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GENETIC EVALUATION OF SPROUTING BROCCOLI HYBRIDS UNDER MID HILLS OF HIMACHAL PRADESH

THESIS

By

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(A-2010-30-57)

Submitted to

CHAUDHARY SARWAN KUMAR
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PALAMPUR – 176 062 (H.P.) INDIA

in

partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE IN AGRICULTURE
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CERTIFICATE – I

This is to certify that the thesis entitled **"Genetic evaluation of sprouting broccoli hybrids under mid hills of Himachal Pradesh"** submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Agriculture)** in the discipline of **Vegetable Science** of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur is a bonafide research work carried out by **Kumari Shiwani (A-2010-30-57)** daughter of **Shri Shashi Sukhwal** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

(Dr. Viveka Katoch)
Major Advisor

Place: Palampur
Dated: 11th September, 2012

CERTIFICATE- II

This is to certify that the thesis entitled **"Genetic evaluation of sprouting broccoli hybrids under mid hills of Himachal Pradesh"** submitted by **Kumari Shiwani (Admission No. A-2010-30-57)** daughter of **Shri Shashi Sukhwal** to the CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Master of Science (Agriculture)** in the discipline of **Vegetable Science** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Needless to say, error and omissions are mine

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LIST OF ABBREVIATIONS USED

Sr. No.	Abbreviation	Meaning
1	*et al.*	et alii (and other)
2	*i.e.*	Id (that is)
3	*viz.*	Vi delicet (namely)
4	IU	International Unit
5	L.	Linnaeus
6	var.	Variety
7	P	Page
8	Pp	Particular pages
9	^{0}C	Degree Celsius
10	%	Per cent
11	/	Per
12	mg	Milligram
13	G	Gram
14	Kg	Kilogram
15	Cm	Centimeter
16	cm^2	centimeter square
17	Mm	Millimeter
18	M	Meter
19	l	Liter
20	Fig.	Figure
21	df	degree of freedom
22	N	North
23	E	East
24	>	more than
25	<	less than

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ABSTRACT

The present investigation entitled “Genetic evaluation of sprouting broccoli hybrids under mid hills of Himachal Pradesh” was undertaken to assess the nature of genetic variability, association of various characters with marketable yield and their direct and indirect effects for effective selection under two different environments *viz*., environment I (*Rabi* 2010-11) and environment II (*Rabi* 2011-12). The experimental material comprising of sixteen genotypes of broccoli was evaluated in Randomized Complete Block Design with three replications and data were recorded on yield and other yield related characters. The data analysis was done as per standard statistical procedures. Sufficient genetic variability was observed for all the characters in environment I and environment II. Two genotypes namely, Altar and Green Magic were observed to be promising for marketable yield. Genotype CBH-1 was found to be early maturing. High heritability coupled with high genetic advance was observed for number of spears per plant, terminal head weight per plant, marketable yield per plant, weight of spears per plant and harvest index which indicated the predominance of additive gene action and phenotypic selection would be effective for improvement in the early generations. Based on correlation and path coefficient analysis, terminal head weight per plant, harvest index, gross weight per plant, head size index and leaf size with leaf stalk were observed to be the best selection parameters because of their high positive direct and indirect contributions towards marketable yield per plant.

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1. INTRODUCTION

Broccoli (*Brassica oleraceae* L. var. *italica* Plenck.) a member of family Brassicaceae is one of the most nutritious cole crop. It is native to Southern Europe and Mediterranean region, whereas Italy is thought to be primary centre of origin. The name broccoli has been derived from an Italian word “brocco” meaning, the young shoot. Broccoli heads are composed of number of immature floral buds (florets) and thick, fleshy flower stalks attached to the central plant axis which is collectively named as head.

In Italy, broccoli has been used as a vegetable from early times but did not become popular until its introduction into the USA by Italian immigrants in 1930 (Verma and Sharma 2000). The major broccoli growing areas are Italy, Northern Europe and cooler region of Far East. However, USA is the largest producer in the world.

Broccoli is known for its taste, flavour, medicinal and nutritive value especially with respect to vitamin A (2500 IU), vitamin C (113 IU), calcium (103 mg) and potassium (382 mg) per 100 g of edible portion (Tiwari 2010). Broccoli also contains the compound glucoraphanin, which can be processed into an anti-cancer compound sulphoraphane, a compound associated with reducing the risk of cancer (Aires *et al*. 2006). Broccoli has multiple uses, it can be served as salad, pickle, soup and vegetable. Considerable quantity of broccoli is utilized for processing mainly freezing.

In India, broccoli and cauliflower are cultivated over an area of 3,14,900 hectares with the production of 59,88,500 metric tonnes (Anonymous 2011). Broccoli is a cool season vegetable and its off season cultivation fetches lucrative remuneration to the growers during summer season in hills when it cannot be grown in plains due to prevailing high temperature. These days broccoli is highly preferred on an account of its nutrition and the crop is being sold at higher prices in comparison to other cole crops *viz.,* cabbage, cauliflower, knol-khol, kale and

brussel sprouts. Furthermore, hill farmers with small land holdings are benefited with sprouting type of broccoli as two to three harvestings can be taken.

For initial systematic breeding/improvement programme in any crop, it is essential to study variability present in the basic genetic material/germplasm. The improvement in any crop is proportional to the magnitude of genetic variability present in the germplasm (Dhankar and Dhankar 2002). Therefore, genetic restructuring of germplasm is the first step to identify the potential genotypes for use in breeding programme.

Most of the desirable traits are quantitative in nature and their expression is influenced by the environment. These traits exhibits continuous variation and are under the control of heritable and non-heritable factors (Fisher 1918). The response of selection depends upon the relative proportion of the heritable components in the continuous variation which is due to genotype while the non-heritable portion is mainly due to the environmental factors. Hence, it is essential to partition overall variability into heritable and non-heritable components with the help of genetic parameters namely, coefficient of variation, heritability and genetic advance.

