability for the characters like fruit length, fruit width, days to first appearance of female flower and number of fruits per vine. The highest genetic advance as per cent of mean was obtained for fruit length followed by yield/ha and yield per vine. High heritability estimates coupled with high expected genetic advance as per cent of mean were observed for fruit length, number of fruits per vine, and fruit width. On the other hand, high values of heritability associated with low genetic advance as per cent of mean were observed for fruit width, days to first appearance of female flower.

Variability among eight horticultural characters of twenty bitter gourd hybrids was studied by Pathak *et al.* (2014). High genotypic (GCV) and phenotypic coefficient of variation (PCV) was observed for number of fruits per plant, fruit weight and fruit length whereas low GCV and PCV was observed for days to first male and female flower anthesis (days after sowing). For most of the parameters under study, PCV was found to be higher than GCV. High heritability with high genetic advance (GA) was observed for fruit weight, fruit length and number of fruits per plant. High heritability with low genetic advance was observed for days to first male and female flower anthesis and days to marketable maturity from anthesis.

The nature and magnitude of genetic diversity were estimated in 25 bitter gourd genotypes on 10 quantitative traits during the summer season by Singh *et al.* (2014). The results indicated that high phenotypic and genotypic coefficients of variation were found for fresh fruit yield per plant followed by fruit length, fruit width and number of fruits per plant, indicating high genetic variability in these traits. High heritability coupled with high genetic advance as percent of mean was observed for fruit length, yield per plant, fruit diameter, fruit weight, branch per plant and seeds per fruit, indicating the possible role of additive gene action.

A study was conducted to calculate genetic variability, heritability and genetic advance for yield and its 11 contributing traits in 32 bitter gourd genotypes by Singh *et al*. (2015). From this study it was found that, ANOVA represents highly significant treatment differences for all the traits representing inherent genetic difference among the genotypes. PCV and GCV were found to be highest for fruit yield per plant followed by number of fruit per plant. Highest heritability and genetic advance in per cent of mean was estimated for number of fruit per plant followed by fruit length suggesting predominance of additive and non-additive gene action.

Other cucurbits

From a variability study in sweet gourd, Sanwal *et al.* (2007) observed that the phenotypic coefficient of variation (PCV) were individually higher than their corresponding genotypic coefficient of variation (GCV). High heritability coupled with high genetic advance observed for fruit yield per plant, number of fruits per plant and days to flowering, however, high heritability accompanied with low genetic advance values were observed for fruit length, average fruit weight.

Pandey *et al.* (2009) found that high phenotypic and genotypic coefficient of variation was observed for fruit weight and yield per plant in snap melon.

A variability study conducted in bottle gourd by Pandit *et al.* (2009) revealed considerable variability in all the traits except fruit per plant. The moderate genotypic coefficient of variation and genetic advance in fruit length and fruit weight indicate the probable likelihood of additive gene action. They suggested that correlation between both genotypes and phenotypes indicate the overriding importance of fruit length and fruit width in determining the average fruit weight, which in turn adequately describes the increase in fruit yield per plant in this crop.

Hossain *et al*. (2010) conducted a variability study of 58 long type of cucumber accessions. Wide variability was found for the plant characteristics of days to seed germination, vine length harvest, petiole length and yield contributing characters namely, days to first male and female flowering, number of fruits per plant, average fruit weight, fruit length and fruit diameter. The highest GVC was recorded in yield per plant (42.75%) where 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%) were recorded. Among the long type cucumber accessions, CSL51 gave the highest yield per plant (2.69kg).

Khule *et al.* **(**2011**)** reported that high magnitude of genotypic and phenotypic variance for all the characters *viz.*, days to appear first male flower, days to appear first female flower, node umber at which first female flower appear, number of fruit per plant, fruit weight, fruit length, fruit diameter, number of seeds per fruit, 100-seed weight, and marketable fruit yield per plant in sponge gourd.

An experiment conducted in cucumber by Veena *et al.* (2012) consisting of thirty-eight advanced lines for variability, heritability and genetic advance for yield and contributing traits and reported that genotypic coefficient of variation and phenotypic coefficient of variation were highest 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 and high estimated genetic advance over mean were observed for nodes per vine (83.43), node at first female flower appearance (82.17), days to first female flower opening (83.72), days to first male flower opening (92.63), days to first harvest (83.04), number of fruits per plant (85.78), fruit length (88.92), fruit breadth (86.91), seed cavity length (85.97), seed cavity breadth (85.09), number of seeds per fruit (95.17) and 100 seed weight (93.10).

Akter *et al.* (2013) found significant variations among the genotypes for most of the characters studied in pumpkin. Further, high genotypic coefficient of variation and high heritability coupled with high genetic advance in per cent of mean were observed for number of seeds per fruit, fruit yield per plant, flesh thickness, number of male flowers per plant and number of female flowers per plant.

In an investigation conducted by Devi and Mariappan (2013) in snake gourd recorded higher values of phenotypic coefficient of variation and genotypic coefficient variation for fruit length, fruit weight and number of fruits per plant. They also observed high heritability along with high genetic advance for fruit length, fruit yield, fruit girth and number of fruits per plant in snake gourd which is indicative of additive gene action in control of these traits.

Dubey *et al.* (2013) reported wide genetic variability among the accessions in ridge gourd. The genotypic coefficient of variation and heritability estimates were high in days to 50% germination, vine length, fruit length and fruit yield per plant. However, genotypic coefficient of variation and heritability estimates were low in number of branches per plant and fruit weight.

Kumar *et al*. (2013) observed the significant variations for all the characters in all the genotypes of sponge gourd used in the experiment. Highest genotypic and phenotypic variations were observed for total yield per vine followed by number of seeds per fruit, average weight of fruits and total soluble solids.

Fifty-two cucumber (*Cucumis sativus* L.) genotypes were evaluated for genetic variability, heritability and genetic advance by Basavarajeshwari *et al*. (2014) and they reported that variance due to genotypes was highly significant (p=0.01) for average fruit weight (g), length of fruit (cm), number of fruits per vine (g), flesh thickness (cm), number of seeds per fruit and hundred seed weight (g). Moderate to high genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) was observed for number of fruits per plant and fruit yield per vine. High heritability coupled with high genetic advance over mean was observed for number of fruits per vine, fruit yield per vine (g) and number of seeds per fruit. High heritability with low genetic advance over mean was observed for length of fruit and flesh thickness.

Choudhury *et al.* (2014) concluded from a variability study that the fruit length had the highest heritability (93.5%) followed by node at which first hermaphrodite flower appeared (78.0%) in ridge gourd.

Jat *et al.* (2014) reported that the maximum phenotypic and genotypic coefficient (PCV and GCV) for acidity of fruit (27.46 and 28.73) followed by weight of fruit (24.06 and 24.99), total fruit yield per vine (24.04 and 25.07), rind thickness (22.29 and 24.46) and total soluble solids (20.43 and 21.03) in cucumber. Further, high estimates of heritability (broad sense) were observed for days to anthesis of first female flower (96.66 per cent), weight of fruit (92.67 per cent) and diameter of fruit (92.51 per cent) with high genetic advance. The maximum genetic gain in per cent was observed for acidity of fruit (54.06), weight of fruit (47.71) and total yield per vine (47.49) among the evaluated lines.

In pumpkin, Muralidhara *et al.* (2014) reported that high heritability coupled with high genetic advance percent as mean for the characters like per cent fruit set, carotene content, days to 50 per cent female flowering, days to first male and female flower flowering. Further, TSS, pulp thickness, weight of fruit and weight of seeds per fruit recorded high heritability coupled with high genetic advance under study.

Munawar *et al.* (2015) found that considerable genetic variability among genotypes for all traits in tinda gourd. High heritability coupled with low genetic advance for leaf area, fruit length, fruit diameter, number of vines per plant, number of fruit per plant, and fruit yield. Fruit weight had additive gene action as indicated by high heritability and genetic advance.

2.5. Character Associaton (Correlation)

Correlation coefficient is a statistical measure which is used to find out the size and direction of relationship between two or more variables. Correlation coefficient measures the degree of association either in positive or negative direction.

Phenotypic correlation is the observable correlation between two variables. Genotypic correlation, on the other hand, is inherent association between two variables; it may be either due to pleiotropic action of gene, linkage or both or due to developmentally induced relationships. Correlations are helpful to ascertain the real components of yield which is a complex character. Some of the works done in bitter gourd as well as in other cucurbits are reviewed below.

Character associations in bitter gourd

An investigation was conducted to find out the correlation and path coefficient effects in bitter gourd by Mangal *et al*. (1983). They reported that the fruit yield per plant was positively and significantly correlated with number of fruits and weight of fruit but negative correlation with days to flowering.

From a correlation study on bitter gourd, Parhi *et al.* (1995) recorded positive significant correlations of yield/plant with fruit weight, fruit length, number of seeds per fruit, vine length and days to first harvest.

Studies carried out by Rajput *et al*. (1996) on correlation on 21 genotypes of bitter gourd indicated that fruit yield/vine was positively correlated with number of fruits/vine, average fruit weight, fruit length, percentage fruit set, vine length and leaf area/vine. Fruit yield/vine was negatively correlated with number of days to first harvest, both at genotypic and phenotypic levels.

Sharma and Bhutani (2001) found significant positive correlations for total chlorophyll content, first female flowering node and fruit length with fruits per plant; fruit length and fruit diameter with average fruit weight; fruits per plant and average fruit weight with total fruit yield per plant in bitter gourd.

Correlation for yield and quality traits were conducted by Bhave *et al*. (2003) by using 15 F_2 lines obtained from crosses involving 6 bitter gourd cultivars (Konkan Tara, Pusa Vishesh, Colong, Arka Harit, RHR 4-1 and Priya). At the phenotypic and genotypic levels, it was found that fruit yield per vine was positively correlated with flowering duration, harvesting span, fruit length, fruit breadth, fruit rind thickness, number of fruits per vine, average fruit weight, biological yield, dry matter and harvest index, and negatively correlated with days to first flowering.

Dey *et al.* (2005) observed that fruit yield per vine had highly positive association with fruit weight followed by fruits per plant, flesh thickness, days to fruit set to maturity, fruit index, fruit length and fruit diameter. Traits like number of male flowers per plant, ascorbic acid and total carotenoids content, days to first male flower, days to first female flower and node number of first female flower appearance exhibited negative correlation with yield.

A correlation study conducted by Kumar *et al.* (2008) revealed that fruit yield was positively correlated with number of fruits per vine, average fruit weight and number of nodes per vine in bitter gourd.

Yadav *et al*. (2008) studied correlation coefficient analysis in 28 genotypes of bitter gourd and reported that the vine length had significant and positive correlation with days to first appearance of male flower, first effective node, fruit weight, number of fruit per vine, number of fruits per plot, yield per plot, yield and significant negative correlation with days to first appearance of female flower and vitamin C. The inter node length showed significant and positive correlation with days to first appearance of male flower and significant negative correlation with fruit length and fruit weight. Days to first appearance of male flower exhibited significant positive correlation with number of fruits per plot and significant negative correlation with fruit length and fruit width. Further, days to first appearance of female flower recorded significant negative correlation with fruit length, fruit width, fruit weight, number of fruit per vine, yield per vine and yield per plot. The first effective node showed significant and negative correlation with vitamin C, fruit length and fruit width. The fruit length showed significant positive correlation with fruit width and significant positive correlation with number of fruit per plot. The fruit width recorded significant and positive correlation with number of fruit per plot. The fruit weight had significant negative correlation with number of fruits per plot, yield per vine and yield per plot. The number of fruits per vine exhibited significant and positive correlation with yield per plot.

In a correlation study in bitter gourd Islam *et al*. (2009), observed that yield per plant had high positive and significant association with number of nodes per vine.

Twenty genotypes of bitter gourd (*Momordica charantia* L.) were evaluated by Sundaram (2010) for fourteen biometric traits under saline sodic soil condition. The trait *viz*., number of female flowers per vine, number of fruits per vine, vine length and fruit weight had recorded significant positive association with yield. The maximum positive correlation was observed between number of female flowers per vine and number of fruits per vine. Sex ratio of male to female flower has shown significant negative association with yield and it had recorded the maximum negative correlation with the number of female flowers per vine.

From a correlation study carried out by Singh *et al.* (2012) in bitter gourd, it was reported that fruit yield per plant was positively and significantly correlated with number of fruits per plant and fruits yield per plant was positively and directly associated with number of fruits per plant at phenotypic as well as genotypic level.

Chakraborty *et al.* (2013) found significant positive association of fruit yield per vine with vine length, number of primary branches per vine, fruit weight, fruit length, flesh thickness, number of seeds per fruit and seed weight per fruit in bitter gourd.

Correaltion studies on 50 indigenous and exotic genotypes of bitter gourd by Dalamu and Behera (2013) indicated that ovary length, fruit L: D ratio, fruit weight and number of fruits/plant were positively correlated with yield/plant.

A study conducted to assess genetic variability and correlation in 26 accessions of bitter gourd genotypes by Gupta *et al*. (2013) revealed the highest genotypic correlation coefficient between fruit yield per ha and number of marketable fruits per vine (0.684) followed by between number of days to first picking and number of days to first female flower appearance (0.627).

Correlation study for different characters in thirteen diverse genotypes of bitter gourd was conducted by Yadav *et al*. (2013). The results revealed that vine length had significant and positive correlation with number of nodes per vine, inter nodal length, fruit width and number of fruit per vine. Number of primary branches per vine had significant and negative correlation with intermodal length and significant positive correlation with fruit length. Number of nodes per vine had negative and significant correlation with days to first appearance of male flower. Significant and negative correlation for inter nodal length was found with days to first appearance of female flower and fruit length. Days to first appearance of male flower showed significant and negative correlation with number of fruits per vine. Significant and positive correlation for first effective node was recorded with fruit length. Fruit weight had highly significant and positive correlation with yield per vine. Significant and positive correlation for number of fruits per vine was recorded with yield per vine.

Correlation analysis by Pathak *et al.* (2014) revealed that days taken to marketable maturity showed non significant negative association whereas number of fruits per plant exhibited significant positive correlation for marketable yield per plant. Fruit length showed significant high correlation for fruit weight. Days to first female flower anthesis, fruit weight and fruit length had negative but non-significant phenotypic and genotypic correlation whereas fruit width exhibited significant negative correlation with yield. A strong significant positive correlation was observed between days to first female flower anthesis, fruit weight, fruit length and fruit width.

As per the investigation carried out by Radha Rani *et al.*(2014), fruit length, number of fruits/vine, vine length, number of laterals/vine and average fruit weight were identified as major characters contributing to yield as these traits were significantly and positively associated with yield/vine. A significant negative correlation of yield was observed with days to first male and female flower appeared, node number at which first male and female flower appeared and sex ratio.

The experiment carried out by Singh *et al.* (2014) revealed that fruit weight, fruit length, fruit diameter and plant height have positive correlation with fruit yield per plant.

According to Singh *et al*. (2015) in a correlation study it was reported that fruit yield per plant had highly significant and positive association with number of fruit per plant followed by average fruit weight and negatively associated with node number to anthesis of first pistillate flower at genotypic level.

Other cucurbits

Sanwal *et al.* (2007) found that fruit yield per plant positively and highly significantly correlated with number of fruits per plant (0. 988), fruit length (0.575) and average fruit weight (0.478) in sweet gourd.

Pandey *et al.* (2009) reported that fruit yield had positive and significant correlation with fruit weight, polar and equatorial circumference of fruit at both phenotypic and genotypic level and with days to first female flower anthesis at genotypic level. Fruit weight, polar and equatorial circumference of fruit had positive correlation coefficient among themselves in snap melon.

The correlation co-efficient study of 58 long type cucumber accessions by Hossain *et al*. (2010) revealed that, yield per plant had highly positive and significant association with fruit length and diameter, average fruit weight and number of fruits per plant.

Resmi and Srelathakumary (2012) observed that fruit length, fruit girth, average fruit weight, seeds per fruit and 1000-seed weight had positive and significant correlation with fruit yield in ash gourd.

Akter *et al.* (2013) observed in pumpkin that correlation coefficient between fruit yield per plant was positive and highly significant with number of primary branches, number of fruits per plant and single fruit weight. On the other hand, days to first female flower, number of male flowers per plant showed positive and non significant correlation with fruit yield per plant.

Dubey *et al.* (2013) observed that vine length, fruit length, number of fruits per plant and fruit weight had a significant ($P < 0.0\ 1$) positive correlation with fruit yield per plant in ridge gourd.

Kumar *et al.* **(**2013**)** reported that the total fruit yield per vine was positively and significantly correlated with number of fruits per vine, average weight of fruit and number of seeds per fruit in sponge gourd.

Correlation and path analysis studies were carried out by Shivananda *et al.* (2013) on 19 growth paremeters, *viz.*, earliness, yield and quality traits in 57 genotypes of pumpkin (*Cucurbita* spp.). They observed highest significant positive association of fruit yield per vine with average fruit weight followed by vine length, number of leaves per vine, number of seeds per fruit, length of fruit, fruit cavity size, leaf size, hundred seed weight, fruit flesh thickness, number of primary branches per vine, total soluble solids, number of fruits per vine and circumference of fruit.

Choudhury *et al.* (2014) found significant positive correlation between fruit yield per plant and fruit weight (0.877), number of fruits per cluster (0.590) and fruit length (0.356) at phenotypic level. Significantly negative correlation at phenotypic level was observed between fruit yield per plant and days to first fruit harvest (-0.403), days to first hermaphrodite flower (-0.337) and node at which first hermaphrodite flower appeared (-0.315) in ridge gourd.