Knowledge of correlation coefficients provide the degree and direction of relationship between yield and its components but they do not give an exact picture of relative importance of direct and indirect influence of each of the component characters towards the yield. Path coefficient analysis developed by Wright (1921) is a standardized partial regression analysis which is helpful in finding the direct and indirect causes of association. Therefore, determination of correlation and path coefficients between yield and yield components is important for the selection of desirable plant types for effective broccoli breeding programme.

High yield, earliness, compact and medium size head with maximum number of lateral heads (spears) are the main criteria which are being taken into consideration for genetic improvement of broccoli. First ever recommended variety, Palam Samridhi was released by CSK HPKV, Palampur at national level but these days lots of hybrids are made available to the farmers by various private concerns owing to earliness and higher yield. However, many of these

hybrids do not form proper heads which inturn lead to huge losses to the growers. So, it is appropriate to evaluate the broccoli hybrids so that promising ones can be identified for their direct and indirect use in broccoli improvement program.

Based on afore-mentioned reasons, the present investigation entitled "Genetic evaluation of sprouting broccoli hybrids under mid hills of Himachal Pradesh" was carried out at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSK HPKV, Palampur with the following broad objectives:

1. To estimate the extent of variation in hybrids for marketable yield and horticultural traits,
2. to find out the nature and magnitude of association among different horticultural traits and
3. to identify the most promising hybrid(s).

2. REVIEW OF LITERATURE

Genetic variability among the genotypes is the basis of all the crop improvement programmes. The knowledge of nature and magnitude of genetic variability, inter-relationship of various traits with yield and path coefficient analysis is essential to plan effective strategies for the crop improvement. The research work related to these aspects in broccoli is inadequate. Therefore, the literature pertaining to various aspects included in the present study in broccoli and its related crop cauliflower, is briefly reviewed under the following subheadings:

2.1 Studies on genetic variability

2.2 Correlation coefficient analysis

2.3 Path coefficient analysis

2.1 Studies on genetic variability

The primary aim of any breeding programme is to evolve varieties with high yield, early maturity and other desirable characters. Sufficient genetic variability, if present, can be exploited to develop superior cultivars with desired characters under consideration. Vavilov (1951) probably was the first to realize the importance of wide range of variability in the initial/base material to ensure the better chance of producing desirable strains.

According to Fisher (1918), the continuous variation exhibited by a quantitative character included the heritable and non-heritable components. The heritable component is due to the consequence of genotypes and non-heritable one is due to environmental factors. A knowledge of heritability for different component traits has great importance for any crop improvement programme because the heritable component is transmitted from parent to off-spring. Lush (1940) classified heritability into broad sense and narrow sense. Heritability in

broad sense is the proportion of genetic variance to the total variance, whereas the narrow sense heritability is the proportion of additive variance to the total variance.

High heritability alone does not mean high genetic gain thus, the estimation of expected genetic advance is important to have an idea of effectiveness of selection. Burton and De Vane (1953) suggested that genetic coefficient of variation together with heritability estimates, gives a reliable indication of the extent of improvement expected from selection and further remarked that expected genetic gain under particular system supplies true practical information which is needed by a breeder. Johnson *et al.* (1955) also found it more useful to estimate the heritability value together with genetic advance in predicting the expected progress to be achieved through selection. High heritability coupled with high genetic advance might be due to the action of additive genes (Panse 1957), whereas high heritability associated with low genetic advance might be due to the non-additive gene action (Liang and Walter 1969).The earlier studies on variability and heritability in broccoli and to some extent in closely related crop cauliflower are reviewed as follow:

Legg and Lippert (1966) evaluated two broccoli cultivars, namely De Cicco and Walthman 29 and reported significant estimates of dominance variance for days to maturity, stalk diameter and leaf length. Piazza (1974) observed seven promising cultivars of broccoli *viz.,* Topper 43, Waltham 29, Primo, Medium 90, Coastal, Atlantic and Early One and reported marked variability for marketable yield (37-44 quintal per hectare).

Cassaniti and Signorelli (1977) studied bioagronomic behaviour of fourteen local and commercial cultivars of broccoli under European conditions and found that the early maturing cultivars were Broccolo di Jaci Precoce and Paturnisi (both local) and Barca F_1, Corvet F_1 and Atlantic. They also found that the weight of the main (terminal) spear was highest in the local cultivars. Local cultivars had globular/cone shaped (terminal) spears and the commercial

cultivars had funnel shaped (terminal) spears.

Crisp and Kesavan (1978) observed genotypic × environmental effects on curd weight of autumn-maturing cauliflower. They observed that the high mean curd weight was exhibited by cultivar, Autumn Glory (328 g). Dhiman (1979) evaluated nine lines of cauliflower and reported that heritability estimates in broad sense were high for days to curd initiation (73.51%) and days to curd maturity (61.33%) coupled with low genetic advance. For marketable yield, curd size index and gross weight per plant, the heritability was of medium order with high genetic advance.

Benoit and Ceustermans (1986) observed wide range of variability for days to first harvest and head weight in a study involving different varieties of broccoli for summer and winter culture. They further reported that none of the genotypes under study were suitable for year round production.

Jones *et al.* (1987) evaluated forty cultivars of broccoli and selected eleven cultivars as the most promising for fresh market and processing. Of these, Green Valaint, Emperor, Prominence and Packman gave the highest yield. However, they reported that overall yield and quality were inconsistent among cultivars, sites and crop due to large variation in temperature, rainfall and humidity between the spring and autumn growing season.

Lisiewska (1990) studied six broccoli F_1 hybrids from Netherland and two Polish varieties of broccoli and observed that the early maturing hybrid was Sebastan (65 days) and the late maturing was Kayak (73 days). He also noticed largest and heaviest heads in hybrids Crison and Corret.

Dutta (1991) evaluated six families each having four progenies in cauliflower and observed significant differences for days to marketable maturity and curd diameter. The estimates of heritability and genetic advance were high for marketable yield, gross plant weight, number of leaves per plant and days to curd initiation.

Jamwal *et al.* (1992) conducted an experiment for two years and reported substantial variability for curd yield/plant, gross weight/plant, curd size index and leaf size in late cauliflower. Estimates of PCV and GCV were high for curd yield/plant during first year and leaf size during second year, whereas days to curd maturity showed low PCV and GCV during both the years. The magnitudes of heritability were high for leaf size during both years. They also reported high heritability coupled with high genetic advance for curd yield/plant.