A field experiment conducted by Rashid *et al*. (2014) in snake gourd revealed that marketable fruit yield per plant exhibit significant positive correlation with number of fruits per plant and fruit length. In general, genotypic correlation coefficient was higher than the corresponding phenotypic correlation coefficient suggesting that the environmental influence reduces the relationship between yield and yield contributing characters of snake gourd.

Janaranjani and Kanthaswamy (2015) reported that fruit yield was positively and significantly correlated with fruit flesh thickness, number of fruits per vine and number of fruit pickings in bottle gourd.

Munawar *et al.* (2015) observed that fruit length, fruit diameter, fruit weight, and number of fruit per plant had a strong positive association with fruit yield and numbers of vines per plant was negatively correlated with yield at genotypic and phenotypic levels in tinda gourd.

Muralidhara *et al.* (2014) reported that yield characters like fruit weight and rind thickness showed positive and highly significant association with fruit yield in pumpkin. A negative relationship has been observed between fruit yield and number of days to first female flowering. The association of number of fruits per vine with fruit weight was negative and significant. This made a clear indication that increase in number of fruits per vine would indirectly affect the total yield which is more dependent on fruit weight.

2.6 Path Analysis

Wright (1921) defined the path coefficient technique as the ratio of the standard deviation of the effect of the total standard deviation, which all the causes are constant except that one in question, the variability of which kept unchanged. The concept of path coefficient analysis was originally developed by Wright (1921), but the technique was first used for plant selection by Dewey and Lu (1959). Path coefficient is the measure of direct influence of one variable upon another which permits the separation of correlation coefficient into component of direct and indirect effects. The use of path coefficient analysis requires a cause and effect situation among variables.

Information on correlation and path coefficient may be advantageously used for the identification of characters which are useful indices for consideration in the improvement of yield. Some of the works done in bitter gourd as well as in other cucurbits are reviewed below.

Path analysis in bitter gourd

A study involving 21 genotypes of bitter gourd by Paranjape and Rajput (1995) revealed that the fruit weight had maximum direct bearing on yield. However, vine length, primary branches, nodes on main axis, leaf area, fruit length, number of fruits/vine and seed content indirectly contributed towards yield.

In an experiment conducted by Rajput *et al*. (1996) strong positive direct effects on yield were observed for dry matter/vine and percentage fruit set. Direct negative effects on yield were observed for days to first female flower appearance and days to first harvest.

An investigation was carried out by Sharma and Bhutani (2001) using five parent half diallels along with the parents, and the path analysis indicated that fruits per plant had the highest direct contribution towards yield, followed by fruit length and fruit diameter, while vine length had the highest indirect contribution towards yield, followed by inter node length, average fruit weight, fruit diameter and fruit length via number of fruits per plant.

Path analysis study by Bhave *et al*. (2003) revealed that harvesting span, number of leaves per vine, fruit length, average fruit weight, number of seeds per fruit, number of fruits per vine, biological yield and keeping quality had direct positive effects on fruit yield, whereas fruit length had positive and indirect effects on fruit yield.

From a path analysis study Dey *et al.* (2005) reported that fruit weight, number of fruits per plant and node number to first female flower appearance may be most dependable and reliable criteria for selection for improving yield of cultivars in bitter gourd.

According to Singh *et al.* (2008) from a path analysis study in bitter gourd, the direct effect of primary vine numbers per plant on fruit yield was positive (0.35) and indirect positive effect on yield of fruit via number of days to anthesis of first flower, length of fruit and length of vines in bitter gourd. The direct effect of length of vine (cm) on fruit yield was negative (0.75) and genotypic correlation coefficient was also found to be negative (-0.06) but non-significant.

Path coefficient analysis study conducted by Islam *et al*. (2009) revealed that number of fruit per plant followed by vine length had the maximum direct contribution towards yield per plant in bitter gourd.

The path coefficient analysis conducted by Sundaram (2010) under saline sodic soil condition revealed that the highest positive direct effect on yield by number of fruits per vine, while the highest negative direct effect on yield was recorded by number of female flowers per vine. Further the number of female flowers produced per vine had exerted the maximum indirect positive effect on yield through number of fruits per vine, was reported by him.

Chakraborty *et al.* (2013) reported that the largest direct effect on fruit yield per vine was through traits like number of fruits per vine followed by fruit weight at phenotypic level in bitter gourd.

Dalamu and Behera (2013) conducted a study on path coefficient analysis in 50 indigenous and exotic bitter gourd genotypes and reported that number of fruits/plant, fruit weight, ovary length and fruit L: D ratio had high phenotypic and genotypic direct effects on yield/plant.

Genotypic path coefficient analysis study conducted by Yadav *et al*.(2013), reported highest positive direct effect for yield per vine, followed by number of fruits per vine, fruit weight, days to first appearance of male flower, number of nodes per vine, vine length with the dependent variable yield per hectare. On the other hand negative and direct effect was observed for the character fruit width, fruit length, first effective node, days to first appearance of female flower, intermodal length and number of primary branches per vine with the dependent variable yield per hectare.

Path coefficient analysis by Pathak *et al.* (2014) revealed that fruit number followed by fruit weight, days to first male flower anthesis, days to first female flower anthesis and fruit length exhibited maximum positive direct effect on fruit yield. Days to first male flower anthesis exhibited negative effect on yield. Phenotypic path coefficient showed positive direct effect of fruit length and days to marketable maturity on yield whereas genotypic path coefficient had negative direct effect. Fruit weight, fruit length and days to first female flower anthesis although, exhibited high positive direct effect upon yield but negative correlation because of indirect effect by means of other characters. The fruit weight showed more negative indirect effect via fruit length.

The path analysis study conducted by Radha Rani *et al.* (2014) exhibited that most of the characters indirectly influenced the yield through number of fruits/vine, average fruit weight and fruit length towards the favourable direction which had positive direct effect on yield/vine, suggesting that emphasis must be given characters having high direct effect, while exercising selection to improve the yield of bitter gourd.

According to a study on genetic architecture and path analysis in bitter gourd by Singh *et al.* (2014), it was reported that plant height had the highest positive direct effect on fruit yield.

Singh *et al*. (2015) conducted a path analysis study for yield and its 11 contributing traits in 32 bitter gourd genotypes and found that maximum positive direct effect value was observed on fruit yield per plant by number of fruit per plant followed by average fruit weight while maximum negative direct effect value on fruit yield per plant contributed by node number to anthesis of first staminate flower at genotypic level.

Other cucurbits

Dora *et al*. (2002**)** observed that the number of branches per plant, diameter of fruit, fruit length and days taken from fruit set marketable maturity had weak positive and direct effect with fruit yield. A positive direct and negative effect with fruit yield was observed in days taken for appearance of fruit female flowers weight of fruit and number of nodes per plant in pointed gourd.

From a path analysis study in sweet gourd, Sanwal *et al.* (2007) observed that the number of fruits per plant, average fruit weight and fruit length exercised maximum direct effect on fruit yield.

Pandey *et al.* (2009) reported high and positive direct effect on yield was exerted by number of fruits per plant followed by fruit weight, polar and equatorial circumference of fruit, days to first male flower anthesis and node at which first female flower appears in snap melon.

Path analysis study in cucumber by Hossain *et al*. (2010) showed that the fruit length and fruit diameter, average fruit weight and number of fruits per plant directly contributed towards the yield per plant in the long type cucumber.

In ash gourd path analysis study conducted by Resmi and Srelathakumary (2012) revealed that fruit length, average fruit weight and fruits per plant had the positive direct effect on fruit yield.

Akter *et al.* (2013) reported that the maximum direct contribution towards fruit yield was obtained through number of fruits per plant followed by days to first female flower and single fruit weight suggesting that these traits should be considered as primary components of fruit yield in pumpkin. Negative direct effect on yield was exerted by number of female flowers per plant, reducing sugar and brix content.

A path analysis study conducted by Duvey *et al.* (2013) revealed that the number of fruits per plant and fruit weight had the highest positive direct effect on fruit yield per plant in ridge gourd.

According to a study in pumpkin by Shivananda *et al.* (2013), number of fruits per vine and average fruit weight had high positive direct effect indicating their true positive and significant association with yield.

Choudhury *et al.* (2014) observed that the maximum direct and desirable effect on fruit yield per plant was exerted by fruit length (0.850), number of fruits (0.334), days to first fruit harvest (-0.019) and node at which first hermaphrodite flower appeared (-0.057) at phenotypic level in ridge gourd.

Path coefficient analysis study in ash gourd conducted by Dewan *et al*. (2014), exhibited that the number of fruits per plant and average weight of fruit directly contributed to the yield of ash gourd accessions and the flesh thickness indirectly effected yield.

Muralidhar *et al*. (2014) reported that the characters like vine length, number of branches, days to first female flowering, days to first harvest, number of fruits per plant, weight of fruit and TSS were most important characters which had positive and direct effect on fruit yield in pumpkin. Further, the direct effects of number of leaves, days to first male flower flowering, sex ratio, days to 50 per cent female flowering and fruit set per cent were negative in their association with fruit yield.

Janaranjani and Kanthaswamy (2015) observed that number of fruits per vine, days to first female flower opening, fruit cavity and fruit weight had positive direct effect on fruit yield in bottle gourd.

According to a path analysis study in tinda gourd by Munawar *et al.* (2015), it was reported that fruit weight had the most direct effect on yield, followed by fruit diameter and stem diameter.

2.7 Genetic divergence

Selection of genetically divergent varieties is important in the exploitation of heterosis and in the development of transgressive segregates for an efficient breeding programme. The information regarding the nature and magnitude of genetic distance among the genotypes will help the breeder choosing the suitable diverse combinations. Some of the salient research findings on bitter gourd as well as other related cucurbits are presented below.

Genetic divergence in bitter gourd

Genetic divergence among forty genotypes of bitter gourd of different eco geographic origin was assessed by Kutty *et al*. (2005) using Mahalonobis' D^2 statistics. The total genotypes were grouped into 10 clusters on similarities of D^2 values. The characters like number of leaves at 50% flowering and productive length of vine contributed maximum to divergence.

Dey *et al*. (2007) conducted a genetic divergence study by using 38 bitter gourd genotypes including two promising gynoecious lines for 17 characters and grouped the genotypes into six clusters irrespective of geographic divergence, indicating no parallelism between geographic and genetic diversity. Cluster IV was very large containing 17 genotypes including some of the commercially released cultivars, while cluster IV was represented by two gynoecious lines. The maximum inter-cluster distance was obtained between cluster II and IV while minimum distance was between II and VI. Cluster IV followed by cluster III showed superiority for yield and other desirable traits, which indicate the potentiality of these diverse genotype collection for providing basic material for future breeding programmes as most of the commercially released cultivars were represented in cluster III.

In a genetic diversity study in 22 genotypes in bitter gourd collected from different geographical locations by Sunderam (2008), reported the presence of wide genetic diversity. Among the fourteen quantitative characters studied, individual fruit weight constituted a maximum of 26.83 per cent to the divergence, followed by yield of fruits per vine and length of fruit.

From a genetic divergence study in bitter gourd, Islam *et al.* (2009) observed that the cluster II had highest mean value for weight per fruit. The inter cluster distances were much higher than the intra cluster distances. Cluster I exhibited the highest intra cluster distance while the lowest distance was observed in cluster III. The highest inter cluster distance was observed between I and II while the lowest distance was observed between the cluster II and IV. The highest intra cluster means for weight per fruit and five important yield contributing characters were obtained from cluster II.

Kundu *et al.* (2012) studied genetic divergence among 36 genotypes of bitter gourd (*Momordica charantia* L.). By using multivariate analysis based on 22 characters, 36 genotypes were grouped into six distant clusters. Days to first male flower opening, number of primary branches per vine, fruit yield per vine, days to green fruit maturity, seed weight per fruit mature seed width had the highest contribution towards the divergence. Cluster diagram exhibited that the genotypes include in the cluster III were far diverse from the genotypes of cluster IV while the genotypes belonging to the cluster II and VI were least diversed.

In a genetic divergence study in 33 bitter gourd genotypes for twenty characters, Resmi and Sreelathakumary (2012) grouped the genotypes into five clusters irrespective of geographic divergence, indicating no parallelism between geographic and genetic diversity. Cluster-I was the largest comprising 11 genotypes, followed by Clusters-III and V with 10 genotypes each. Clusters-II and IV comprised one genotype each. As regards cluster means, Clusters-II and IV performed better in most of the biometric characters studied. Maximum inter-cluster distance was observed in Clusters-III and IV, followed by Clusters-II and III, and clusters-I and IV. Intra-cluster distance was highest in Cluster I.

A study was conducted by Singh *et al.* (2013), to evaluate the nature and magnitude of genetic divergence in 30 bitter gourd genotypes. Results revealed the presence of wide genetic diversity. The genotypes were grouped into 6 clusters based on Mahalonobis' D^2 statistics using Tocher's method. The clustering pattern of genotypes revealed that the genetic diversity was independent of the geographical diversity. Among the 12 quantitative characters studied, individual fruit weight contributed a maximum of 64.14% to the divergence, followed by days to first female flower appearance.

An experiment was carried out by Singh *et al.* (2015) to analyze multivariate analysis based on cluster and principal component (PC) for yield and its eleven contributing traits in 32 bitter gourd genotypes including two checks, *i.e.* Pusa DoMausami and Kalyanpur Sona during summer. The cluster analysis categorized all 32 bitter gourd genotypes into 6 major clusters. Extreme genetic divergence was estimated among clusters. Average inter-cluster distance was found maximum (717.86) between cluster V (NDBT-12) and cluster VI (NDBT-76). The proportionate contribution of fruit weight and fruit length towards genetic divergence was 74 and 13%, respectively. Highest cluster mean values for fruits/ plant, fruit weight (g) and fruit yield/plant (kg) was found in cluster V followed by cluster II. Principal component analysis revealed that first six principal components (PC1, PC2, PC3, PC4, PC5 and PC 6) accounted for 83.19% of the total variations with the proportionate contribution values of 23.88, 16.81, 13.28, 11.23, 9.38 and 8.61%, respectively. The first PC has positive association with node number to anthesis of first staminate flower and days to first fruit harvest, while negative association with fruit weight (g), fruits/ plant and fruit yield/ plant (kg).

Other cucurbits

Sanwal *et al.* (2007) reported that the genotypes under study were grouped into six cluster in sweet gourd and the maximum inter cluster distance was exhibited between cluster I and IV.

Choudhary *et al.* (2011) conducted an investigation involving thirty-five genotypes for eight quantitative traits. According to them the genotypes were grouped into four clusters irrespective of geographic divergence, indicating no parallelism between geographic and genetic diversity. Cluster IV was very large containing 16 genotypes, while cluster III was represented by three genotypes. The maximum inter-cluster distance was recorded between cluster II and IV, while minimum distance was between cluster I and II. Cluster IV showed superiority for fruit yield per plant which indicates the potentiality of these genotypes, providing basic material for future improvement breeding programmes of hermaphrodite ridge gourd.

Muralidhara *et al.* (2014) reported that the maximum intra cluster distance between Cluster I and II followed by II and V, V and VI. Cluster II recorded highest mean values for number of leaves, number branches, days to first male and female flowering, sex ratio, days to 50 percent female flowering, days to first harvest, number of fruits per plant and TSS in pumpkin. Cluster V recorded highest mean values for weight of fruits per plant, number of seeds per fruit, weight of seeds per fruit, rind thickness, carotene content and yield per plant. Cluster I recorded least mean values for days to first male and female flowering, days to 50 percent female flowering, weight of fruits per plant, TSS and fruit yield per plant.

◆

MATERIALS AND METHODS

The present investigation entitled “Variability Studies in Bitter gourd [*Momordica charantia* L.]” was carried out during kharif season of the year 2014-15 at Department of Vegetable Science, College of Agriculture, Orissa University of Agriculture and Technology, Bhubaneswar. The investigation was carried to study the genetic variability, correlation, path analysis and D^2 analysis of 23genotypes of bitter gourd. The seeds of the genotypes of bitter gourd were collected from different sources.

3.1 Cropping history of the plot

Prior to the present investigation, detail information on cropping history of the experimental plot was collected & presented in Table-1, for three successive years.

Table 1.Cropping history of the experimental plot

Year	Kharif	Rabi	Summer
2011	Cowpea	Cauliflower	Cucumber
2012	Brinjal	Broccoli	Cowpea
2013	Okra	Tomato	Cowpea

3.2 Soil

A composite soil sample was taken from a depth of 15 cm surface from the experimental field before raising the crop for investigation. The sample was subjected to laboratory analysis to determine the physical and chemical compositions by following various standard methods. It is observed that the soils of experimental plot comes under sandy loam (Sand-73.14%, Silt-14.76%, Clay-11.76%) having pH 6.5.

Table 2. Source of collection of 23 bitter gourd genotypes

Code	Genotypes	Source of collection
V_1	Green Long	Hyderabad, Andhra Pradesh
V_2	Arka Harit	IIHR, Bangalore
V_3	Priya	KAU, Kerala
V_4	Pusa Domousumi	IARI, New Delhi
V_5	Pusa Vishesh	IARI, New Delhi
V_6	Pusa Asudhi	IARI, New Delhi
V_7	CO-1	TNAU, Coimbatore
V_8	Phule Greengold	MPKV, Rahuri
V_9	Meghana -1	Kumar Seeds, Odisha
V_{10}	Peta kalara	Pipili Local Collection, Odisha
V_{11}	Thusi	Local Collection, Odisha
V_{12}	NBR Noble Katahi	Noble Seeds, Karnataka
V_{13}	Improved Katahi	Noble Seeds, Karnataka
V_{14}	Japani Green kalara	Amtala Hitech, West Bengal
V_{15}	IIVR-2	IIVR, Varanasi
V_{16}	IIVR-4	IIVR, Varanasi
V_{17}	IIVR-5	IIVR, Varanasi
V_{18}	NDUAT-3	NDUAT, Faizabad
V_{19}	Nakhara Local	Odisha
V_{20}	BBG-5	AICRP Vegetable project, Odisha
V_{21}	Hirkani	MPKV, Rahuri
V_{22}	Samanta Goberta Green Long All Season	Samanta Seeds, Jajpur, Odisha
V_{23}	High Tech Meghana-2	Cuttack, Odisha

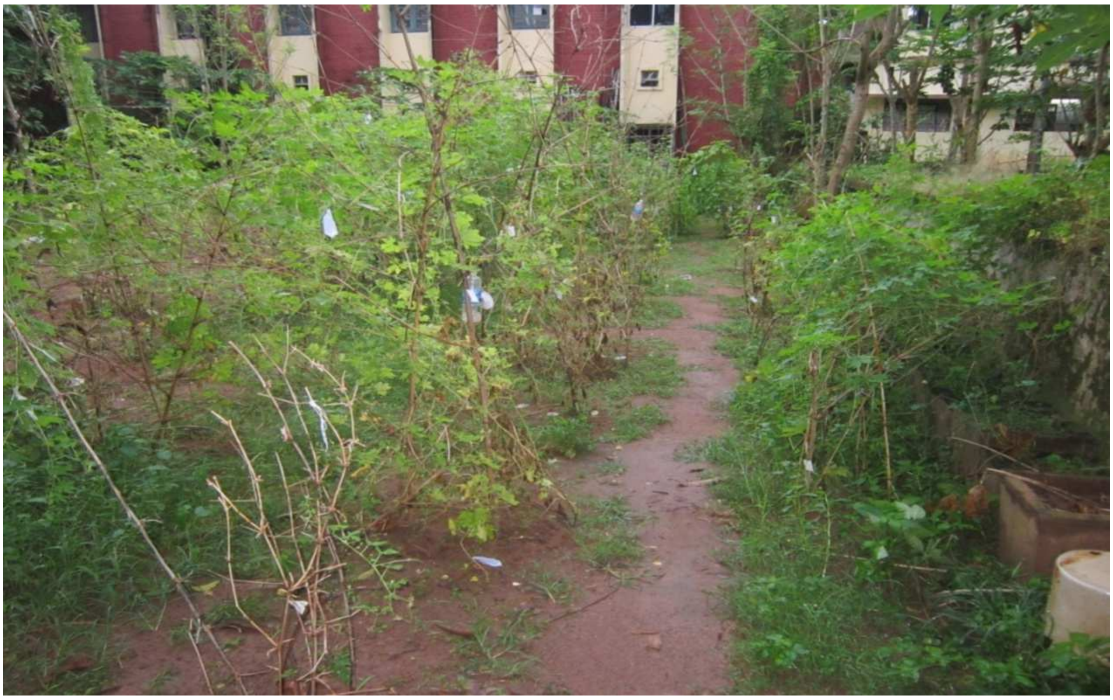
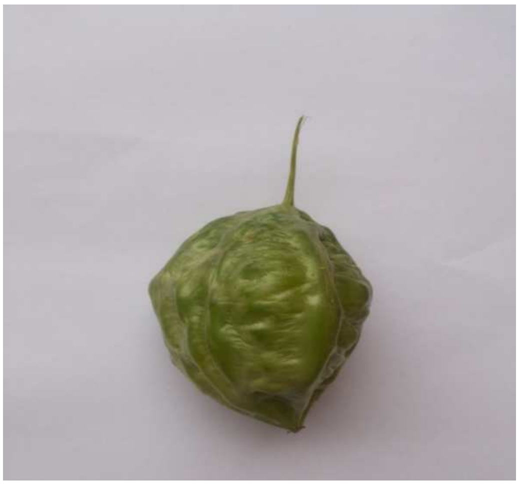


Fig 1. Field view of the experimental field of bitter gourd

Fig 2 Some of the bitter gourd genotypes



ARKA HARIT

HIGH TECH MEGHANA-2

JAPANI GREEN KALARA

HIRKANI

NAKHARA LOCAL

PRIYA

PHULE GREEN

CO-1

THUSI

IIVR-5

GREEN LONG

NBR NOBLE KATAHI

PETA KALARA

MEGHANA-1

3.3 Geographical location of the experimental site

Bhubaneswar is located at latitude of 20^0 15' N & 85^0 52' East longitude. It is about 60kms away from Bay of Bengal at an altitude of 25.5 meter above mean sea level (MSL).

3.4 Climate

The experimental site comes under the eighteenth agro-climatic region of the country i.e. Eastern Coastal Plain and is termed as sub-humid characterized by warm moist climate with mild winter.

The average annual rainfall of Bhubaneswar is 1552mm (Based on average of preceding 10 years). Most of the rainfall i.e. 85% is received from July to September. The rainfall code of the place is $D_1 E_3 (B_1A_2B_1) C_1D_1E_2$. The average temperature varies from 14^0c in winter to 40^0c in summer & relative humidity varies between 49 or 90% from June to December.

Monthly average meteorological data during cropping season was recorded at meteorological Observatory of Orissa University of Agriculture and Technology Bhubaneswar in Table-1

Table 3. Meteorological data collected during the experimental period (July 2014-Nov 2014)

Month	Temperature(^{0} C)			Rainfall(mm)		Relative Humidity (%)			Wind Velocity	Bright sunshine hour
	Max	Min	Mean	Rainfall in mm	No. of rainy days	morning	afternoon	mean		
July 2014	31.55	24.75	28.15	291.900	19	92.75	81.25	87.00	5.57	2.57
August 2014	32.13	24.70	28.42	53.725	21	92.75	79.25	86.00	5.35	3.38
Sept 2014	31.88	24.40	28.14	100.58	20	95.20	80.00	87.60	3.98	4.26
Oct 2014	32.90	23.40	28.15	40.525	8	93.50	64.75	79.13	3.20	6.55
Nov 2014	30.80	19.10	24.95	0.200	0	89.60	49.60	69.60	2.54	6.60

3.5 Experimental details:

(i)	Design of Layout	: Randomized Block Design (RBD)
(ii)	Number of Treatments	: 23
(iii)	Number of Replication	: 3
(iv)	Total no. of plots	: 69
(v)	Spacing	
	a) Row to Row	: 2m
	b) Hill to hill	: 1m
(vi)	Number of plants per pit	: 3
(vii)	Number of pits per plot	: 4
(viii)	Number of plants per plot	: 12
(ix)	Total number of plants	: 828

3.5.1 Field operation and Crop raising

Prior to the commencement of the experiment, the field was ploughed thoroughly and leveled properly. Then pits of 60cm diameter and 60cm deep were dug and pit soil was mixed with well decomposed farm yard manure at the rate of thoroughly. Seeds are soaked in water over night to obtain better germination. The seed sowing was done on 23rd July 2014 in each pit at a depth of 2 to 3 cm. Light irrigation was given with rose cane for the first time in main field.

A fertilizer dose of 80 kg N, 60kg P_2O_5 and 60 kg K_2O per ha were applied. The total amount of phosphorous with 25 kg of nitrogen and 30 kg of potash were applied as basal at the time of pit preparation and remaining fertilizers were applied in two top dressings , as 30kg of nitrogen along with ½ of potash after one month of seeding and remaining nitrogen was applied at 20 days after first top dressing.

After emergence, the plants were thinned to three per pit, taking care of uniform growth and vigour of plants. Hoeing, weeding and earthing up were done at periodic interval. Manually hoeing followed by weeding, top dressing and earthing up were done followed by irrigation at 25 and 45 days after sowing. Adequate plant protection measures like spraying of Ekalux, Carbaryl and Malathion for the control of epilachna beetle and fruit borer were carried out at regular interval to raise the crop successfully.

3.5.2 Biometric observations

3.5.3 Sampling Technique

Observations on various biometric characters were recorded by selecting randomly five competitive plants of each cultivar in a replication which were tagged properly. The border plants were excluded while selecting the sample plants. The observations of these plants were taken time to time starting from initiation of first flowering to final harvesting of fruits. The average values for various characters from the selected plant were taken for statistical analysis.

3.5.4 Characters studied

1. **Vine length (VL)**

   This was recorded in meter from the base to the tip of the main vine.

2. **Number of primary branches per plant (BN)**

   This was calculated by counting the total number of branches emerging from the main vine from the selected sample plants.

3. **Node number bearing first female flower (NNF)**

   The node at which first flower appeared counted from the base and expressed in number.

4. **Days to opening of first male flower (DMF)**

   This character was recorded by counting the number of days taken from the date of sowing to the opening of first male flower.

5. **Days to opening of first female flower (DFF)**

   This was recorded by counting the number of days taken from the date of sowing to the opening of first female flower in the observational plants.

6. **Leaf area (LA)**

   This was recorded by measuring the total area of five leaves from the sample plants with the help of leaf area meter.

7. Days to first harvest (DH)

This was recorded by counting the number of days taken from sowing to the first harvest of fruits of edible stage in each genotype.

8. Number of fruits per plant (FN)

By counting the total number of fruits harvested at different pickings in the sample plant till the final marketable harvest, this character was recorded.

9. Fruit weight (FW)

Individual fruit weight was obtained by taking average weight of the five fruits at edible stage from the selected plants per treatment and this was expressed in grams.

10. Fruit length (FL)

This character was recorded by measuring length from the basal end to the beak tip of five fruits randomly selected from the plant with the help of a veneer caliper. The average fruit length was worked out on five plants basis and was expressed in cm.

11. Fruit breadth (FB)

This was recorded from the fruits selected for fruit length and was measured in cm at the point of maximum thickness with the help of a veneer caliper and the mean value was taken for analysis of this character.

12. Number of seeds per fruit (SN)

This was recorded by the total number of seeds obtained from the randomly selected five ripe fruits in each genotype. The average value was taken to calculate the number of seeds per fruit for analysis.

13. Seed/flesh ratio (SFR)

This was obtained by taking the fresh weight of the seeds to the weight of the flesh excluding the mucilaginous material in the selected ripe fruits and the average was worked out.

14. **100 seed weight (SW)**

Observations for this character were recorded by weighing 100 numbers of well drained seeds and were expressed in grams.

15. Yield per plant (PY)

Observation for this character was recorded by taking the fresh weight of total number of fruits harvested at different pickings till marketable harvest from five tagged plants in each replication and the total yield was expressed in terms of grams.

3.5.5 Statistical analysis

The data recorded for various characters were subjected to statistical analysis based on their sample means (Gomez and Gomez, 1983). Observations of all the 15 characters were analyzed for variability and other genetic parameters related to fruit yield were taken for character association, path analysis, and genetic divergence study.

Analysis of variances

The analysis of variances for each of the characters stated was done to find out varietals differences. The analysis was carried out separately for each trait following the procedure of randomized block design analysis (Panse and Sukhatme, 1954).

Analysis of variance was done on basis of following model.

$$Y_{ij} = m + g_i + r_j + e_{ij}$$

Where,

Y_{ij} = Phenotypic observation in the i^{th} genotype and the j^{th} replication

m = General mean

g_i = Effect of the i^{th} genotype/treatment

r_j = Effect of j^{th} replication

e_{ij} = random error associated with i^{th} genotype in j^{th} replication

Table 4. Analysis of variance and expected mean sum of square

SOURCE	df	MSS	EXPECTED MEAN SUM OF SQUARE
Replication	(r-1)	M_R	$\sigma^2_e + g\sigma^2_r$
Genotype	(g-1)	M_G	$\sigma^2_e + r\sigma^2_g$
Error	(r-1)(g-1)	M_E	σ^2_e

3.5.6 Mean, range, standard error and critical differences

Sample mean values were calculated for each character by dividing the total by corresponding number of observations, while the highest and lowest values for each character were taken as the range. The S.E. and C.D. values were calculated by using the following formula.

Standard error mean (SEM) = $\sqrt{\frac{\text{EMS}}{\text{r}}}$

Critical difference (C.D.)

$= \sqrt{\frac{\text{EMS}}{\text{r}}}$ × t value at error d.f. at 5% and 1% level of significance

Where, r = number of replications

EMS = Error mean sum of square

3.5.7 Co-efficient of variation

For comparing the variability of two or more than two characters, co-efficient of variation were calculated by using the formula given below:

C.V. = $\frac{SD}{X} \times 100 = \sqrt{\frac{\text{EMS}}{\text{r}}} \times 100$

Where,

S.D. = standard deviation which is the square root of mean square due to error (EMS)

X = Experimental mean

From the structure of the analysis of variance

Error variance = $\sigma e^2 = M_E$

Genotypic variance = $\sigma^2{}_g = \frac{M_G - M_E}{r}$

Phenotypic variance = $\sigma^2{}_p = \frac{M_G}{r} = \frac{\sigma_g^2 + \sigma_e^2}{r}$

The genotypic co-efficient of variation (GCV) and the phenotypic co-efficient of variation (PCV) were calculated by the formula given by Burton (1952).

$$\text{GCV} = \frac{\text{Genotypic standard deviation}}{\text{Grand mean}} \text{ X } 100$$

$$\text{PCV} = \frac{\text{Phenotypic standard deviation}}{\text{Grand mean}} \text{ X } 100$$

3.5.8 Heritability (broad sense)

The heritability estimates were used to measure the degree of correspondence between phenotypic value and breeding value. It is worked out by using the formula suggested by Lush (1949) and Burton and Devance (1953) and expressed in percentage according to Weber and Moorthy (1952).

$$h^2 \text{ (broad sense)} = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}}$$

$$h^2 \text{ (broad sense in percentage)} = \frac{\text{Genotypic variance}}{\text{Phenotypic variance}} \times 100$$

3.5.9 Expected genetic advance

Genetic advance was estimated as per the formula suggested by Johnson *et al* (1995).

$GA = K.\ h^2\sigma_p$

Where,

K = Selection differential in standard units (which is 2.06 per 5% selection intensity).

h^2 = Heritability in broad sense

σ_p = Phenotypic standard deviation

GA expressed as percentage of mean = $\frac{\text{GA}}{\text{Mean}} \times 100$

3.5.10 Estimation of correlation co-efficient

Simple correlation co-efficient were computed at phenotypic and genotypic levels between pairs of 15 characters that contribute to total plant yield using the following formula.

Genotypic correlation (r_g) = $\frac{\sigma_g(xy)}{\sigma_g(x)} \times \sigma_g(y)$

Phenotypic correlation (r_p) = $\frac{\sigma_p(xy)}{\sigma_p(x)} \times \sigma_p(y)$

Where,

$\sigma_g(xy)$ = Genotypic co-variance between the two traits x and y.

$\sigma_p(xy)$ = Phenotypic co-variance between the two traits x and y.

$\sigma_g(x)$ and $\sigma_g(y)$ = Genotypic standard deviation for x and y respectively.

$\sigma_p(x)$ and $\sigma_p(y)$ = Phenotypic standard deviation for x and y respectively.

The estimated values were compared with the table value at (n - 2) and at degrees of freedom at 5% and 1% levels of significance in order of test the significance of correlation co-efficient at phenotypic and genotypic level.

3.5.11 Path co-efficient analysis

The cause and effect relationship among the various correlated characters are determined by path co-efficient analysis. Path co-efficient were standardized by partial regression coefficients which individually provide a measure of direct effect of the casual factors on the effect variable. These permit partitioning of the correlation between casual factors and the effect of variables into components of direct and indirect effect and thus give a better picture of the association of the casual factors with the effect variable.

In the present investigation, fruit yield per plant was taken as the effect with other characters like vine length, number of primary branches per plant, node number bearing first female flower, days to opening first male flower, days to opening first female flower, leaf area, days to first harvest, number of fruits per plant, fruit weight, fruit length, fruit breadth, number of seeds per fruit, seed/flesh ratio and 100 seed weight related to this as the casual factor.

The path coefficients were obtained by solving the following the simultaneous equations which give the basic relationship between correlations and path coefficients in a system of correlated causes. (Dewey and Lu, 1959)

$$r_{112} = r_{11}p_{112} + r_{12}p_{112} + r_{13}p_{112} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. + r_{111}p_{1112}$$

$$r_{212} = r_{21}p_{112} + r_{22}p_{112} + r_{23}p_{112} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. + r_{211}p_{1112}$$

$$r_{312} = r_{31}p_{112} + r_{32}p_{112} + r_{33}p_{112} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. + r_{311}p_{1112}$$

$$r_{1112} = r_{111}p_{112} + r_{112}p_{212} + r_{113}p_{312} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. + p_{1112}$$

Where, r_{ij} is the coefficient of correlation between ith and jth characters and p_{qi} is the path coefficient (direct effect of ith character total yield per plant (1, 2).

The solutions for path coefficients, direct and indirect effects of the casual factors were estimated as the values of the individual terms of the above equations in R.H.S.

The coefficient of determination (R^2) and the residual effect ($p_{12.R}$) were calculated as follows:

$$I = p^2_{12.R} + \sum p_{iy}r_{iy}$$

$$R^2 = \sum p_{iy}r_{iy}$$

$$= p_{112}r_{112} + p_{212}r_{212} + p_{312}r_{312} + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. + p_{1112}r_{1112}$$

$$P_{12.R} = \sqrt{I - R^2}$$

The path analysis at the genotypic level with the same cause and effect relationship was computed using the genotypic correlations as stated earlier.

3.7.7 Genetic divergence

Mahalanobis' (1928) generalized distance, D^2 statistics was used for computing genetic divergence as described by (Rao, 1952). The original measurements were transformed to standardized uncorrelated variables by pivotal condensation (Rao, 1952). The divergence between any two varieties was obtained as the sum of squares of the difference in the values of the corresponding transformed values (V_{ij})

$$D^2_{jk} = \sum^{n}_{i=1} Y_{i}j - Y_{i}k$$

Gives the D^2 between J^{th} and K^{th} germplasm for 'n' characters. The all possible 253 pairs of D^2 were calculated from the 23 varieties using the formula n (n - 1) / 2.