Radhakrishna (1992) evaluated seventeen F_4 progenies of cauliflower and observed high estimates of heritability and genetic advance for gross plant weight, net curd weight, days to marketable maturity and stalk length.

Radhakrishna and Korla (1994) studied seventeen F_4 progenies derived from the cross of commercial cauliflower cultivar, Pusa Snowball-1 with the heading broccoli, Janavon. They reported high heritability coupled with high genetic advance for gross plant weight, net curd weight, days to marketable maturity and stalk length.

Kalia (1995) reported high variability for yield in green sprouting broccoli. High phenotypic and genotypic coefficients of variation were observed for number of spears, plant weight, terminal head weight, marketable yield per plant, leaf area and mean spears weight, whereas for plant height up to head and head size index, phenotypic and genotypic coefficients of variation were moderate. He also reported low phenotypic and genotypic coefficients of variation for days to marketable maturity, stem diameter and harvest index.

Khar (1995) studied genetic variability, heritability and genetic advance in seventeen genotypes of late cauliflower and noticed significant variation for all the traits under study. PCV and GCV were high for marketable yield per plant (31.70% and 27.66%) and gross weight per plant (28.20% and 20.59%), whereas moderate for number of leaves per plant (17.79% and 14.25%), leaf size (17.80% and 11.57%) and curd size index (16.99% and 11.64%). He further observed high heritability (76.12%) coupled with high genetic advance (64.10%) for

marketable yield per plant.

Gray and Doyle (1996) evaluated inbred lines of cauliflower and observed significant differences between the families for mean number of days from sowing to harvest, mean maturity date, mean curd weight, mean curd size, mean curd diameter and mean curd depth.

Shakuntla (1996) studied genetic variability, heritability and genetic advance in nineteen genotypes of sprouting broccoli and observed wide variation in marketable yield per plant, days to marketable maturity, terminal head weight, head size index and harvest index. High heritability coupled with high genetic advance was observed for marketable yield, terminal head weight, number of spears, mean spears weight, leaf size, head size index and plant weight, whereas high heritability coupled with low genetic advance was noticed for days to marketable maturity.

Khattra *et al*. (1997) studied sixteen genotypes of sprouting broccoli for various horticultural traits showing significant differences for all the traits. PCV and GCV values were moderate for number of leaves per plant, number of axillary sprouts, yield of axillary sprouts and average weight of primary sprouts. Plant height, days to first harvest, 50 per cent harvest and harvest span showed low PCV and GCV. They also observed high heritability coupled with high genetic advance for yield of axillary sprouts per plant.

Kumar (1999) evaluated twenty five genetically diverse genotypes of cauliflower and recorded significant differences among these genotypes for all the traits studied. Net curd weight and gross curd weight exhibited moderate estimates of phenotypic and genotypic coefficient of variation and high estimates of genetic advance.

Roosters and Callens (1999) compared fifteen broccoli cultivars and reported the highest head yield in cultivars Montop, EX-98898, Marathan, Lord and Fiesta. They also noticed that terminal head in Marathan and Lord was pale in colour and the development of lateral heads was irregular, affecting the quality

of produce.

Vanparys (1999) studied seven purple cultivars of broccoli and reported highest yield in RS-84090 followed by Violet Queen and Purple Mountain. The cultivars, RS-84090 and Purple Queen recorded the highest number of marketable lateral heads.

Callens *et al*. (2000) compared eleven cultivars of broccoli and recorded highest yield in Trianthalon, Monterey, RS-261295 and Milady, while Milady was recorded to be early maturing cultivar and RS-261295 was found to be promising cultivar with high yield.

Gautam (2001) evaluated eighteen diverse genotypes of broccoli and reported significant differences for all the traits except stalk length. The magnitudes of PCV and GCV were high for marketable yield per plant and moderate for harvest index. Days to first harvest showed low PCV and GCV. He further observed high heritability for marketable yield and moderate heritability for gross weight per plant.

Kumar and Korla (2001) while studying variability, heritability and genetic advance in thirteen genotypes of cauliflower, reported maximum variability for gross curd weight. Phenotypic and genotypic coefficients of variability were high for gross curd weight, net curd weight, stalk length and leaf size. High heritability was recorded for number of leaves per plant, whereas genetic advance was highest for stalk length.

Mihov and Antonova (2001) evaluated five broccoli hybrids *viz*., Beaufort F_1, Sumosun F_1, Skiff F_1, Neptune F_1 and Tribute F_1 and revealed highest genotypic coefficient of variation (38.8%) for curd diameter and lowest (9.03%) for the diameter of the leaf rosette. High heritability was recorded for diameter of leaf rosette (89.91%) and number of rosette leaves (99.05%). Genetic advance varied from 3.24% to 65.64% for stem weight and curd diameter, respectively.

Kalia and Shakuntla (2002) evaluated nineteen diverse genotypes of green sprouting broccoli and reported high estimates of phenotypic and

genotypic coefficients of variation for number of spears, terminal head weight, marketable yield per plant and mean spears weight. High heritability estimates along with high genetic advance were noticed for marketable yield per plant, terminal head weight, plant height up to leaf, plant height up to head, head size index, number of spears and mean spears weight, whereas high heritability associated with low genetic advance was recorded for harvest index.

Kanwar and Korla (2002) studied sixteen F_2 progenies derived from intervarietal cross (PSBK-1×KT-25) of late maturing cauliflower and noticed high estimates of heritability for days to marketable maturity, net curd weight, harvest index and stalk length. High heritability accompanied with moderate genetic advance was observed for stalk length.

Kumar (2002) studied twenty two divergent genotypes of cauliflower and observed significant differences for all the horticultural traits. The magnitudes of PCV and GCV were high for gross curd weight, whereas moderate for number of leaves per plant and net curd weight. Heritability in broad sense was highest for days to marketable maturity, while genetic advance was highest for gross curd weight.