Following Tocher's method as described by Rao (1952), the genotypes were grouped into clusters. The criterion of grouping was that any two genotypes belonging to the same cluster should have a smaller D^2 value than those between genotypes belong to different clusters. Inter and intra-cluster distances were determined and represented.

◆

RESULTS

During the course of investigation on the project entitled "Variability Studies in Bitter gourd (*Momordica charantia* L.)" observations on fruit yield per plant and its component characters were recorded. The mean values of the traits studied were statistically analyzed to estimate the variability, heritability and genetic gain for selection and their association with yield as well as among themselves. The direct and indirect effect of these traits on fruit yield and the nature and extent of genetic divergence among 23 genotypes were also studied. The salient findings as revealed from the investigation are explained below:

4.1 Analysis of variance

The variance (mean square values) between genotypes for 15 characters such as vine length, number of primary branches per plant, node number bearing first female flower, days to opening of first male flower, days to opening of first female flower, leaf area, days to first harvest, number of fruits per plant, fruit weight, fruit length, fruit breadth, number of seeds per fruit, seed flesh ratio, 100 seed weight and yield per plant are presented in Table 5. The data revealed the existence of significant difference among the genotypes for most of the characters studied.

4.2 Mean performance and co-efficient of variation

4.2.1 Mean and range

The mean performance, standard error of variance (SE) and critical difference (C.D.) values are presented in Table 6.

4.2.1.1 Vine length

A wide variability ranging from 1.81 m to 7.68 m was noticed with respect to vine length. The vine length was maximum for genotype IIVR-5 which is followed by IIVR-4 (6.57m) and the minimum length was observed in Pusa Vishesh followed by Pusa Asudhi (2.30m). The cultivars like Improved Katahi (4.42m), IIVR-2 (4.56m), Samanta Goberta Green Long All Season (4.52m) and High Tech Meghana-2(4.43m) were of medium types.

Table 5. Analysis of variance for 15 quantitative characters studied in bitter gourd genotypes

Sl. No.	Characters	Mean Sum of Square		
		Replication (2)	Genotypes (22)	Error (44)
1.	Vine length (m)	0.128	7.184**	0.052
2.	Number of primary branches per plant	0.151	17.621**	3.773
3.	Node no bearing 1st female flower	0.016	30.794**	5.018
4.	Days to opening of 1st male flower	0.329	41.706**	7.429
5.	Days to opening 1st female flower	0.597	131.875**	6.985
6.	Leaf area(cm^2)	265.286**	1322.883**	45.299
7.	Days to 1st harvest	97.169	289.953**	31.843
8.	Number of fruits per plant	19.788	271.760**	9.618
9.	Fruit weight(g)	24.173	1322.649**	18.387
10.	Fruit length (cm)	2.747	68.973**	2.677
11.	Fruit breadth (cm)	0.416	36.926**	1.481
12.	Number of seeds per fruit	2.254	35.610**	2.402
13.	Seed flesh ratio (SFR)	0.000	0.008**	0.000
14.	100 seed weight(g)	3.920	20.118**	1.222
15.	Yield per plant	59446.433	1387489.500**	56650.210

** Significant at 1% level and * significant in 5% level

Figure in the parenthesis indicate degree of freedom of respective sources of variation

4.2.1.2 Number of primary branches per plant

Number of primary branches per plant varied from 7.77 (Pusa Domousumi) to 16.55 (IIVR-5) with a general mean of 11.55. The cultivars like Green long (11.10), Priya (11.44) and Phule Green Gold (11.99) exhibited intermediate value for this trait. The lowest number of branches of 7.77 was recorded in Pusa Domousumi, followed by Pusa Asudhi (8.33).

4.2.1.3 Node number bearing first female flower

Significant range was observed for this trait among the genotypes evaluated. The highest value under this character was recorded in Green Long (26.38) where as Priya(14.18) recorded the lowest value. Genotypes like Meghana-1 (19.32), Peta Kalara (20.11) and NBR Noble Katahi (20.33) exhibited medium value for this trait in higher order.

4.2.1.4 Days to opening of first male flower

Earlier male flowering was noticed in variety, Arka Harit (32.62 days) after seed sowing followed by NDUAT-3 (32.73 days), Improved Katahi (34.50 days), Pusa Asudhi (34.71 days) and Meghana-1 (34.95 days) whereas the cultivar Priya was the late type (46.13 days) followed by Green Long (46.03 days), Nakhara Local (42.56 days) and IIVR-2 (42.27 days) in succession. The varieties Thusi (38.12 days), IIVR-5 (39.69 days) and Pusa Domousumi (38.58 days) were of medium types.

4.2.1.5 Days to opening of first female flower

A distinct variation was observed with respect to this character. The variety Pusa Asudhi (34.02 days) produced female flowers first followed by Japani Green Kalara (38.53 days) and NBR Noble Katahi (39.34 days) in order. The genotype Samanta Goberta Green Long All Season (59.10 days) produced female flowers late closely followed by Pusa Vishesh (58.56 days). The cultivars CO-1 (47.99 days), BBG-5 (48.93 days) and Thusi (49.04 days) were of medium types.

Table 6. Mean of performance of 23 bitter gourd genotypes for 15 characters

Genotypes		**Vine length (m) (VL)**	**Number of primary branches per plant (BN)**	**Node no bearing 1st female flower (NNF)**	**Days to opening of 1st male flower (DMF)**	**Days to opening 1st female flower (DFF)**	**Leaf area (cm²)**	**Days to 1st harvest (DFF)**	**Number of fruits per plant**	**Fruit weight (FW) (g)**	**Fruit length (FL) (cm)**	**Fruit breadth (FB) (cm)**	**Number of seeds per fruit (SN)**	**Seed flesh ratio (SFR)**	**100 seed weight (SW) (g)**	**Yield per plant (PY)**
V_1	Green Long	5.37	11.10	**26.38**	46.03	50.91	84.63	62.16	14.77	42.90	11.90	9.70	12.88	0.145	18.48	666.15
V_2	Arka Harit	2.33	8.61	16.88	**32.62**	42.77	63.21	53.88	11.55	49.66	9.59	13.83	16.33	**0.257**	18.85	594.41
V_3	Priya	5.74	11.44	**14.18**	**46.13**	51.29	95.45	67.90	12.80	73.67	14.24	13.51	16.53	**0.034**	19.82	939.01
V_4	Pusa Domousumi	2.57	**7.77**	18.31	38.58	41.38	85.77	56.74	8.10	**109.40**	15.96	**4.04**	**20.65**	0.073	18.03	883.33
V_5	Pusa Vishesh	**1.81**	13.77	21.64	36.31	58.56	51.71	71.73	9.99	60.23	12.58	5.91	12.33	0.074	19.13	613.30
V_6	Pusa Asudhi	2.30	8.33	21.61	34.71	**34.02**	55.05	50.30	9.55	56.06	11.54	5.52	19.33	0.156	18.44	451.48
V_7	CO-1	5.37	12.77	17.22	41.25	47.99	97.80	53.01	**37.05**	60.08	15.06	11.47	13.22	0.079	**21.03**	**2298.21**
V_8	Phule Greengold	4.60	11.99	24.44	36.96	46.21	101.84	57.76	28.54	70.60	18.58	**18.95**	16.77	0.050	17.50	2218.49
V_9	Meghana -1	3.31	12.77	19.32	34.95	56.15	**110.20**	68.24	31.55	71.02	11.12	15.18	17.44	0.083	20.26	2168.37
V_{10}	Peta kalara	2.40	8.66	20.11	36.74	47.50	71.13	**92.67**	8.22	50.88	12.58	13.17	10.33	0.050	17.22	294.33
V_{11}	Thusi	3.41	13.77	20.54	38.12	49.04	47.04	57.46	23.20	**10.74**	**5.20**	8.82	**5.33**	0.133	13.37	263.69
V_{12}	NBR Noble Katahi	5.75	13.33	20.33	40.27	39.34	102.56	59.61	22.33	67.35	17.12	14.25	14.32	0.037	16.50	1349.54
V_{13}	Improved Katahi	4.42	8.44	23.22	34.50	41.61	91.67	52.65	32.77	53.26	15.22	13.30	13.88	0.067	17.16	1584.33
V_{14}	Japani Green kalara	2.38	9.55	22.20	37.94	38.53	105.21	**47.94**	28.77	87.56	13.83	13.07	16.77	0.057	20.00	1996.81
V_{15}	IIVR-2	4.56	10.22	21.34	42.27	57.81	103.26	72.84	33.66	79.96	15.54	13.18	17.44	0.050	17.66	2184.26

Genotypes		**Vine length (m) (VL)**	**Number of primary branches per plant (BN)**	**Node no bearing 1st female flower (NNF)**	**Days to opening of 1st male flower (DMF)**	**Days to opening 1st female flower (DFF)**	**Leaf area (cm^2)**	**Days to 1st harvest (DFF)**	**Number of fruits per plant**	**Fruit weight (FW) (g)**	**Fruit length (FL) (cm)**	**Fruit breadth (FB) (cm)**	**Number of seeds per fruit (SN)**	**Seed flesh ratio (SFR)**	**100 seed weight (SW) (g)**	**Yield per plant (PY)**
V_{16}	IIVR-4	6.57	15.44	21.25	42.00	51.44	89.44	57.88	21.66	57.24	21.02	9.35	14.77	0.040	17.03	1218.40
V_{17}	IIVR-5	**7.68**	**16.55**	21.27	39.69	52.02	91.85	61.51	27.55	65.89	**29.08**	8.98	15.63	0.037	17.50	1611.83
V_{18}	NDUAT-3	3.40	10.21	14.84	32.73	49.71	88.51	58.56	15.11	57.44	9.81	8.10	13.06	0.037	16.42	818.78
V_{19}	Nakhara Local	3.57	12.99	21.04	42.56	47.26	**43.72**	63.03	**6.88**	34.68	11.26	10.30	11.65	0.093	11.33	**233.77**
V_{20}	BBG-5	5.44	9.21	23.64	40.69	48.93	54.02	59.01	21.80	30.71	8.01	8.90	10.89	0.077	**10.44**	559.91
V_{21}	Hirkani	5.19	13.32	16.31	37.43	47.37	99.38	58.34	26.77	45.78	12.06	13.29	19.73	0.063	18.16	1277.00
V_{22}	Samanta Goberta Green Long All Season	4.52	13.09	16.84	40.86	**59.10**	99.77	76.29	31.10	52.21	12.30	12.44	16.42	0.080	18.00	1466.66
V_{23}	High Tech Meghana-2	4.43	12.44	15.48	40.97	54.73	97.55	59.86	17.77	89.08	11.98	14.10	15.44	0.037	18.52	1467.11
SE(±)		0.725	1.586	1.829	2.226	2.158	5.495	4.607	2.532	3.501	1.336	0.994	1.266	0.011	0.903	194.337
C. D. (0.05)		1.461	3.197	3.686	4.485	4.349	11.075	9.286	5.103	7.056	2.692	2.003	2.551	0.023	1.820	391.663

4.2.1.6 Leaf Area

Considerable variation was also noticed for leaf area varying from 43.72cm^2 to 110.20cm^2. Highest leaf area was seen in the cultivar Meghana -1 followed by Japani Green Kalara (105.21cm^2). On the contrary, the variety Nakhara Local has the smallest leaf area followed by Thusi (47.04 cm^2). However, Green Long (84.63cm^2) and Pusa Domousumi (85.77cm^2) have shown medium value for this character.

4.2.1.7 Days to first harvest

A wide variation ranging from 47.94 days to 92.67 days was recorded for this character among the genotypes. Japani Green Kalara (47.94days) was of the earliest maturing type whereas it was maximum in Peta Kalara (92.67 days). Green Long (62.16 days), High Tech Meghana-2 (59.86 days) and IIVR-5 (61.51 days) were of medium maturing type among the genotypes evaluated.

4.2.1.8 Number of fruits per plant

A significant variation was visualized with respect to the number of fruits per plant among the genotypes which ranged from 6.88 to 37.05. The highest number of fruit (37.05) was recorded in CO-1 followed by IIVR-2 (33.66) and the lowest number of fruits (6.88) was observed in Nakhara Local followed by Pusa Domousumi (8.10) in higher magnitude. Cultivars like IIVR-4 (21.66) and BBG-5 (21.80) showed medium value for this character.

4.2.1.9 Fruit weight

Considerable variation ranging from 10.74g to 109.40g was observed in case of fruit weight. The variety Pusa Domousumi recorded the highest fruit weight 109.40g followed by High Tech Meghana-2 (89.08g) and Japani Green Kalara (87.56g). The genotypes like Pusa Vishesh (60.23g) and CO-1 (60.08g) have shown medium value for this character. Further, the lowest fruit weight was recorded in Thusi (10.74g) followed by BBG-5 (30.71g) in higher order.

4.2.1.10 Fruit length

A significant variation was obtained in case of fruit length among the genotypes. The highest value 29.08cm was recorded in case of IIVR-5 which was followed by IIVR-4 (21.02cm) and Phule Greengold (18.58cm). The lowest value of 5.20cm was recorded in Thusi followed by BBG-5 (8.01cm). Some of the lines showing medium value for this trait were Pusa Vishesh and Peta Kalara, each having 12.58cm length and Japani Green Kalara (13.83cm) in ascending order.

4.2.1.11 Fruit breadth

Fruit breadth of different genotypes ranged from 4.04 to 18.95 cm with a general mean of 11.28 cm. The genotypes Pusa Domousumi recorded the lowest fruit breadth while Phule Greengold exhibited highest fruit breadth (18.95cm). The genotypes like Nakhara Local (10.30cm), CO-1 (11.47cm), Japani Green Kalara (13.07cm) and Peta Kalara (13.17cm) have shown medium value for this character.

4.2.1.12 Number of seeds per fruit

A wide range of variation from 5.33 to 20.65 was observed for this character. The cultivar Pusa Domousumi produced 20.65 number of seeds per fruit followed by Hirkani (19.73) and Pusa Asudhi (19.33). Thusi produced the lowest number of seeds per fruit (5.33). Moderate values were obtained for this trait in High Tech Meghana-2, IIVR-4, NBR Noble Katahi and Improved Katahi producing 15.44, 14.77, 14.32 and 13.88 seeds respectively.

4.2.1.13 Seed / flesh ratio

Lowest seed/flesh ratio was found in variety Priya (0.034) and highest in Arka Harit (0.257). Moderate values were obtained in the varieties Pusa Vishesh (0.074), BBG-5 (0.077), CO-1 (0.079) and Samanta Goberta Green Long All Season (0.080).

4.2.1.14 100 seed weight

The tested genotypes exhibited a wide range from 10.44g to 21.03g for this character. The variety CO-1 showed the highest 100 seed weight (21.03g) closely followed by Meghana-1 (20.26g). Lowest seed weight was recorded in BBG-5 (10.44g) followed by Nakahra Local (11.33g). Moderate values were obtained in cultivars like Phule Greengold and IIVR-5 (17.50g) each and IIVR-2 (17.66g).

4.2.1.15 Yield per plant (g)

A significant wide range of variation for this character was recorded ranging from 233.77g to 2298.21g among the genotypes. The maximum value 2298.21g was recorded in CO-1 which was followed by Phule Green Gold (2218.49g), IIVR-2 (2184.26g), Meghana-1 (2168.37g) and Japani Green Kalara (1996.81g) in decreasing order. The lowest yield (233.77g) was obtained from Nakhara Local followed by Thusi (263.69g) and Peta Kalara (294.33g) in ascending order. However, IIVR-5 (1611.83g), Improved Katahi (1584.33g), High Tech Meghana-2 (1467.11g) and Samanta Goberta Green Long All Season (1466.66g) were the medium yielders.

4.2 Co-efficient of variance (C.V)

The co-efficient of variation with respect to different characters are presented in Table 7, which ranged from 5.45% to 19.15%. The highest variation (19.15%) was noticed in yield per plant followed by vine length (19.00%), seed flesh ratio (17.64%) and number of primary branches per plant (16.80%). The lowest variation 5.45% was recorded in days to opening of first female flower followed by 100 seed weight (6.34%), days to opening of first male flower (7.00%), fruit weight (7.16%) and leaf area (8.01%) in ascending order. Characters showed moderate value ranging from 9.14% to 16.80% for this trait.

Table 7. General mean, range, co-efficient of variation (C.V), genotypic variance, phenotypic variance for 15 quantitative characters in bitter gourd genotypes

Sl. No.	Characters	General Mean	Range	C.V (%)	Genotypic Variance	Phenotypic Variance
1.	Vine length	4.227	1.81-7.68	19.00	2.132	2.920
2.	Number of primary branches per plant	11.558	7.77-16.55	16.80	4.616	8.389
3.	Node no bearing 1st female flower	19.933	14.18-26.38	11.23	8.592	13.610
4.	Days to opening of 1st male flower	38.886	32.62-46.13	7.00	11.426	18.855
5.	Days to opening 1st female flower	48.425	34.02-59.10	5.45	41.630	48.615
6.	Leaf area(cm^2)	83.949	43.72-110.20	8.01	425.861	471.161
7.	Days to 1st harvest	61.715	47.94-92.67	9.14	86.037	117.880
8.	Number of fruits per plant	20.938	6.88-37.05	14.81	87.381	96.999
9.	Fruit weight	59.846	10.74-109.40	7.16	434.754	453.142
10.	Fruit length	13.723	5.20-29.08	11.92	22.099	24.776
11.	Fruit breadth	11.280	4.04-18.95	10.78	11.815	13.296
12.	Number of seeds per fruit	14.834	5.33-20.65	10.44	11.069	13.472
13.	Seed flesh ratio (SFR)	0.079	0.034-0.257	17.64	0.003	0.003
14.	100 seed weight	17.431	10.44-21.03	6.34	6.298	7.521
15.	Yield per plant	1180.836	233.77-2298.21	19.15	443613.094	500263.313

4.3 Estimation of genetic parameters

The estimate of genetic parameters such as genotypic variance and phenotypic variance are presented in Table-7, and their respective co-efficient of variation, broad sense heritability and genetic advance are presented in Table 8.