Pathania (2003) studied twenty genotypes of cauliflower and reported significant differences for all the horticultural traits under study. The highest PCV and GCV values were exhibited by gross curd weight and net curd weight. High heritability coupled with high genetic advance was recorded for net curd weight.

Gautam *et al.* (2004) evaluated eighteen diverse genotypes of broccoli for various horticultural traits and found significant differences among all the traits except stalk length. They also recorded high heritability coupled with high genetic advance for marketable yield per plant.

Jindal and Thakur (2004) evaluated thirty six genotypes of cauliflower and revealed the existence of wide genotypic differences for all the traits except number of leaves per plant, curd diameter and curd depth. High heritability was recorded for harvest index and gross weight per plant, whereas moderate heritability was exhibited by plant spread, plant height and days to curd maturity.

Harvest index showed high genetic advance and plant height showed low genetic advance.

Kumar *et al.* (2006) studied twenty five diverse genotypes of cauliflower and observed significant differences among different genotypes for all the characters under study. Moderate estimates of PCV and GCV were observed for leaf size index, whereas stalk length and days to marketable maturity showed low PCV and GCV. High heritability coupled with high genetic advance was noticed for net curd weight.

Rattan *et al.* (2006) evaluated twenty three broccoli genotypes and observed maximum variability for plant frame, leaf area, yield, central head size and days to central head maturity. The heritability estimates were high for central head size. They further noticed high genetic advance for plant frame, central head size and leaf size.

Sharma *et al*. (2006) studied genetic variability, heritability and genetic advance for yield components in thirteen cauliflower cultivars and reported that phenotypic and genotypic coefficients of variation were high for net curd weight, stalk length, marketable curd yield per plant, gross plant weight and harvest index. High levels of heritability and genetic advance were recorded for marketable curd yield per plant, net curd weight and stalk length.

Toth *et al*. (2007) evaluated twelve broccoli hybrids *viz*., Belstar, Captain, Fiesta, General, Griffen, Heritage, Liberty, Lord, Lucky, Marathan, Milady and Shadow for different yield contributing characters. They revealed that hybrid Captain recorded the highest inflorescence weight and marked earliness followed by Lucky, General, Griffen, Liberty and Milady.

Dhatt and Garg (2008) while studying genetic variability in twenty one genotypes of December maturing cauliflower revealed that marketable curd weight, gross curd weight, net curd weight and stalk length exhibited considerable genetic variability, whereas days to curd maturity was least variable character. High heritability coupled with high genetic advance were recorded for marketable curd weight and stalk length, while high heritability accompanied with

moderate genetic advance was observed for leaf size index.

Kopta and Pokluda (2009) compared five cultivars of Chinese broccoli *viz.,* Suiho, Green Lamnce, Hon Tsai Tai, Summer Jean and Happy Rich for stem weight, leaf area and leaf/stem ratio and found that the cultivar Happy Rich was significantly best performing cultivar among other cultivars under study.

Kumar (2010) evaluated nineteen genetically diverse genotypes of mid-group cauliflower and revealed that values of PCV were greater than GCV. The estimates of phenotypic and genotypic coefficients of variation were high for marketable yield per plant and leaf size. High heritability coupled with high genetic advance were recorded for leaf size, gross weight per plant and marketable yield per plant.

Kumar *et al.* (2011) studied genetic variability, heritability and genetic advance in thirty six genotypes of cauliflower and observed significant differences among genotypes for all the traits under study. Three genotypes *viz*., DC-98-4, DC-98-10 and DC-124 appeared significantly superior with respect to yield. High estimates of PCV and GCV were recorded for duration of curd availability and high estimates of heritability coupled with high genetic advance were reported for net curd yield.

2.2 Correlation coefficient analysis

The correlation coefficient is a measure of the degree of association between two characters worked out at the same time (Hayes *et al.* 1955). To raise the genetic potential of a crop, the knowledge of nature and magnitude of association among different characters is of immense value to any breeding programme and forms the basis for selection. For selection of several characters simultaneously, the knowledge of character association is helpful to avoid undesirable correlated changes in other characters. Johnson *et al.* (1955) stated that estimates of phenotypic and genotypic correlations among the characters are useful in planning and evaluating breeding programmes. Correlation

coefficients for a given character vary with the genotypes studied and the environment where the test is carried out.

Cassaniti and Signorelli (1977) while studying bioagronomical behavior of fourteen local and commercial cultivars of broccoli under European condition found positive correlation between number of leaves per plant and days to maturity.

Dhiman (1979) observed that number of leaves, curd size index and gross weight per plant were positively associated with marketable yield of cauliflower. Sharma *et al*. (1982) revealed significant and positive correlation of curd yield with curd diameter and leaf area index based upon two years study in cauliflower.

Thamburaj *et al.* (1982) noticed significant and positive correlation of curd yield with plant weight, plant height and curd girth. Dhiman *et al.* (1983) while studying nine diverse cultivars of cauliflower, observed a strong positive association of the number of leaves per plant, curd size index and gross weight per plant with marketable yield per plant.

Dutta (1991) conducted correlation studies in cauliflower and revealed that marketable yield per plant was positively associated with days to curd maturity, gross weight per plant, harvest index, curd length and curd diameter.

Jamwal *et al*. (1992) observed that in late cauliflower, curd yield per plant was positively and significantly associated with gross weight per plant and curd size index. Leaf size and leaves per plant showed non-significant correlation with each other and curd yield per plant, whereas days to curd maturity had significant negative correlation with curd yield per plant and curd size index.

Radhakrishna (1992) found that net curd weight of cauliflower was significantly and positively correlated with gross plant weight, curd diameter, curd depth and days to curd maturity, while it was negatively associated with days to curd initiation.

Khar (1995) reported positive association of marketable yield per plant

with gross weight per plant, curd size index and harvest index in cauliflower. Guan *et al*. (1995) conducted correlation studies in broccoli and found significant positive correlation between head weight and plant weight.

Radhakrishna and Korla (1995) noticed that net curd weight of cauliflower was positively and significantly correlated with gross plant weight, curd diameter, curd depth and days to curd maturity.