The phenotypic variance ranged from 0.003 for seed/flesh ratio to 500263.313 for yield per plant and the genotypic variance ranged from 0.003 for seed/flesh ratio to 443613.094 for yield per plant. In general, all the characters exhibited parallel values between these two variances showing higher value in the former than the later.

Table 8. Genotypic co-efficient of variance (GCV), Phenotypic co-efficient of variance (PCV), Heritability (in broad sense) and Genetic advance for 15 quantitative characters studied in bitter gourd

Sl. No.	Characters	Phenotypic co-efficient of variation (PCV)	Genotypic co-efficient of variation (GCV)	Heritability (in broad sense) (%)	Genetic advance	GA Expressed in % of mean
1.	Vine length (m)	40.430	34.544	73.0	2.570	60.802
2.	Number of primary branches per plant	25.059	18.588	55.0	3.282	28.403
3.	Node no bearing 1st female flower	18.508	14.705	63.1	4.797	24.068
4.	Days to opening of 1st male flower	11.166	8.692	60.6	5.420	13.939
5.	Days to opening 1st female flower	14.398	13.324	85.6	12.299	25.399
6.	Leaf area(cm^2)	25.856	24.582	90.3	40.415	48.143
7.	Days to 1st harvest	17.592	15.029	72.9	16.323	26.450
8.	Number of fruits per plant	47.037	44.644	90.0	18.276	87.288
9.	Fruit weight(g)	35.569	34.840	95.9	42.071	70.300
10.	Fruit length(cm)	36.270	34.254	89.1	9.145	66.643
11.	Fruit breadth(cm)	32.326	30.473	88.8	6.674	59.174
12.	Number of seeds per fruit	24.742	22.427	82.1	6.212	41.879
13.	Seed flesh ratio	67.647	65.306	93.2	0.074	93.876
14.	100 seed weight(g)	15.733	14.397	83.7	4.730	27.141
15.	Yield per plant	59.897	56.404	88.6	1055.856	89.416

Further the perusal of data in Table 8, revealed that the phenotypic co-efficient of variation (PCV) was higher than genotypic co-efficient variation (GCV) for all traits studied. The PCV was highest (67.647) in seed/flesh ratio followed by yield per plant (59.897). The traits like vine length (40.430), fruit length (36.270) and fruit weight (35.569) exhibited moderate value for this parameter. The other traits like node number bearing first female flower (18.508), days to first harvest (17.592), 100 seed weight (15.733) and days to opening of first female flower (14.398) showed lower value for this parameter. However, lowest value of 11.166 was recorded for days to opening of first male flower among the characters evaluated.

More or less similar trend was observed in the estimates of GCV for all the traits with seed/flesh ratio having the highest value (65.306) followed by yield per plant (56.404). Moderate values were obtained for fruit weight (34.840), vine length (34.544) and fruit length (34.254). Days to opening of first male flower exhibited the lowest value (8.692) which was closely followed by days to opening of first female flower (13.324) and in 100 seed weight (14.397) in ascending order for this parameter.

4.3.1 Heritability

Heritability (broad sense) estimates ranged from 55.0% for number of primary branches per plant to 95.9% for fruit weight. High heritability above 85% was observed in eight characters such as fruit weight (95.9%), seed/flesh ratio (93.2%), leaf area (90.3%), number of fruits per plant (90.0%), fruit length (89.1%), fruit breadth (88.8%), yield per plant (88.6%) and days to opening of first female flower (85.6%). Moderate to high heritability (60-85%) was observed in six characters such as 100 seed weight (83.7%), number of seeds per fruit (82.1%), vine length (73.0%), days to first harvest (72.9%), node number bearing first female flower (63.1%) and days to opening of first female flower (60.6%) while number of primary branches per plant has the lowest heritability (55.0%).

4.3.2 Genetic advance

The genetic advance varied from 0.074 (seed/flesh ratio) to 1055.856 (yield per plant). Other characters showing high genetic advance were fruit weight (42.071) and leaf area (40.415). However, number of fruits per plant (18.276), days to first harvest (16.233) and days to opening of first female flower (12.299) have shown moderate genetic advance. On the other hand, lower genetic advance ranging from 2.570 (vine length) to 9.145 (fruit length) were also observed for rest of the characters under study.

The predicted genetic advance expressed as percent of population mean ranged from 13.939% for days to opening of first male flower to 93.876% for seed/ flesh ratio. The characters like yield per plant (89.416%), number of fruits per plant (87.288%), fruit weight (70.300%) and fruit length (66.643%) exhibited genetic gain of higher magnitude, while rest of the character showed moderate values.

4.4 Character association

Estimates of phenotypic and genotypic correlation co-efficient of all pairs of 15 characters related to fruit yield among the tested genotypes of bitter gourd are presented in Table-9 and Table-10 respectively.

4.4.1 Phenotypic correlation

Fruit yield per plant was positively and significantly correlated with fruit length (0.438), 100 seed weight (0.472), fruit breadth (0.502), fruit weight (0.510), leaf area (0.793) and number of fruits per plant (0.800). Other characters like days to opening of first male flower (0.052), number of primary branches per plant (0.137), days to opening of first female flower (0.167), vine length (0.313) and number of seeds per fruit (0.396) are positively associated with fruit yield per plant with insignificant values. On the other hand, seed/flesh ratio (-0.400), days to first harvest (-0.125) and node number bearing first female flower (-0.051) were negatively and insignificantly associated with fruit yield per plant.

Table 9. Phenotypic correlation co-efficient (r_p) between all pairs of 15 quantitative characters in bitter gourd genotypes

Characters		**BN**	**NNF**	**DMF**	**DFF**	**LA**	**DH**	**FN**	**FW**	**FL**	**FB**	**SN**	SFR	SW	PY
VL	r_p	0.459^{*}	0.041	0.493^{*}	0.172	0.358	-0.083	0.361	-0.063	0.523^{**}	0.190	-0.025	-0.369	-0.102	0.313
BN	r_p		0.061	0.266	0.346	0.113	0.064	0.213	-0.145	0.307	0.073	-0.099	-0.271	- 0.052	0.137
NNF	r_p			0.134	-0.201	-0.179	-0.097	0.088	-0.197	0.162	-0.019	-0.173	0.094	-0.245	-0.051
DMF	r_p				0.219	0.114	0.173	0.071	0.030	0.151	0.042	-0.068	-0.245	-0.071	0.052
DFF	r_p					0.131	0.506^{*}	0.211	-0.063	0.023	0.070	-0.144	-0.256	0.061	0.167
LA	r_p						0.035	0.602^{**}	0.595^{**}	0.431^{*}	0.513^{*}	0.491^{*}	-0.488^{*}	0.557^{**}	0.793^{**}
DH	r_p							-0.117	-0.037	-0.013	0.137	-0.157	-0.220	-0.037	-0.125
FN	r_p								0.048	0.257	0.458^{*}	0.098	-0.271	0.187	0.800^{**}
FW	r_p									0.425^{*}	0.094	0.648^{**}	-0.389	0.555^{**}	0.510^{*}
FL	r_p										0.076	0.304	-0.438^{*}	0.239	0.438^{*}
FB	r_p											0.081	-0.136	0.191	0.502^{*}
SN	r_p												-0.057	0.500^{*}	0.396
SFR	r_p													-0.020	-0.400
SW	r_p														0.472^{*}

*and ** indicates significant at 5% and 1% level respectively

Vine length was significantly and positively correlated with number of primary branches per plant (0.459), days to opening of first male flower (0.493) and fruit length (0.523), whereas it is positively associated with node number bearing first female flower (0.041), days to opening of first female flower (0.172), fruit breadth (0.190), yield per plant (0.313), leaf area (0.358) and number of fruits per plant (0.361) having insignificant values. On the contrary, this trait exhibited negative association with seed/flesh ratio (-0.369), 100 seed weight (-0.102), days to first harvest (-0.083), fruit weight (-0.063) and number of seeds per fruit (-0.025) having insignificant values.

Number of primary branches per plant was positively correlated with node number bearing first female flower (0.061), days to first harvest (0.064), fruit breadth (0.073), leaf area (0.113), yield per plant (0.137), number of fruits per plant (0.213), days to opening of first male flower (0.266), fruit length (0.307) and days to opening first female flower (0.346) and negatively correlated with seed/flesh ratio (-0.271), fruit weight (-0.145), number of seeds per fruit (-0.099) and 100 seed weight (-0.052). In all these cases the association was found to be insignificant.

Node number bearing first female flower was positively correlated with number of fruits per plant (0.088), seed/flesh ratio (0.094), days to opening of first male flower (0.134) and fruit length (0.162) and negatively correlated with 100 seed weight (-0.245), days to opening of first female flower (-0.201), fruit weight (-0.197), leaf area (-0.179), number of seeds per fruit (-0.173), days to first harvest (-0.097), fruit yield per plant (-0.051) and fruit breadth (-0.019) with insignificant values.

Days to opening of first male flower was positively correlated with fruit weight (0.030), fruit breadth (0.042), yield per plant (0.052), number of fruits per plant (0.071), leaf area (0.114), fruit length (0.151), days to first harvest (0.173) and days to opening of first female flower (0.219) and negatively correlated with seed/flesh ratio (-0.245), 100 seed weight (-0.071) and number of seeds per fruit (-0.068) with insignificant values in all cases.

Days to opening of first female flower was positively and significantly correlated with days to first harvest (0.506). Rest of the characters like leaf area (0.131), number of fruits per plant (0.211), fruit length (0.023), fruit breadth (0.070), 100 seed weight (0.061) and yield per plant (0.167) were positively correlated and fruit weight (-0.063), number of seeds per fruit (-0.144) and seed flesh ratio (-0.256) were negatively correlated with this trait having insignificant values.

Leaf area was significantly and positively correlated with number of fruits per plant (0.602), fruit weight (0.595), 100 seed weight (0.557), yield per plant (0.793), fruit length (0.431), fruit breadth (0.513) and number of seeds per fruit (0.491). Further, positive correlation of this character was with days to first harvest (0.035), but the association was not significant. On the contrary, seed/flesh ratio (-0.488) was significantly and negatively associated with this character.

Days to first harvest was positively associated with fruit breadth (0.137) and negatively correlated with fruit length (-0.013), 100 seed weight (-0.037), number of fruits per plant (-0.117), fruit weight (-0.037), number of seeds per fruit (-0.157), seed/flesh ratio (-0.220) and yield per plant (-0.125). However, in none of the case the association was found to be significant.

Number of fruits per plant was significantly and positively correlated with yield per plant (0.800) and fruit breadth (0.458). Rest of the characters like number of seeds per fruit (0.098), fruit weight (0.048), fruit length (0.257) and 100 seed weight (0.187) were positively correlated with this trait, but the association was insignificant. Further, this character was negatively and insignificantly associated with seed/flesh ratio (-0.271).

Fruit weight was significantly and positively correlated with number of seeds per fruit (0.648), 100 seed weight (0.555), fruit length (0.425) and yield per plant (0.510). Fruit breadth (0.094) was positively and seed/flesh ratio (-0.389) was negatively associated with this character, but this association was not significant.

Fruit length was significantly and positively correlated with yield per plant (0.438). On the other hand, fruit breadth (0.076), number of seeds per fruit (0.304) and 100 seed weight (0.239) were positively correlated with fruit length having insignificant values. On the contrary, seed/flesh ratio (-0.438) was significantly and negatively associated with this character.

Fruit breadth was significantly and positively correlated with yield per plant (0.502). Number of seeds per fruit (0.081) and 100 seed weight (0.191) were positively and seed/flesh ratio (-0.136) was negatively associated with this trait, having insignificant values.

Number of seeds per fruit was significantly and positively correlated with 100 seed weight (0.500). However, yield per plant (0.396) was positively and seed/flesh ratio (-0.057) was negatively associated with this character having insignificant association.

Seed/flesh ratio was negatively correlated with 100 seed weight (-0.020) and yield/plant (-0.400) having insignificant values.

4.4.2 Genotypic correlation

The genotypic correlation co-efficient for all the 15 characters related to fruit yield per plant are presented in Table 10. The perusal of the data in the above cited table indicated that, fruit yield per plant was significantly and positively correlated to leaf area (0.870), number of fruits per plant (0.857), fruit breadth (0.589), fruit weight (0.539), 100 seed weight (0.545), fruit length (0.490), number of seeds per fruit (0.472) and other characters like vine length (0.345), number of primary branches per plant (0.262), node number bearing first female flower (0.025), days to opening of first male flower (0.037) and days to opening of first female flower (0.176) were positively associated with fruit yield per plant with insignificant values. On the other hand, this character was negatively correlated with seed/flesh ratio (-0.414) and days to first harvest (-0.180) having significant value only with the former character.

Vine length was significantly and positively correlated with number of primary branches per plant (0.665), days to opening first male flower (0.659), fruit length (0.630), leaf area (0.426) and number of fruits per plant (0.491) while negatively and significantly correlated with seed/flesh ratio (-0.446). Rest of the characters like, node number bearing first female flower (0.066), days to opening first female flower (0.289), fruit breadth (0.206), number of seeds per fruit (0.026) and yield per plant (0.345) were positively and days to first harvest (-0.075), fruit weight(-0.076) and 100 seed weight (-0.103) were negatively associated with insignificant values.

Number of primary branches per plant exhibited significant positive association with days to opening of first female flower (0.635) and fruit length (0.497). Characters like days to opening of first male flower (0.391), leaf area (0.161), days to first harvest (0.104), number of fruits per plant (0.349), fruit breadth (0.082), 100 seed weight (0.005) and yield per plant (0.262) were positively correlated and node number bearing first female flower (-0.155), fruit weight (-0.215), number of seeds per fruit (-0.257) and seed/flesh ratio (-0.358) were negatively correlated with this character.

Node number bearing first female flower was positively correlated with days to opening of first male flower (0.065), number of fruits per plant (0.105), fruit length (0.172), seed/flesh ratio (0.108) and fruit yield per plant (0.025) and negatively associated with days to opening of first female flower (-0.157), leaf area (-0.243), days to first harvest (-0.096), fruit weight (-0.248), fruit breadth (-0.094), number of seeds per fruit (-0.277) and 100 seed weight (-0.330). However, in all these cases the associations were not significant.

Days to opening of first male flower was positively correlated with days to opening of first female flower (0.410), leaf area (0.157), days to first harvest (0.181), number of fruits per plant (0.010), fruit weight (0.028), fruit length (0.245), fruit breadth (0.008) and yield per plant (0.037) and negatively associated with number of seeds per fruit (-0.108), seed/flesh ratio (-0.312) and 100 seed weight (-0.123) having insignificant value in all combinations.

Days to opening of first female flower was strongly and positively correlated with days to first harvest (0.643). Rest of the characters like leaf area (0.154), number of fruits per plant (0.214), fruit length (0.012), fruit breadth (0.103), 100 seed weight (0.041) and yield per plant (0.176) were positively correlated and fruit weight (-0.047), number of seeds per fruit (-0.202) and seed flesh ratio (-0.288) were negatively correlated with insignificant values.

There was significant and positive correlation of the character leaf area with number of fruits per plant (0.649), fruit weight (0.631), fruit length (0.473), fruit breadth (0.586), number of seeds per fruit (0.574), 100 seed weight (0.624) and yield per plant (0.870). Seed/flesh ratio (-0.522) was negatively and significantly associated with this character while days to first harvest (-0.004) was associated with this trait having insignificant value.

Days to first harvest showed a positive association with fruit breadth (0.136) and 100 seed weight (0.009) and a negative correlation with number of fruits per plant (-0.202), fruit weight (-0.067), fruit length (-0.040), number of seeds per fruit (-0.238), seed/flesh ratio (-0.279) and yield per plant (-0.180) but the association was not significant in all these cases.

Number of fruits per plant was significantly and positively correlated with fruit breadth (0.492) and yield per plant (0.857). It was positively correlated with fruit weight (0.055), fruit length (0.272), number of seeds per fruit (0.105) and 100 seed weight (0.230) and negatively correlated with seed/flesh ratio (-0.292) showing insignificant values.

Table 10. Genotypic correlation co-efficient (r_g) between all pairs of 15 quantitative characters in bitter gourd genotypes

Characters		BN	NNF	DMF	DFF	LA	DH	FN	FW	FL	FB	SN	SFR	SW	PY
VL	r_g	0.665^{**}	0.066	0.659^{**}	0.289	0.426^{*}	-0.075	0.491^{*}	-0.076	0.630^{**}	0.206	0.026	-0.446^{*}	-0.103	0.345
BN	r_g		-0.155	0.391	0.635^{**}	0.161	0.104	0.349	-0.215	0.497^{*}	0.082	-0.257	-0.358	0.005	0.262
NNF	r_g			0.065	-0.157	-0.243	-0.096	0.105	-0.248	0.172	-0.094	-0.277	0.108	-0.330	0.025
DMF	r_g				0.410	0.157	0.181	0.010	0.028	0.245	0.008	-0.108	-0.312	-0.123	0.037
DFF	r_g					0.154	0.643^{**}	0.214	-0.047	0.012	0.103	-0.202	-0.288	0.041	0.176
LA	r_g						-0.004	0.649^{**}	0.631^{**}	0.473^{*}	0.586^{**}	0.574^{**}	-0.522^{*}	0.624^{**}	0.870^{**}
DH	r_g							-0.202	-0.067	-0.040	0.136	-0.238	-0.279	0.009	-0.180
FN	r_g								0.055	0.272	0.492^{*}	0.105	-0.292	0.230	0.857^{**}
FW	r_g									0.467^{*}	0.099	0.734^{**}	-0.408	0.616^{**}	0.539^{**}
FL	r_g										0.076	0.391	-0.479^{*}	0.286	0.490^{*}
FB	r_g											0.134	-0.162	0.231	0.589^{**}
SN	r_g												-0.058	0.593^{**}	0.472^{*}
SFR	r_g													0.001	-0.414^{*}
SW	r_g														0.545^{**}

*and ** indicates significant at 5% and 1% level respectively

Fruit weight was significantly and positively correlated with fruit length (0.467), number of seeds per fruit (0.734), 100 seed weight (0.616) and yield per plant (0.539). Further, fruit breadth (0.099) was positively and seed/flesh ratio (-0.408) was negatively correlated with this character having insignificant values.