Shakuntla (1996) while studying correlation in nineteen genotypes of broccoli, reported that marketable yield per plant was significantly and positively correlated with terminal head weight, head size index, mean spears weight, plant weight, plant height up to leaf, harvest index and days to marketable maturity.

Kumar (1998) observed that in cauliflower, net weight of curd was positively and significantly correlated with plant frame, leaf size index, curd depth and gross curd weight.

Kumar (1999) reported that in cauliflower, net curd weight was significantly and positively associated with plant frame, leaf size index, gross weight and harvest index.

Shakuntla *et al*. (1999) noticed that marketable yield per plant of sprouting broccoli exhibited significant positive correlation with terminal head weight, plant height up to leaf, head size index, mean spears weight, plant weight and stem diameter both at phenotypic and genotypic levels.

Yan (1999) evaluated six heading broccoli cultivars and found that marketable yield per plant was closely related to number of leaves per plant, mean head weight, head height and head shape.

Kanwar and Korla (2002) studied correlation in sixteen F_4 progenies of cauliflower and found that net curd weight was significantly and positively correlated with gross plant weight and harvest index, whereas days to marketable maturity had significant negative association with stalk length, gross plant weight, net curd weight and harvest index.

Pathania (2003) revealed that net curd weight of cauliflower had positive and significant correlation with days taken to marketable curd, number of leaves, gross curd weight, curd depth, curd width and curd compactness.

Garg and Lal (2004) studied thirty six genotypes of cauliflower and reported that net curd weight had positive and significant correlation with equatorial diameter of curd, curd size index, plant spread and polar diameter of curd. The equatorial diameter of curd was positively correlated with polar diameter of curd. Liu *et al*. (2004) observed that in cauliflower, curd yield was significantly and positively correlated with leaf mass, leaf area, plant mass, diameter of curd stem and curd mass.

Gautam *et al.* (2004) noticed that marketable yield per plant of broccoli was significantly and positively associated with gross weight per plant, head size index and leaf size. They also reported that gross weight per plant, leaf size, head size index, harvest index and days to maturity could be effectively used as selection indices for the improvement of heading broccoli.

Kumar *et al.* (2005) studied twenty five divergent genotypes of cauliflower and reported that net curd weight was significantly and positively correlated with gross curd weight, plant frame and leaf size index while curd depth was positively correlated with gross weight and negatively correlated with harvest index.

Rattan *et al.* (2006) evaluated twenty three genotypes of broccoli and observed that yield per plant had significant and positive correlation with peduncle length, central head size and plant frame. Plant frame was significantly and positively correlated with plant height, leaf area and harvest duration while central head size had positive and significant correlation with peduncle length.

Sharma *et al*. (2006) while studying correlation in thirteen cultivars of cauliflower revealed that marketable curd yield per plant exhibited positive correlation with net curd weight, curd size index, gross plant weight, curd length and curd depth.

Dhatt and Garg (2008) studied correlation in twenty one genotypes of cauliflower and concluded that net curd weight was positively and significantly correlated with all the characters under study *viz*., days to curd maturity, leaf size index, gross weight, plant height, plant spread and stalk length.

Kumar (2010) revealed that marketable yield per plant in cauliflower exhibited a positive and significant correlation with leaf size, gross weight per plant, curd size index and harvest index at both phenotypic and genotypic levels.

Kumar *et al*. (2011) conducted correlation studies in thirty six genotypes of cauliflower and found positive and significant association of yield with net curd weight, marketable curd weight and harvest index.

2.3 Path coefficient analysis

Path coefficient is simple standardized partial regression coefficient which splits the correlation coefficient into the measures of direct and indirect effects of a set of independent variables on the dependent variable. The studies on correlation coefficients merely indicate the nature of association of different characters and this alone does not provide an exact insight of the relative influence of each of the component characters towards yield, because a character may not be directly correlated with yield but, may influence it through other characters. Hence, the knowledge of direct and indirect effects on yield components is of prime importance to select the suitable genotypes.

Sharma *et al.* (1982), in a standardized regression coefficient study revealed that the diameter of curd contributed maximum to the curd yield in cauliflower. Thamburaj *et al*. (1982) observed that plant weight had exerted maximum direct and positive effect on curd yield in cauliflower. They further observed that curd length and curd girth had positive effect on curd yield through plant weight.

Dutta (1991) revealed direct contribution of gross plant weight and harvest index on marketable yield in cauliflower. Radhakrishna (1992) reported

the maximum direct and indirect contributions of gross plant weight, days to curd initiation and days to marketable maturity on net curd weight.

Khar (1995) recorded positive direct effects of gross weight per plant, harvest index, days to marketable maturity and number of leaves per plant towards marketable yield at both phenotypic and genotypic levels suggesting thereby that the selection based on these traits would be useful for the improvement of yield in cauliflower. Reddy and Varalakshmi (1995) reported that curd size, curd diameter and harvest index had highest positive direct effects on curd weight in cauliflower.

Shakuntla (1996) observed direct positive effects of terminal head weight, days to marketable maturity, head size index, harvest index and leaf size towards marketable yield per plant in sprouting broccoli. Kumar (1998) revealed that in cauliflower, gross curd weight had exerted maximum direct effect on marketable yield per plant followed by harvest index.

Kumar (1999) found that in cauliflower, leaf size index and leaves per plant had the highest direct positive effects on net curd weight. Shakuntla *et al*. (1999) reported the highest positive direct effects of terminal head weight, number of spears and mean spears weight on marketable yield per plant in sprouting broccoli.

Gautam (2001) observed that gross weight per plant had the maximum positive direct effect on marketable yield followed by head size index, harvest index and leaf size in broccoli.

Khattra *et al.* (2001) revealed highest positive direct effects of average weight of primary sprout, yield of axillary sprouts, diameter of primary sprout and number of axillary sprouts per plant on the total yield of sprouting broccoli.

Garg and Lal (2004) reported that curd size index and equatorial diameter of curd exerted highest positive direct effects on net curd weight. On the other hand, Kumar *et al*. (2004) observed the maximum positive direct effects of gross

curd weight and harvest index on the net curd weight in cauliflower.

Kanwar and Korla (2002) noticed maximum direct contribution of gross plant weight and harvest index on net curd weight of cauliflower.