Fruit length was positively correlated with yield per plant (0.490) and negatively correlated with seed/flesh ratio (-0.479). In both these cases significant association was visualized. On the other hand, fruit breadth, number of seeds per fruit and 100 seed weight though exhibited positive association with this trait, but their association was not significant.

Fruit breadth was strongly and positively correlated with yield per plant (0.589). Number of seeds per fruit (0.134) and 100 seed weight (0.231) were positively correlated and seed/flesh ratio (-0.162) was negatively associated with this character. However, the association in all these cases was insignificant.

Number of seeds per fruit was significantly and positively correlated with 100 seed weight (0.593) and yield per plant (0.472). Further seed/flesh ratio (-0.058) was negatively and insignificantly associated with this character.

Seed/flesh ratio was positively and insignificantly correlated with 100 seed weight (0.001) and negatively and significantly correlated with yield per plant (-0.414).

4.5 Path co-efficient analysis

In order to find out the cause and effect relationship on yield per plant, path co-efficient analysis was carried out taking 15 quantitative traits in bitter gourd. The genotypic correlation of fruit yield per plant with other characters (Table-10) were partitioned into component of direct and indirect effects that would reflect on the nature of these association and relative importance of the components in determining fruit yield.

The path analysis based on genotypic correlation (Table-11) revealed that fruit number had the highest positive direct effect (0.921) on yield per plant followed by leaf area (0.815), number of primary branches per plant (0.777) and days to opening of first male flower (0.724) in order. Further, positive direct effects were also observed for number of seeds per fruit (0.461), fruit length (0.390), seed/flesh ratio (0.124), node number bearing first female flower (0.100), days to first harvest (0.071) and fruit breadth (0.017) having moderate to low value. Rest of the characters showed negative direct effect being highest in vine length (-1.614) followed by followed by 100 seed weight (-0.506), days to opening of first female flower (-0.364) and fruit weight (-0.148).

Number of fruits per plant had the highest positive direct effect (0.921) on yield per plant. This highest direct effect were mainly resulted by positive indirect effect via number of primary branches per plant (0.271), node number bearing first female flower (0.010), days to opening of first male flower (0.007), leaf area (0.529), fruit length (0.106), fruit breadth (0.008) and number of seeds per fruit (0.048). The indirect effect of number of fruits per plant via vine length (-0.792), days to opening of first female flower (-0.077), days to first harvest (-0.014), fruit weight (-0.001), seed/flesh ratio (0.015) and 100 seed weight (-0.116) were in negative direction.

Leaf area showed high positive direct effect (0.815) which was mainly contributed by indirect positive via number of primary branches per plant (0.125), days to opening of first male flower (0.114), number of fruits per plant (0.598), fruit length (0.184), fruit breadth (0.010) and number of seeds per fruit (0.264). The indirect effect of fruit length was in negative direction via vine length (-0.687), node at which first female flower appeared (-0.024), days to opening of first female flower (-0.056), days to first harvest (-0.001), fruit weight (-0.093), seed/flesh ratio (-0.064) and 100 seed weight (-0.316).

Number of primary branches per plant showing positive direct effect (0.777) exhibited indirect positive effect via days to opening of first male flower (0.283), leaf area

(0.131), days to first harvest (0.007), number of fruits per plant (0.321), fruit weight (0.031), fruit length (0.194) and fruit breadth (0.001) while for rest of the characters like vine length (-1.074), node at which first female flower appeared (-0.015), days to opening of first female flower (-0.231), number of seeds per fruit (-0.118), seed/flesh ratio (-0.044) and 100 seed weight (-0.002) the effect was on negative direction.

Other characters such as days to opening of first male flower (0.724), number of seeds per fruit (0.461), fruit length (0.390) and seed/flesh ratio (0.124) showed positive direct effect being lowest in fruit breadth (0.017). The lowest positive direct effect for fruit breadth was due to negative indirect effect via vine length (-0.332), node number bearing first female flower (-0.009), days to opening of first female flower (-0.037), fruit weight (-0.014), seed/flesh ratio (-0.020) and 100 seed weight (-0.117), in spite of positive indirect effect via other traits for this character.

Vine length showed the highest negative direct effect (-1.614). The indirect effect of vine length via days to opening of first female flower (-0.105), days to first harvest (-0.005), seed/flesh ratio (-0.055), in spite of positive indirect effects via number of primary branches per plant (0.516), node at which first female flower appeared (0.006), days to opening of first male flower (0.477), leaf area (0.347), number of fruits per plant (0.452), fruit weight (0.011), fruit length (0.246), fruit breadth (0.003), number of seeds per fruit (0.012) and 100 seed weight (0.052).

Characters like 100 seed weight, days to opening of first female flower and fruit weight showed negative direct effect mainly via fruit weight (-0.091) and days to opening of first male flower (-0.088), vine length (-0.466) and number of seeds per fruit (-0.093), 100 seed weight (-0.312) and number of primary branches per plant (-0.166) in spite of high positive indirect effect via leaf area (0.508), number of primary branches per plant (0.493) and leaf area (0.514) respectively.

From the path analysis, it may perused that number of fruits per plant, leaf area, number of primary branches per vine, days to opening of first male flower and number of seeds per fruit showed high direct effect on yield per plant in bitter gourd. High indirect effect through these characters were also visualized.

Table 11. Estimate of direct (diagonal) and indirect effect of component characters on yield in bitter gourd genotypes

Characters	VL	BN	NNF	DMF	DFF	LA	DH	FN	FW	FL	FB	SN	SFR	SW	Genotypic correlation with yield
VL	-1.614	0.516	0.006	0.477	-0.105	0.347	-0.005	0.452	0.011	0.246	0.003	0.012	-0.055	0.052	0.345
BN	-1.074	0.777	-0.015	0.283	-0.231	0.131	0.007	0.321	0.031	0.194	0.001	-0.118	-0.044	-0.002	0.262
NNF	-0.106	-0.120	0.100	0.046	0.057	-0.198	-0.006	0.096	0.036	0.067	-0.001	-0.127	0.013	0.167	0.025
DMF	-1.064	0.304	0.006	0.724	-0.149	0.128	0.012	0.009	-0.004	0.095	0.001	-0.049	-0.038	0.062	0.037
DFF	-0.466	0.493	-0.015	0.297	-0.364	0.125	0.045	0.197	0.006	0.004	0.001	-0.093	-0.035	-0.020	0.176
LA	-0.687	0.125	-0.024	0.114	-0.056	0.815	-0.001	0.598	-0.093	0.184	0.010	0.264	-0.064	-0.316	0.870
DH	0.121	0.080	-0.001	0.131	-0.234	-0.001	0.071	-0.185	0.009	-0.015	0.002	-0.109	-0.034	-0.004	0.180
FN	-0.792	0.271	0.010	0.007	-0.077	0.529	-0.014	0.921	-0.001	0.106	0.008	0.048	-0.036	-0.116	0.857
FW	0.122	-0.166	-0.025	0.020	0.017	0.514	-0.004	0.050	-0.148	0.182	0.001	0.338	-0.050	-0.312	0.539
FL	-1.018	0.386	0.017	0.177	-0.004	0.385	-0.002	0.250	-0.069	0.390	0.001	0.180	-0.059	-0.145	0.490
FB	-0.332	0.063	-0.009	0.005	-0.037	0.478	0.009	0.453	-0.014	0.029	0.017	0.061	-0.020	-0.117	0.589
SN	-0.042	-0.200	-0.027	-0.078	0.073	0.468	-0.017	0.096	-0.108	0.152	0.002	0.461	-0.007	-0.300	0.472
SFR	0.720	-0.278	0.010	-0.226	0.105	-0.425	-0.019	-0.268	0.060	-0.187	-0.001	-0.026	0.124	-0.001	-0.414
SW	0.166	0.001	-0.033	-0.088	-0.014	0.508	0.001	0.211	-0.091	0.111	0.004	0.273	0.001	-0.506	0.545

Residual effect = 0.3293

VL = Vine length LA =Leaf area DH = Days to first harvest NNF = Node at which 1st female flower appeared
BN = Branch number FN = No of fruits per plant FB = Fruit breadth DMF = Days to opening of 1st male flower
FW = Fruit weight SN =No of seeds per fruit SFR = Seed flesh ratio DFF = Days to opening of 1st female flower
SW =100 seed weight FL = Fruit length (Figures underlined denoted the Direct Effect)

This clearly indicated that number of fruits per plant and leaf area are two important yield contributing components in bitter gourd. Further, the correlation co-efficient (0.857) between number of fruits per plant, leaf area (0.870), (both causal factor) and fruit yield per plant (the effect) being positive and having a little difference with its direct effect (0.921) and (0.815) respectively explain the true relationship and thus the direct selection through number of fruits per plant and leaf area in bitter gourd improvement programme could be result oriented.

4.6 Multivariate analysis of genetic divergence

Simultaneous variation in all the characters of 23 genotypes were tested for assessing the nature of genetic divergence among them following D^2 analysis.

4.6.1 D^2 analysis

The D^2 values ranged from 48.82 between the varieties V_3 (Priya) and V_{23} (High Tech Meghana-2) to 959.70 between V_4 (Pusa Domousumi) and V_{11} (Thusi) indicating that some varieties are quite close to each other genetically while others are strongly diversed (Table 12). The genetic closeness between the varieties V_3 (Priya) and V_{23} (High Tech Meghana-2) was apparently due to their closeness in characters such as vine length (5.74m,4.43m), node number bearing first female flower (14.18,15.48), 100 seed weight (19.82g,18.52g), number of primary branches per plant (11.44,12.44), fruit breadth (13.51cm,14.10cm), number of seeds per fruit (16.53,15.44), seed flesh ratio (0.034,0.037) (Table-6). On the other hand, the maximum distance between V_4 (Pusa Domousumi) and V_{11} (Thusi) could be attributed to large difference in number of primary branches per plant (7.77,13.77), days to opening first female flower (41.38days,49.04days), leaf area (85.77cm^2,47.04 cm^2), number of fruits per plant (8.10,23.20), fruit weight (109.40g,10.74g), fruit length (15.96cm,5.20cm), number of seeds per fruit (20.65,5.33). Other divergent combinations were V_{11} (Thusi) and V_{14} (Japani Green Kalara) (D^2 = 707.32) and V_8 (Phule Greengold) and V_{11} (Thusi) (D^2 = 703.10) and V_{11} (Thusi) and V_{17} (IIVR-5) (D^2 = 671.70); thus indicating Thusi as a genetically different entry.

Table 12. D^2 values between genotypes by recombination

	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}	V_{11}	V_{12}	V_{13}	V_{14}	V_{15}	V_{16}	V_{17}	V_{18}	V_{19}	V_{20}	V_{21}	V_{22}	V_{23}
V_1	285.4	215.2	462.5	131.3	266.2	230.5	336.9	221.6	168.8	237.0	230.0	237.2	364.4	222.7	158.4	329.1	153.5	138.0	180.9	206.9	111.3	268.0
V_2		465.7	563.9	501.5	160.1	308.7	383.7	331.9	488.5	508.2	368.2	305.8	341.9	494.7	468.4	597.9	416.4	410.2	555.6	283.8	371.2	495.1
V_3			255.0	234.7	391.6	244.8	199.9	185.5	190.0	612.8	92.96	261.7	233.2	121.9	99.89	205.4	126.9	258.5	382.9	152.5	123.1	48.8
V_4				380.0	291.4	434.4	414.9	434.9	504.4	959.7	278.5	404.9	227.6	293.5	296.6	330.8	306.5	511.8	612.0	434.6	453.0	226.2
V_5					352.4	314.9	442.1	300.7	158.5	304.4	303.0	341.3	422.5	239.8	163.0	305.2	134.0	162.0	220.9	340.4	182.1	237.4
V_6						278.5	395.6	394.4	387.6	451.3	263.3	199.8	242.4	433.7	320.8	427.6	256.1	304.2	369.1	246.6	374.3	444.7
V_7							162.5	105.6	391.1	422.5	121.0	83.04	130.4	154.8	136.9	176.6	200.6	392.6	380.9	99.0	115.7	227.7
V_8								87.74	358.5	703.1	79.59	118.1	90.10	113.2	199.5	254.4	257.5	412.7	484.1	128.7	188.5	155.5
V_9									298.8	453.0	134.4	141.0	134.2	65.59	195.1	287.1	191.6	402.7	421.9	114.8	71.4	124.8
V_{10}										331.3	216.2	384.7	415.1	289.5	237.0	441.0	106.7	134.1	215.8	252.9	184.9	267.8
V_{11}											505.7	377.6	707.3	606.6	429.9	671.7	285.9	197.7	130.3	403.8	336.7	665.7
V_{12}												73.35	92.30	118.2	81.69	156.3	101.0	255.3	301.3	61.5	124.6	113.9
V_{13}													96.86	174.6	165.4	250.4	135.8	301.0	248.4	69.6	155.0	254.1
V_{14}														152.3	233.3	284.0	225.5	470.5	501.8	161.9	251.8	170.6
V_{15}															113.6	179.9	166.4	356.2	355.1	170.4	81.8	61.4
V_{16}																49.17	109.7	206.1	255.5	131.5	95.4	131.9
V_{17}																	267.5	415.9	472.1	235.0	211.7	229.5
V_{18}																		136.8	138.0	120.7	104.0	144.3
V_{19}																			97.4	270.1	232.8	325.8
V_{20}																				290.1	240.1	410.9
V_{21}																					82.6	199.8
V_{22}																						136.3

V_{16} (IIVR-4) and V_{17} (IIVR-5) ($D^2 = 49.17$) and V_{23} (High Tech Meghana-2) and V_{16} (IIVR-2) ($D^2 = 61.41$) are the genetically close combinations among the genotypes evaluated.

4.6.2 Clustering pattern and geographic origin

Twenty-three genotypes were grouped into seven different genetic clusters on the basis of genetic affinity/diversity as measured by D^2 using Tocher's method (Table 13). The cluster I comprised of three genotypes such as V_1 (Green Long), V_3 (Priya) and V_{23} (High Tech Meghana-2). The cluster II comprised of two varieties such as V_{16} (IIVR-4) and V_{17} (IIVR-5) while cluster III comprises of three varieties, V_2 (Arka Harit), V_{12} (NBR Noble Katahi) and V_{21} (Hirkani). V_9 (Meghana-1) and V_{15} (IIVR-2) belong to cluster IV, V_7 (CO-1) and V_{13} (Improved Katahi) belong to cluster V. The cluster VI comprised of three genotypes namely V_4 (Pusa Domousumi), V_8 (Phule Greengold) and V_{14} (Japani Green Kalara) while cluster VII being the largest group comprised of eight varieties such as V_5 (Pusa Vishesh), V_6 (Pusa Asudhi), V_{10} (Peta Kalara), V_{11} (Thusi), V_{18} (NDUAT-3), V_{19} (Nakhara Local), V_{20} (BBG-5) and V_{22} (Samanta Goberta Green Long All Season).

From the above clustering pattern it was observed that genotypes collected from (Table-13) same locality (Geographical origin), has also been clustered in different groups. For example, IIVR-2, IIVR-4 and IIVR-5 collected from IIVR, Varanasi has been clustered under two clusters such as cluster II and cluster IV. Similarly the genotypes from different origin (locality) such as Green Long, Priya and High Tech Meghana-2 collected from Hyderabad (Andhra Pradesh), Kerala (KAU) and Cuttack (Odisha) respectively has been grouped in cluster I. from the above result it appears that there was no correspondence between clustering pattern and geographic origin, rather there was fair correspondence between genetic diversity and morphological diversity.

Table 13. Clustering Pattern of 23 bitter gourd genotypes

Cluster No.	Number of genotypes included in the cluster	Name of Genotypes	Source of collection (Place)
I	3	GREEN LONG(V_1)	Hyderabad, Andhra Pradesh
		PRIYA(V_3)	KAU, Kerala
		HIGH TECH MEGHANA-2(V_{23})	Cuttack, Odisha
II	2	IIVR-4(V_{16}),IIVR-5(V_{17})	IIVR, Varanasi
III	3	ARKA HARIT(V_2)	IIHR, Bangalore
		NBR NOBLE KATAHI(V_{12})	Nobel Seeds, Karnataka
		HIRKANI(V_{21})	MPKV, Rahuri
IV	2	MEGHANA-1(V_9)	Kumar Seeds, Odisha
		IIVR-2(V_{15})	IIVR, Varanasi
V	2	CO-1(V_7)	TNAU, Coimbatore
		IMPROVED KATAHI(V_{13})	Nobel Seeds, Karnataka
VI	3	PUSA DOMOUSMI(V_4)	IARI, New Delhi
		PHULE GREEN GOLD(V_8)	MPKV, Rahuri
		JAPANI GREEN KALARA(V_{14})	Amtala Hitech, West Bengal
VII	8	PUSA VISHESH(V_5), PUSA ASUDHI(V_6)	IARI, New Delhi
		PETA KALARA(V_{10}),THUSI(V_{11}), NAKHARA LOCAL(V_{19}), BBG-5(V_{20}), SAMANTA GOBERTA GREEN LONG ALL SEASON(V_{22})	Local collection, Odisha
		NDUAT-3(V_{18})	NDUAT, Faizabad

4.6.3 Intra and inter-cluster distances

From the average intra and inter cluster distance presented in Table-14, it is evident that among the clusters, Cluster II had the minimum intra-cluster distance (D^2 = 49.174) whereas maximum intra-cluster distance (D^2 = 244.255) was observed in Cluster VI.