Liu *et al*. (2004) observed the significant direct effect of plant mass and curd diameter on curd yield and indirect effects of leaf mass, leaf area and diameter of curd on yield through plant mass and curd diameter.

Kumar *et al*. (2005) reported highest positive direct effects of gross curd weight, harvest index and stalk length on net curd weight, whereas the highest indirect effects on net curd weight were recorded by leaf size index *via* gross curd weight followed by plant frame and curd depth in cauliflower.

Sharma *et al*. (2006) studied thirteen genotypes of cauliflower and observed that gross plant weight had maximum positive direct effect on net curd weight. Dhatt and Garg (2008) revealed that gross curd weight, leaf size index and days to curd initiation exerted maximum positive direct effects on net curd weight.

Kumar (2010) while studying nineteen genotypes of cauliflower revealed that curd compactness, curd size index and gross weight per plant had the highest direct positive effects on marketable yield per plant. Kumar *et al*. (2011) revealed that net curd weight had the highest positive direct contribution towards the total yield in cauliflower

3. MATERIALS AND METHODS

The present investigation entitled “Genetic evaluation of sprouting broccoli hybrids under mid hills of Himachal Pradesh” was carried out at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSK HPKV, Palampur during September-March *rabi*, 2010-2011 and 2011-2012. The details of materials used and methods employed in the present investigation are presented below:

3.1 Experimental site

3.1.1 Location

The Experimental Farm is situated at an elevation of 1290.8 meters above mean sea level with latitude 32°6´ N and longitude 76°3´ E.

3.1.2 Climate

Agro-climatically, the area falls in mid-hill zone 2.2 of Himachal Pradesh (Appendix I) and is characterized by humid temperate climate. The location is characterized by severe winters and mild summers with high rainfall (2500 mm). The week-wise meteorological data with regard to temperature, relative humidity, rainfall and sunshine hours during the cropping seasons are presented in Fig.1 and Appendix II.

3.1.3 Soil

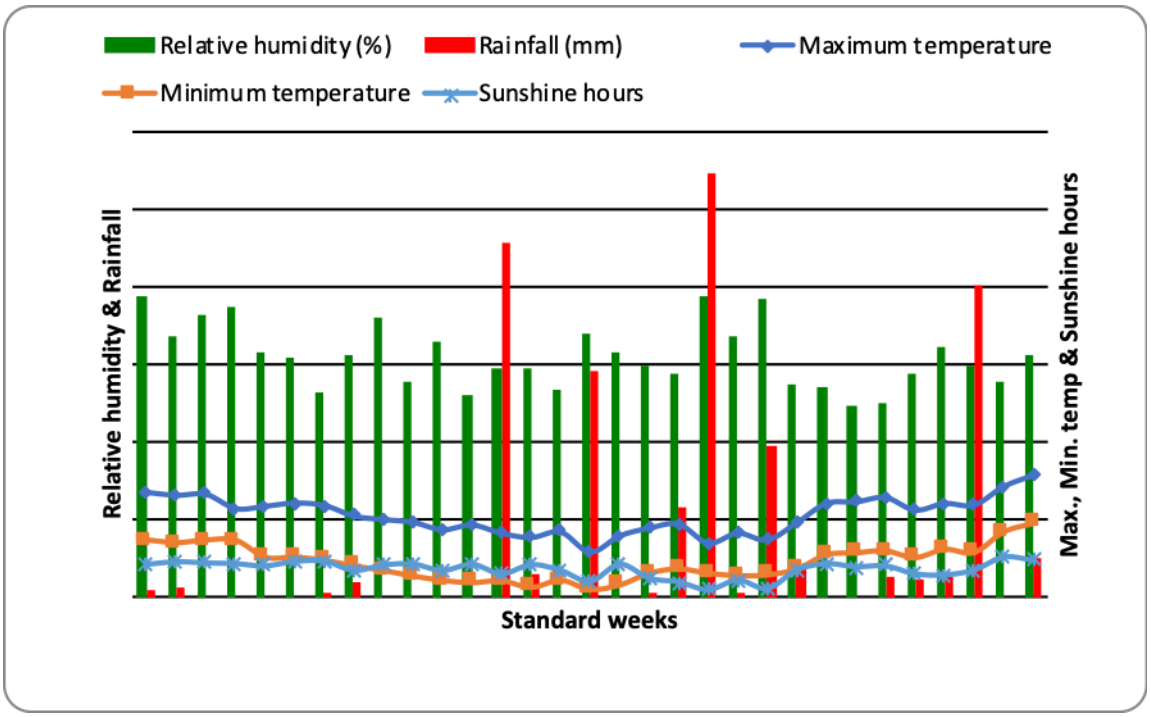
The soil of this area belongs to order “Alfizol” and is acidic in reaction (pH 5-5.6).

3.2 Materials and layout of the experiment

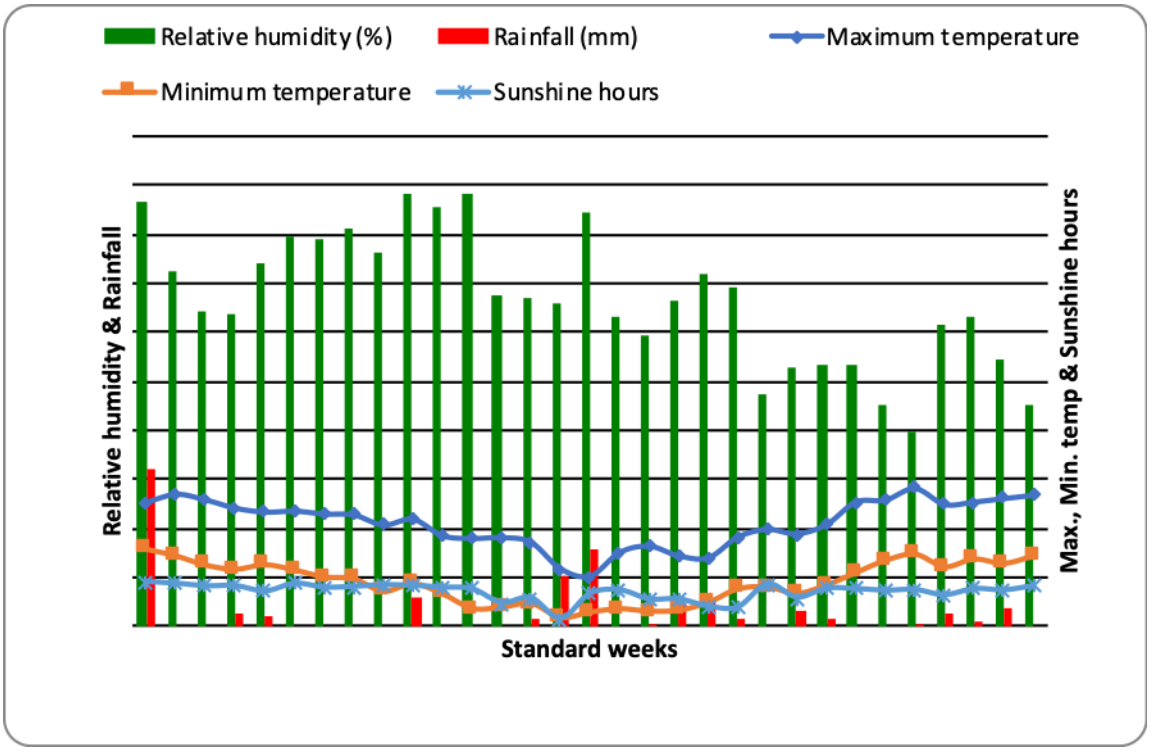
3.2.1 Experimental materials

The experimental materials comprised of sixteen genotypes of sprouting

broccoli. The details of genetic stocks along with their sources are given in Table 3.1.



Weather Graph 2010-2011



Weather Graph 2011-2012

Fig. 1 Mean weekly weather data during the cropping seasons *rabi*, 2010-2011 and 2011-2012

Table 3.1 List of different genotypes of broccoli (*Brassica oleracea* L. var. *italica* Plenck.) evaluated under the present study

Sr. No.	Genotypes	Source
1.	Lucky	Bejo Sheetal Seeds Private Limited, India
2.	Fiesta	Bejo Sheetal Seeds Private Limited, India
3.	Kendi	East West Seeds Private Limited, India
4.	Indica	Indica Hybrid Seeds, India
5.	Green Magic	Sakata Seeds Cooperation, Japan
6.	BR-70	Takii and Cooperation Limited, Kyoto, Japan
7.	BR-60	Takii and Cooperation Limited, Kyoto, Japan
8.	Altar	Clause Private Limited, India

9.	CBH-1	Century Seeds Private Limited, India
10.	Pluto	Nufield Genetics Private Limited, India
11.	Green Beauty	Doctor Seeds Private Limited, India
12.	Supreme	Pahuja Seeds Private Limited, India
13.	Packman	Seminis Private Limited, India
14.	Tiltest	Takii and Cooperation Limited, Kyoto, Japan
15.	Palam Haritika	CSK HPKV, Palampur
16.	Palam Samridhi	CSK HPKV, Palampur

3.2.2 Layout plan

The experiment was laid out with sixteen broccoli genotypes in Randomized Complete Block Design (RCBD) with three replications. Each genotype of broccoli was planted in a plot size of 2.5 m × 1.8 m with a spacing of 60 cm and 40 cm between and within rows, respectively. Thus, there were sixteen plants in each plot.

(*Rabi*, 2010-2011)

(*Rabi*, 2011-2012)

Plate I: General view of the crop

3.2.3 Nursery sowing and transplanting

The nursery sowing was done on 21th September, 2010 and 12th September, 2011 in well prepared nursery beds and the transplanting of seedlings was carried on 2nd November, 2010 and 19th October, 2011, respectively.

3.2.4 Cultural practices

The intercultural operations, such as nutrients application, irrigation and weeding were carried out in accordance with the recommended package of practices to ensure a healthy crop.

3.2.5 Plant protection measures

Seed treatment with Bavistin at the rate of 3 g/kg of seed was done at the time of sowing. For the control of stalk rot, one spray of Dithane M-45 at the rate of 2.5 g/l of water was done.

3.3 Recording of data

Observations were recorded on five competitive plants of each genotype in each replication followed by computing their means for the following characters:

3.3.1 Days to first harvest

Days to first harvest were calculated from the date of transplanting to the date when 50 per cent of the heads in a genotype attained marketable maturity which was decided by the size and compactness of the head.

3.3.2 Marketable yield per plant (g)

Marketable yield refers to the head weight including central stalk having one or two uppermost leaves at the time of marketable maturity.

3.3.3 Terminal head weight per plant (g)

At the marketable maturity, the terminal head was cut just above the uppermost leaf on the central stalk and weighed.

3.3.4 Gross weight per plant (g)

Gross weight was recorded at the time of marketable maturity. It included the weight of head along with leaves and the stalk.

3.3.5 Number of spears per plant

Spears those appeared in the axils of the leaves present on the central stalk after removal of central head were counted.

3.3.6 Head size index (cm_2)

Polar and equatorial diameters of the head were measured and multiplied to obtain head size index.

3.3.7 Plant frame (cm_2)

The observation was recorded at the time of harvesting by measuring spread of the entire plant in east-west and north-south directions and multiplied to get plant frame.

3.3.8 Leaf size with leaf stalk (cm_2)

Leaf size with leaf stalk was calculated as an average of the product of length and breadth including the leaf stalk of three leaves selected at random from the middle whorls in each plant.

3.3.9 Leaf size without leaf stalk (cm_2)

Leaf size without leaf stalk was calculated as an average of the product of length and breadth excluding the leaf stalk of three leaves selected at random from the middle whorls in each plant.

3.3.10 Plant height up to longest leaf (cm)

The total length of a plant from ground level to the tip of the longest leaf was measured at the time of harvesting.

3.3.11 Plant height up to head (cm)

The total length of a plant from ground level to the top of head was measured at the time of harvesting.

3.3.12 Stalk length (cm)

The length of the stalk was measured from first secondary root to first leaf.