The average inter-cluster distance revealed that the most divergent clusters were Cluster VI and VII (D^2 = 437.461), followed by Cluster IV and VII (D^2 = 322.148) and Cluster II and VII (D^2 = 314.431) and Cluster III and VII (D^2 = 312.473).

4.6.4 Characteristic features of the clusters

The cluster means of fifteen quantitative characters for groups of bitter gourd genotypes are presented in Table 15.

Cluster I consisting of three genotypes exhibited the maximum value for days to opening of first male flower (44.379 days) and minimum value for number of fruits per plant (15.119). Rest of the characters have shown moderate expressions.

Cluster II having two genotypes was characterized for its highest values for characters like vine length (7.130m), number of primary branches per vine (15.995) and fruit length (25.050 cm) while fruit breadth (9.170 cm) and seed flesh ratio (0.038) were the lowest.

Cluster III consisting of three genotypes had the distinction of having the lowest values for characters such as node at which first female flower appeared (17.842) and days to opening of first male flower (36.777 days) while seed/flesh ratio (0.119) was the highest.

Cluster IV comprising of two genotypes had maximum values for most of the characters like days to opening first female flower (56.980 days), leaf area (106.732 cm^2), days to first harvest (70.545 days), fruit breadth (14.180 cm) and yield per plant (2176.315g) respectively.

Table 14. Intra Diagonal and Inter cluster average (D^2) corresponding D ($\sqrt{D^2}$) Values (in parenthesis) among groups

Cluster	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
I	177.359 (13.318)	192.738 (13.883)	249.181 (15.785)	156.367 (12.505)	242.734 (15.580)	267.180 (16.346)	264.197 (16.254)
II		49.174 (7.012)	278.507 (16.689)	193.942 (13.926)	182.404 (13.506)	266.489 (16.324)	314.431 (17.732)
III			237.873 (15.423)	227.467 (15.082)	162.942 (12.765)	273.934 (16.551)	312.473 (17.677)
IV				65.593 (8.099)	144.043 (12.002)	202.673 (14.236)	322.148 (17.948)
V					83.047 (9.113)	224.571 (14.986)	283.822 (16.847)
VI						244.255 (15.629)	437.461 (20.916)
VII							233.251 (15.273)

Table 15. Mean of 15 characters in different clusters of bitter gourd genotypes

Clusters **Characters**	**I** **(3)**	**II** **(2)**	**III** **(3)**	**IV** **(2)**	**V** **(2)**	**VI** **(3)**	**VII** **(8)**
VL	5.182	7.130**	4.427	3.938	4.902	3.188*	3.361
BN	11.662	15.995**	11.756	11.497	10.608	9.773*	11.258
NNF	18.684	21.265	17.842*	20.333	20.220	21.653**	20.035
DMF	44.379**	40.847	36.777*	38.613	37.878	37.830	37.843
DFF	52.316	51.735	43.164	56.980**	44.807	42.044*	49.269
LA	92.547	90.647	88.387	106.732**	94.742	97.609	63.870*
DH	63.310	59.697	57.280	70.545**	52.833*	54.153	66.133
FN	15.119*	24.610	20.220	32.608	34.917**	21.807	15.734
FW	68.554	61.567	54.266	75.493	56.673	89.189**	44.122*
FL	12.711	25.050**	12.929	13.333	15.143	16.126	10.411*
FB	12.440	9.170*	13.794	14.180**	12.387	12.023	9.149
SN	14.952	15.203	16.794	17.440	13.553	18.069**	12.419*
SFR	0.072	0.038*	0.119**	0.067	0.073	0.060	0.087
SW	18.944	17.267	17.840	18.967	19.102**	18.51*	15.546*
PY	1024.092	1415.115	1073.656	2176.315**	1941.272	1699.548	587.744*

* and ** indicate lowest and highest values respectively
figures in the parenthesis indicate number of cultivars in a cluster.

Cluster V also having two germplasm was characterized by its highest value with respect to the traits like number of fruits per plant (34.917) and 100 seed weight (19.102g) and lowest value for days to first harvest (52.833days).

Cluster VI consisting of three germplasm exhibited highest value for node number bearing first female flower (21.653), fruit weight (89.189g) and number of seeds per fruit (18.069) while lowest value was also exhibited for vine length (3.188m), number of branches per vine (9.773), days to opening of first female flower (42.044 days) and 100 seed weight (18.51g).

Cluster VII comprising of eight genotypes was characterized by its lowest values for leaf area (63.870 cm^2), fruit weight (44.122g), fruit length (10.411cm), number of seeds per fruit (12.419), 100 seed weight (15.546g) and yield per plant (587.744g).

4.6.5 Relative contribution of characters to divergence

The relative contribution of 15 quantitative traits to genetic divergence among the 23 genotypes of bitter gourd was assessed by rank average of individual character over all 253 paired combinations and presented in Table-16.

Table 16. Relative contribution to different characters to genetic divergence in bitter gourd genotypes

Sl. No.	Characters	No. of first rank	% Contribution
1.	Vine length (m)	0	0.000
2.	Number of primary branches per plant	0	0.000
3.	Node no bearing 1st female flower	1	0.395
4.	Days to opening of 1st male flower	1	0.395
5.	Days to opening 1st female flower	7	2.766
6.	Leaf area(cm^2)	5	1.976
7.	Days to 1st harvest	2	0.790
8.	Number of fruits per plant	15	5.928
9.	Fruit weight(g)	43	16.996
10.	Fruit length(cm)	18	7.114
11.	Fruit breadth(cm)	16	6.324
12.	Number of seeds per fruit	11	4.347
13.	Seed flesh ratio	57	22.529
14.	100 seed weight(g)	24	9.486
15.	Yield per plant	53	20.946
Total		253	100

The character contributing maximum divergence needs greater emphasis for deciding on the cluster for the purpose of selection of parents in respective cluster for hybridization. The number of times, each of the component character appeared first in rank and its respective percent of contribute on towards genetic divergence was analyzed.

The perusal of data in Table-16 revealed that among the yield contributing characters, the maximum contribution towards divergence was made by seed/flesh ratio (22.529%) followed by yield per plant (20.946%) and fruit weight (16.996%). Rest of the characters contributing towards divergence were 100 seed weight (9.486%), fruit length (7.114%), fruit breadth (6.324%), number of fruits per plant (5.928%), number of seeds per fruit (4.347%), days to opening of first female flower (2.766%), leaf area (1.976%), days to first harvest (0.790%) and node number bearing first female flower and days to opening of first male flower each having (0.395%) in order. Further, seed/flesh ratio followed by yield per plant and fruit weight occupied first rank 57, 53 and 43 times respectively among the 253 paired characters taken for study.

◆

DISCUSSION

In any crop improvement programme, practical application of breeding methodology and its success depends on the amount and nature of genetic variability existed in the base population that is evaluated for improvement. Adequate variation among genotypes/varieties and the mode of inheritance of character analysed on per se performance of the progeny are basis to success in any crop improvement programme. Yield of any crop is a complex character and is manifested in superior expression of its components. Considering the importance of these factors for improvement in bitter gourd, an experiment was laid out during the kharif season of 2014 at Department of Vegetable Science, OUAT, Bhubaneswar to select the superior genotypes in order to improve their productivity and adaptability under Odisha (Bhubaneswar) condition. The experimental findings of the above studies are presented in foregoing chapters have shown some outstanding results which have been discussed here after.

5.1 Pattern of variation in plant attributes

It is established that yield is the most economic character in any crop. Other supporting characters influencing yield and yield itself are governed by polygenes which are quantitatively inherited (Hayes, Immer and Smith, 1955). Further, in any improvement programme selection based on phenotypic observations (visual/ measured), their reflection on genotypic value may not hold good unless the observations on the quantitative characters are subjected and interpreted according to statistical procedures, since the ultimate effect yield is much influenced by the environmental factors where the crop is grown . Therefore, in addition to calculating ANOVA, the genetic parameters like mean, range and variances for different traits in bitter gourd have been computed to draw a valid inference on the genotypes evaluated in the present study.

An examination of ANOVA (Table-5), the nature and magnitude of variability for 15 different quantitative characters can be clearly understood in bitter gourd. The values indicated highly significant differences for all the characters under study, thereby suggesting existence of great amount of variation among the genotypes. So, there is a scope for considerable improvement in the crop through the characters studies such as vine length, number of primary branches per plant, node number bearing first female flower, days to opening of first male flower, days to opening of first female flower, leaf area, days to first harvest, number of fruits per plant, fruit weight, fruit length, fruit breadth, number of seeds per fruit, seed/flesh ratio, 100 seed weight and yield per plant. Similar to the present findings, significant differences for various characters was reported by Ram *et al*. (2006), Agasimani *et al*. (2008), Yadav *et al*. (2008), Islam *et al*. (2009), Gupta *et al*. (2013), Yadav *et al*. (2013), Pathak *et al*. (2014), Singh *et al*. (2014) and Singh *et al*. (2015) in bitter gourd; Pandit *et al*. (2009) in bottle gourd; Akter *et al*. (2013) in pumpkin; Dubey *et al*. (2013) in ridge gourd; Kumar *et al*. (2013) in sponge gourd and Munawar *et al*. (2015) in tinda gourd.

It may be generalized from the statistics of range, mean and general mean values of the character that there is a great deal of variability for each character under study. Further, the magnitude of wide spectrum of variation as visualized in each character suggests a better opportunity of selecting genotypes for specific goals.

Among the genotypes IIVR-5 produced longest vine while Pusa Vishesh was identified as dwarf genotype. Similarly, highest number of primary branches produced by IIVR-5 while Pusa Domousumi produced lowest number of primary branches having vine length of lower side. Thus in bitter gourd, genotypes producing longer vines also produced more number of branches per vine.

Considering the flowering behavior and harvesting such as node number bearing first female flower, days to opening of first male flower, days to opening of first female flower and days to first harvest, more or less parallelism effect has been noticed for these characters indicating that there characters are much more interdependent and interrelated.

With regards to different direct contributes of yield such as number of fruits per plant, fruit weight, fruit size (length and breadth), number of seeds per fruit and seed weight from the phenotypic mean values, it may be generalized that the variations observed are high in magnitude within among the genotypes. Further, a direct relationship between fruit size with fruit weight and an inverse relationship between fruit number and fruit weight with some slight deviations has been observed. Further, the genotypes having medium fruit size, more number of fruit per vine, more number of 100 seed weight, a medium number of seed/ flesh ratio and more number of seeds per fruit are high yielders showing a happy indication of synergistic effect with a very favourable disposition for selection. Instead of being competitive, the compatible association of these characters as evident in the genotypes may be explained due to their further association with other yield attributing characters like growth habit (plant vigour), branching nature, flowering behavior, leaf area and days to first harvest. Considering all these characters together, the genotypes showing high to moderate value for most of the yield attributing characters producing higher yield in the long run in order of merit are CO-1, Phule Greengold, IIVR-2, Meghana-1 and Japani Green Kalara are suitable to be grown in Bhubaneswar condition.

Two aspects are most important for understanding the breeding principles i.e. (i) selection cannot create variability but act only on that which is already in existence, (ii) selection can act effectively only on heritable differences (Allard, 1960).Thus it is a prime requisite for selection is to ascertain whether genetic variability is present at significant level or not in the evaluated population. Further, the phenotypic mean values are the basis of comparison may fall far short of requirement and may even be misleading as the phenotypic effect sometimes influenced by the environment, thereby may not necessarily represent the genotypic values. To avoid this confusion for correct interpretation of data on a logistic genetic principle, statistics such as variance and co-efficient of variation etc. need to be computed for drawing valid inference. Estimate of genetic parameters such as phenotypic and genotypic variance along with their co-efficient of variation as suggested by Burton and Devance (1953) afford a sound basis to assess the variability components so as to know the relative amount of heritable and non-heritable variation for each of these characters.

From the present investigation, it is clearly observed that there lies a wide range of phenotypic as well as genotypic variation (variance) for all the 15 quantitative characters studied in bitter gourd (Table-7). The interpretation of minimum variation between these two parameters in most of the characters indicated that environment has little effect in expression of this character and phenotype truly represents the genotype. The existence of large genotypic variability for the characters like yield per plant, fruit weight, leaf area, number of fruits per plant, days to first harvest etc. indicated that major part of these characters are attributed through its additive interaction instead of dominance and epistatic component and usually favours an effective selection. The present findings are in agreement with findings reported earlier by Agasimani *et al.* (2008) for fruit yield and number of fruits per vine, Islam *et al.* (2009) for fruit weight, Singh *et al*. (2014) for most of the characters studied in bitter gourd; Khule *et al*. (2011) for number of fruits per plant, fruit weight and yield per plant in sponge gourd and Kumar *et al*. (2013) for yield per vine and fruit weight in sponge gourd.

In comparing the phenotypic coefficient of variation with genotypic coefficient of variation (Table-8), it is observed that in general, the former values are greater than the later in respect of all the quantitative characters studied. Further, the differences between these two values are quite less in most of the characters suggesting a negligible influence of environment on such characters. Bhave *et al*. (2003), Narayan *et al*. (2006), Raja *et al*. (2007) and Yadav *et al*. (2013) in bitter gourd reported similar trend of variation for genotypic coefficient of variation and phenotypic coefficient of variation of various characters studied which is in conformity with the present findings. Further, phenotypic coefficient of variation showing parallelism effect with the genotypic coefficient of variation indicated that phenotypes truly represent the genotypes. In the present investigation presence of high to moderate genotypic coefficient of variation for seed/ flesh ratio, yield per plant, number of fruits per plant, fruit weight, fruit length and fruit breadth indicating the presence of good amount of variability among the genotypes evaluated, so selection for these characters will be beneficial in bitter gourd improvement programme. In agreement with the present findings, higher genotypic coefficient of variation as well as phenotypic coefficient of variation was reported by Mangal *et al*. (1983) for yield, number of fruits per vine and fruit weight, Islam *et al*. (2009) for number of fruits per plant and fruit weight, Chakroborty *et al*. (2013) for fruit yield, fruit weight, fruit length, number of fruits per vine and Pathak *et al*. (2014) for number of fruits per vine, fruit weight and fruit length in bitter gourd; Pandey *et al*. (2009) for fruit weight and yield per plant in snap melon; Akter *et al*. (2013) for yield per plant in pumpkin; Jat *et al*. (2014) for fruit weight and yield per vine in cucumber.

The index of transmissibility of a character interpreted by heritability is of interest to a plant breeder primarily as a measure of selection for a particular character in various type of progenies. A character not influenced by environment will have high heritability (Poehlman and Borthakur, 1972). Further, Randhawa *et al*. (1975) suggested that higher the heritability value of a character, less will be the environmental influence thereby, indicating better opportunity for selecting a genetically ideal individual. In the present investigation, very high heritability (above 85%) in broad sense has been recorded in eight characters such as fruit weight, seed/flesh ratio, leaf area, number of fruits per plant, fruit length, fruit breadth, yield per plant and days to opening of first female flower, suggesting that these characters might be highly heritable and less influenced by environment and selecting the genotypes basing on such characters could be worthwhile. Results obtained here in agreement with the findings of Srivastava and Srivastava (1976) for number of fruits per plant, Mangal *et al*. (1983) for yield, number of fruits and fruit weight, Narayan *et al*. (2006) for fruit length, number of fruits per plant and yield per plant, Islam *et al*. (2009) for days to first female flowering, Dalamu and Behera (2013) for number of fruits per plant and fruit weight, Chakraborty *et al*. (2013) for fruit yield per plant, Gupta *et al*. (2013) for fruit size, Yadav *et al*. (2013) for fruit length, days to opening of first female flower, fruit numbers per vine, Pathak *et al*. (2014) for fruit weight, fruit length, number of fruits per plant and Singh *et al*. (2015) for number of fruits per plant in bitter gourd; Sanwal *et al*. (2007) for fruit yield in sweet gourd; Dubey *et al*. (2013)for fruit weight in ridge gourd and Chodhury *et al*. (2014) for fruit length in ridge gourd; Jat *et al*. (2014) for fruit weight in cucumber; Muralidhar *et al*. (2014) for days to opening of first female flower, fruit weight in pumpkin; Munawar *et al*. (2015) for leaf area, fruit length, fruit number, fruit weight and fruit yield per plant in tinda gourd.

According to Weber and Moorthy (1952), information concerning heritability of quantitative characters, genetic and environmental variances when considered together will be helpful for improving efficiency of the selection. In the present investigation, comparing the heritability estimated with genotypic coefficient of variation values (Table-8), high values are obtained for both the parameters for seed/ flesh ratio, number of fruits per plant, yield per plant, fruit weight, fruit length and vine length. So selection may be quite effective based on these characters in bitter gourd. High coefficient of variation and heritability was reported for vine length, fruit length and yield per plant by Dubey *et al*. (2013) in ridge gourd, which is in accordance with the present findings.

In spite of importance of heritability estimate in crop improvement programme involving selection, the scope is limited due to its broad sense estimation as well as their prone to change with change in environment and the tested material. Further, the heritability estimate by itself may not be solely and useful index of genetic potentiality of a character. According to Eswro *et al*. (1963) genetic advance indicate the potentiality of selection at a particular level of selection intensity. Thus, heritability estimate along with its genetic advance are more reliable than heritability alone in predicting the response to selection (Johnshon *et al*., 1955; Robinson, 1963). It is an established fact that, high heritability will not show high genetic advance for a particular character under selection. But in cases where such compatible association exists (high heritability and high genetic advance), additive genes come into prominence, because no genetic advance is due to non additive genes. A selection based on a character showing high genetic advance may desirable particularly in case of directional selection when the main aim of selection is to change the mean value of a character to have better standards. On the other hand, high heritability accompanied with low genetic advance indicates the prominence of non additive gene effect, suggesting heterosis breeding instead of direct selection. In the present investigation, high heritability coupled with high genetic advance for characters such as yield per plant, fruit weight, leaf area, number of fruits per plant, days to first harvest may be ascribed due to additive genes (Panse and Sukhatme, 1954; Liang and walter, 1968) and may become favourable for selection. Similar to the present findings high heritability along with high genetic advance was reported by Raja *et al*. (2007) for fruit weight and yield per plant, Chakraborty *et al*. (2013) for fruit yield, Gupta *et al*. (2013) for fruit weight, Yadav *et al*. (2013) for number of fruits per vine, Pathak *et al*. (2014) for fruit weight and number of fruits per plant, Singh *et al*. (2015) for number of fruits per plant and fruit yield per plant in bitter gourd; Sanwal *et al*. (2007) for fruit yield in sweet gourd; Veena *et al*. (2012) for days to first harvest, number of fruits per plant in cucumber; Devi and Mariappan (2013) for fruit yield and number of fruits per plant in snake gourd and Basavrajeswari *et al*. (2014) for number of fruits per plant and fruit yield in cucumber. Whatever deviations are observed in the present study from that of the previous worker may be interpreted due to difference in genetic material tested on different environmental conditions.

By taking a simultaneous study of three important genetic parameters such as genotypic coefficient of variation, heritability estimate and predicted genetic gain at a glance characters such as seed/flesh ratio, yield per plant, number of fruits per plant, fruit weight, fruit length and vine length showing higher values for the above three important genetic parameters suggesting additive gene action for expression of these characters. So, direct selection through these characters will be effective in improvement programme of bitter gourd. This is in conformity with the findings of previous workers as reported the higher value for this three genetic parameters by

Srivastava and Srivastava (1976) for number of fruits per plant, Mangal *et al*. (1983) for yield per plant, number of fruits per plant and fruit weight, Narayan *et al*. (2006) for fruit length, number of fruits per plant and fruit yield, Devmore *et al*. (2010) for fruit length, vine length and number of fruits per plant, Dalamu and Behera (2013) for number of fruits and fruit weight in bitter gourd; Akter *et al*. (2013) for yield per plant in sponge gourd and Veena *et al*. (2012) and Basavrajeswari *et al*. (2014) for number of fruits and fruit yield in cucumber.

5.2 Character association (Correlation study)

In bitter gourd, the fruit yield is most important character which is the ultimate effect of interaction of several quantitative characters that are highly susceptible to change in environment. Therefore, selection based on fruit yield alone may not be a very sound criterion for effective selection. It is established that various component characters that are directly and positively correlated with fruit yield often act as an useful indicator in selection. Hence, a sound knowledge of such association among yield and its components is of prime importance in planning a successful improvement programme in bitter gourd. Robinsons (1966) suggested that, correlation studies are helpful in choosing superior genotypes from phenotypic expressions. Therefore, after getting information on variability, heritability and genetic advance available in the present set of genotypes taken for study attempt, has been made to examine the interrelationship of these quantitative characters through correlation studies both at genotypic and phenotypic levels.

The perusal of results Table-9 and 10 of the present investigation showed that the genotypic correlation coefficient was of higher magnitude for most of valuable pairs than the phenotypic correlation coefficients suggesting that there is a strong inherent association between the various characters studied. Further genotypic correlation coefficient showing values parallel to that of phenotypic correlation coefficient, assuming that there is not much influence of environment in determining the association of these attributing characters with the fruit yield in bitter gourd which is probably due to a strong genetical make up of the evaluated genotypes.

According to Wigan and Mather (1942) and Spargue (1966), a strong positive association of character with yield may be attributed to linkage and pleiotropy. In the present study, significant positive correlation both at phenotypic and genotypic level were observed for fruit yield with leaf area, number of fruits per plant, fruit weight, fruit length and 100 seed weight. Further, leaf area is being significantly correlated with yield is also positively and significantly correlated with number of fruits per plant, fruit weight, fruit length, fruit breadth, number of seeds per fruit and 100 seed weight in both the levels. Similarly, number of fruits positively and significantly correlated with fruit breadth, fruit weight, fruit length and number of seeds per fruit. These associations suggested that selection for these component traits simultaneously will be effective in improving yield of bitter gourd. In case of other pair of character showing significant negative correlation as well as insignificant values either positive or negative at a phenotypic and genotypic level have least importance for effective selection based on these characters. Result of similar trend were also reported by Srivastava and Srivastava (1976), Mangal *et al.* (1983), Parhi *et al.* (1995), Rajput *et al.* (1996), Bhave *et al.* (2003), Dey *et al.* (2005), Ram *et al.* (2006), Kumar *et al.* (2008), Yadav *et al.* (2008), Islam *et al.* (2009), Singh *et al.* (2012), Chakravorty *et al.* (2013), Dalamu and Behera (2013), Radha Rani *et al.* (2014), Singh *et al.* (2014) and Singh *et al.* (2015) in bitter gourd; Sanwal *et al.* (2007) in sweet gourd; Pandey *et al.* (2009) in snap melon; Hossain *et al.* (2010) in cucumber; Resmi and Sreelathakumary (2012) in ash gourd; Choudhury *et al.* (2014) in ridge gourd and Rashid *et al.* (2014) in snake gourd.

From the above discussion on correlation it may be inferred that leaf area, number of fruits per plant, fruit weight, fruit length, 100 seed weight, vine length and number of seeds per fruit are the important correlated characters contributing towards fruit yield in bitter gourd and simultaneous improvement in these characters will be helpful in bitter gourd improvement programme.

5.3 Direct and indirect effects of characters

Correlation coefficient which measure the association between any two characters may not always give true comprehend picture in complex situation. The associations between any two characters which are measured do not exist by themselves alone but are part of complicated pathway in which other traits are also intermingled. The indirect associations become complex and important due to number of variables in the correlation study. Further, the mutual relationship among different characters which may be positive or negative make the situation complicated. In such situation, path coefficient analysis devised by Wright (1921), provides a better knowledge as it reveals direct and indirect causes of association and permits a critical examination of the specific courses acting to produce a given correlation and measure the relative importance of each casual factor. The cause and effect relationship with the values of correlation and path coefficient (direct and indirect effect) are presented in Table-11 for the components of yield at genotypic level in the present investigation are discussed below.

The genotypic path coefficient analysis revealed that number of fruits per plant, leaf area, number of primary branches per plant, days to opening of first male flower, number of seeds per fruit, fruit length, seed/ flesh ratio, node number bearing first female flower, days to first harvest and fruit breadth have shown positive direct effect on fruit yield having maximum in fruit number followed by leaf area, number of primary branches per plant, days to opening of first male flower, number of seeds per fruit and fruit length in descending order. On the other hand, maximum negative direct effect was observed in vine length followed by 100 seed weight, days to opening of first female flower and fruit weight in order. The characters showing low, positive or negative direct effect are resulted due to cancellation by their respective indirect effect via number of fruits per plant, leaf area, number of primary branches per plant, days to opening of first male flower, number of seeds per fruit and fruit length.

The indirect effect of fruit number via leaf area, number of primary branches per plant, node number bearing first female flower, days to opening of first male flower, fruit length, fruit breadth and number of seeds per fruit thus producing high positive direct effect for these characters. Similarly, leaf area, number of primary branches per plant, days to opening of first male flower, number of seeds per fruit and fruit length have the high direct effect via fruit number, number of fruits per plant and days to opening of first male flower, number of primary branches per plant, leaf area and number of seeds per fruit respectively. High positive direct effect of number of fruits per plant on fruit yield of bitter gourd as observed in present investigation was also reported by Sharma and Bhutani (2001), Bhave *et al*. (2003), Dey *et al*. (2005), Radha Rani *et al*. (2014) and Singh *et al*. (2015) in bitter gourd; Sanwal *et al*. (2007) in sweet gourd; Pandey *et al*. (2009) in snap melon; Hossain *et al*. (2010) in cucumber; Resmi and Sreelathakumary (2012) in ash gourd; Akter *et al*. (2013) in pumpkin; Dubey *et al*. (2013) and Chodhury *et al*. (2014) in ridge gourd; Janaranjani and Karthaswamy (2015) in bottle gourd.

Similarly, high positive direct effect of number of primary branches per plant and fruit length on yield as observed in present investigation was also reported by Dora *et al*. (2002) in bottle gourd and Hossain *et al*. (2010) in cucumber.

On the basis of foregoing discussion, it may be inferred that number of fruits per plant, leaf area, number of primary branches per plant, days to opening of first male flower, number of seeds per fruit and fruit length had considerable direct contribution towards fruit yield. High indirect effects through these traits were also observed. Further, out of the above mentioned six characters, number of fruits per plant, leaf area and fruit length showing significant positive correlation with fruit yield, direct selection for these characters could be beneficial for improvement in yield of bitter gourd.

5.4 Genetic divergence

The multivariate analysis based on Mahalonobis'D^2 statistics is being employed as a powerful tool for measuring the genetic divergence among the test genotypes (Nair and Gupta, 1971). Further, published reports of Ramanujan *et al*. (1974) have emphasized the merits of D^2 statistics for genetic grouping of germplasm. In the present study the genotype by multivariate techniques have shown some interesting results (Table-13) are discussed below.

It is an established phenomenon that hybrid derivatives from divergent parents are found to be promising because of complementary interaction of divergent genes in the parents. From the present investigation, cluster VI consisting of three genotypes and cluster VII consisting of eight genotypes are more divergent clusters. So, promising hybrid derivatives can be obtained by crossing parents of these two divergent groups. Further, Pusa Domousumi and Thusi are the two most genetically divergent genotypes and hybridization involving this two could be result oriented. Some promising results may also be obtained between Thusi and Japani Green Kalara, Thusi and IIVR-5, Thusi and Phule Greengold and Thusi and Samanta Goberta Green Long All Season. These genotypes are expected to produce heterotic hybrids and wide variation in segregating generations favouring selection of superior progeny.

The clustering pattern does not necessarily bear any relevance with geographically origin of the test genotypes observed in the present study. Such an observation is in conformity with the findings of Dey *et al*. (2007), Kundu *et al*. (2012), Resmi and Sreelathakumary (2012) and Singh *et al*. (2013) in bitter gourd.

It was also observed that characters like seed/ flesh ratio, yield per plant, fruit weight predominantly contribute towards genetic divergence. Further, 100 seed weight, fruit size (length and breadth), number of fruits per plant also contribute considerably towards genetic divergence in bitter gourd. So, selection of parents differing in above mentioned seven quantitative characters proved to be useful for heterosis breeding programme in bitter gourd. Sunderam (2008), Kundu *et al*. (2012), Singh *et al*. (2012), Singh *et al*. (2013) and Singh *et al*. (2015) reported distinct role of fruit weight, fruit yield and fruit length, fruit yield and 100 seed weight, fruit weight, number of fruits per plant and fruit weight and fruit weight and fruit length respectively contributing towards divergence in bitter gourd similar to our present findings.

SUMMARY AND CONCLUSION

6.1 Summary

During the course of present investigation entitled “Variability studies in Bitter gourd (*Momordica charantia* L.)” attempt was made to assess the comparative performance of genetic variability, character association, the cause and effect relationship to determine the direct and indirect contribution of various characters to the most economic character fruit yield through path analysis and genetic divergence among the genotypes by Mahalonobis’D^2 statistics, to select and formulate a suitable breeding programme for improvement in bitter gourd. 23 genotypes collected from different geographical locations were subjected to evaluation for 15 quantitative characters such as vine length, number of primary branches per plant, node number bearing first female flower, days to opening of first male flower, days to opening of first female flower, leaf area, days to first harvest, number of fruits per plant, fruit weight, fruit length, fruit breadth, number of seeds per fruit, seed/flesh ratio, 100 seed weight and yield per plant.

The results of the investigation are summarized below.

1. Analysis of variance indicated that 23 genotypes of bitter gourd under study differ significantly among themselves for all the 15 quantitative characters. Further, wide range of variation was noticed as revealed through statistics of mean, range and coefficient of variation suggesting considerable improvement achievable in this crop. However, some of the promising genotypes producing desirable values for yield and its attributes are CO-1, Phule Greengold, IIVR-2, Meghana-1 and Japani Green Kalara are in order of merit and suitable for growing in Odisha condition.
2. Closeness of phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) for most of the characters studied indicated that phenotype represents true to the genotypes. Expression of high to moderate GCV in characters like seed/ flesh ratio, yield per plant, number of fruits per plant, fruit

weight, fruit length and fruit breadth indicated good amount of genetic variability among the test genotypes. So, selection based on these characters will be useful.

3. High to very high heritability (above 85%) was recorded in eight characters such as fruit weight, seed/flesh ratio, leaf area, number of fruits per plant, fruit length, fruit breadth, yield per plant and days to opening of first female flower while moderate heritability was observed in rest of the characters being lowest in number of primary branches per plant (55.0%).

4. Highest genetic advance in percentage of mean was observed in seed/flesh ratio followed by yield per plant, number of fruits per plant, fruit weight, fruit length and vine length (above 60%) in order of merit. Lowest value for this parameter was recorded in days to opening of first male flower (13.939%). Rest of the characters showed moderate value (above 20%) for this genetic parameter.

5. Considering the heritability estimate and genetic advance together the characters like yield per plant, fruit weight, leaf area, number of fruits per plant and days to first harvest showing higher values for both the parameters may be due to additive gene effect. So, in bitter gourd selection based on these characters will be effective.

6. Further, reviewing the three important genetic parameter such as genotypic coefficient of variation, heritability estimate and genetic advance as percentage of mean all together at a glance phenotypic selection based on seed/flesh ratio, yield per plant, number of fruits per plant, fruit weight, fruit length and vine length may proved an effective criteria for direct selection (due to additive gene effect) and less influenced by environment. For rest of the characters showing high heritability and low genetic advance warrant heterosis breeding for improvement.

7. Genotypic correlation coefficient showing higher values than phenotypic correlation coefficient for most important valuable pairs of characters influencing fruit yield suggested that there is a strong inherent association between the various characters studied. The occurrence of significant positive correlation both at phenotypic and genotypic level for fruit yield with leaf area, number of fruits per

plant, fruit weight, fruit length and 100 seed weight; vine length with number of primary branches per plant, days to opening of first male flower and fruit length; days to opening of first female flower with days to first harvest; leaf area with number of fruits per plant, fruit weight, fruit length, fruit breadth, number of seeds per fruit and 100 seed weight; number of fruits per plant with fruit breadth; fruit weight with fruit length, number of seeds per fruit and 100 seed weight and number of seeds per fruit with 100 seed weight suggested that selection for these component trait simultaneously will be effective in improving the fruit yield in bitter gourd. Rest of the character combinations having negative and insignificant positive value offer least importance for effecting selection.

8. Path coefficient (genotypic path) analysis of various quantitative characters indicated that number of fruits per plant, leaf area, number of primary branches per plant, days to opening of first male flower, number of seeds per fruit and fruit length have high positive direct effect whereas vine length, 100 seed weight, days to opening of first female flower and fruit weight have direct negative effect on fruit yield of bitter gourd.

9. By using D^2 statistics and Tocher's method, the 23 genotypes were grouped into seven clusters. Cluster VII, the largest group consisting of eight number of germplasm. Then cluster I, III and VI are the second largest group consisting of three genotypes in each. Cluster II, cluster IV and cluster V are the smaller clusters consisting of two germplasm in each.The cluster VI and VII are the most divergent clusters. Pusa Domousumi and Thusi are the two most genetically divergent genotypes.

10. The clustering pattern in relation to the geographic origin of the test genotypes/ germplasm was found to be inconclusive.

11. The characters like seed/flesh ratio, yield per plant, fruit weight, 100 seed weight, fruit length and number of fruits per plant contribute considerably towards divergence being of higher magnitude (above 15%) in first three character.

6.2 Conclusion

From the findings of the present investigation, it may be concluded that besides direct selection for fruit yield, indirect selection through seed/flesh ratio, number of fruits per plant, fruit weight and vine length should be considered for further improvement in fruit yield of bitter gourd. Further, leaf area, number of fruits per plant, fruit weight, fruit length and 100 seed weight being significantly and positively correlated with yield, selection for these component traits simultaneously will be effective in improving the fruit yield in bitter gourd. The genotypes such as CO-1, Phule Greengold, IIVR-2, Meghana-1 and Japani Green Kalara are suitable for growing in Odisha condition. Among the genotypes Pusa Domousumi and Thusi are the two most genetically divergent types. The most divergent cluster VI consisting of three genotypes and cluster VII consisting of eight genotypes are the most divergent clusters and as expected may be utilized for heterosis breeding. The clustering pattern in relation to geographic origin of the test genotypes was found to be inconclusive. Seed/flesh ratio, yield per plant and fruit weight contributing maximum towards divergence depicted that special attention should be given to these characters while desiring any crop improvement programme in bitter gourd.

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