3.3.13 Weight of spears per plant (g)

The mature spears were harvested and weighed to arrive at the total weight of spears per plant.

3.3.14 Harvest index (%)

Harvest index was calculated as a ratio of marketable yield per plant to the gross weight per plant and expressed in percentage.

3.4 Statistical analysis

Average values of each genotype in each replication for the traits studied were used for statistical analysis. A brief outline of the procedure adopted for the estimation of different statistical parameters is given below:

3.4.1 Analysis of variance

The data were statistically analyzed as per the following model given by Panse and Sukhatme (1985):

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

where,

Y_{ij} = phenotypic observation of i_{th} genotype grown in j_{th} replication

m = general population mean

g_i = effect of i_{th} genotype

r_j = effect of j_{th} replication, and

e_{ij} = error associated with i_{th} genotype in the j_{th} replication

On the basis of this model the analysis of variance was done as follows:

Analysis of variance

Source of variation	Degree of freedom	Mean Sum of Squares	F- value	Expected Mean Squares
Replications	r-1	Mr	Mr/Me	$\sigma_2 e + g\sigma_2 r$
Genotypes	g-1	Mg	Mg/Me	$\sigma_2 e + r\sigma_2 g$
Error	(r-1) (g-1)	Me	----	$\sigma_2 e$
Total	(rg-1)			

where,

r = number of replications

g = number of genotypes

σ_{2r} = variance due to replication

σ_{2g} = variance due to genotypes

σ_{2e} = error variance

The Standard Error of mean [SE (m)], Standard Error of difference [SE (d)] and Critical Difference (CD) for comparing the means of any two genotypes were computed as follows:

SE (m) = $\pm (Me/r)_{1/2}$

SE (d) = $\pm (2\ Me/r)_{1/2}$

CD = SE (d) x t (5%) value at error degrees of freedom.

The calculated 'F' value was compared with the tabulated 'F' value at 5% level of significance. If the calculated 'F' value was higher than the tabulated, it was considered to be significant. All the characters which showed significant differences among genotypes were further subjected to analysis for the different parameters.

Coefficient of Variation (CV %) was calculated as per the following formula:

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

3.4.2 Estimation of parameters of variability

The genotypic, phenotypic and environmental coefficients of variation were estimated by following method of Burton and De Vane (1953), as follows:

Genotypic coefficient of variation (GCV)

$$GCV\ (\%) = \frac{\sigma_g}{\bar{x}} \times 100$$

Phenotypic coefficient of variation (PCV)

$$PCV\ (\%) = \frac{\sigma_p}{\bar{x}} \times 100$$

Environmental coefficient of variation (ECV)

$$ECV\ (\%) = \frac{\sigma_e}{\bar{x}} \times 100$$

where,

σ_g = genotypic standard deviation

σ_p = phenotypic standard deviation

σ_e = environmental standard deviation

$\bar{x}$ = grand mean

3.4.3 Heritability (h^2_{bs})

Heritability in broad sense (h^2_{bs}) was calculated as per the following formula given by Burton and De Vane (1953) and Johnson *et al.* (1955).

$$\text{Heritability } (h^2_{bs}\,\%) = \frac{\sigma^2_g}{\sigma^2_g + \sigma^2_e} \times 100$$

where,

σ^2_g = genotypic variance

σ^2_e = environmental variance

$\sigma^2_g + \sigma^2_e$ = phenotypic variance

3.4.4 Genetic advance

The expected genetic advance (GA) resulting from the selection of 5% superior individuals was calculated following Burton and De Vane (1953) and Johnson *et al.* (1955).

$$\text{Genetic Advance (GA)} = k.\sigma_p.h^2_{bs}$$

where,

k = 2.06 (selection differential at 5% selection intensity)

σ_p = phenotypic standard deviation

h^2_{bs} = heritability (broad sense)

$$\text{Genetic advance as percentage of mean} = \frac{\text{Expected GA}}{\text{Grand mean}} \times 100$$

3.4.5 Combined analysis of variance over environments

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

The analysis was based upon the following model:

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

where,

Y_{ijk} = phenotype of the i_{th} genotype grown in j_{th} environment in the k_{th} block

m = general population mean

α_i = effect of i_{th} genotype

β_j = effect of j_{th} environment

$\alpha\beta_{ij}$ = effect of interaction of i_{th} genotype with j_{th} environment

r_k = k_{th} replication effect

e_{ijk} = random error

Analysis of variance combined over environments

Source of variation	Degree of Freedom	Mean Sum of Squares	F- value	Expected Mean Squares
Replications	(r-1)	Mr	Mr/Me	σ_{2e}+ gyσ_{2r}
Environments	(y-1)	My	My/Me	σ_{2e}+ rgσ_{2e}+ rσ_{2gy}
Replication× Environments	(r-1) (y-1)	Mry	Mry/Me	σ_{2e}+ gσ_{2ry}
Genotypes	(g-1)	Mg	Mg/Me	σ_{2e}+ rσ_{2gy}+ yrσ_{2g}
Genotype× Environments	(g-1) (y-1)	Mgy	Mgy/Me	σ_{2e}+ rσ_{2gy}
Pooled error	y(r-1) (g-1)	Me	---	σ_{2e}

Where,

r = number of replications

g = number of genotypes

y = number of environments

σ_{2e} = error variance = Me

σ_{2g} = variance due to genotypes = Mg

σ_{2r} = variance due to replications = Mr

σ_{2y} = variance due to environments = My

σ_{2ry} = variance due to replication × environments = Mry

σ_{2gy} = variance due to genotype × environments = Mgy

Standard Errors

Standard Error of mean SE (m) = ± $(Me/ry)_{1/2}$

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

Critical Difference

For comparing the means of two genotypes

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

Coefficient of variation

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

Estimation of parameters of variability in combined over environments

Phenotypic Coefficient of Variation (PCV %) = $[(\sigma g + \sigma gy + \sigma e) / \bar{x}] \times 100$

Genotypic Coefficient of Variation (GCV %) = $(\sigma g / \bar{x}) \times 100$

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

Genetic advance (GA) at 5% selection intensity = $k (\sigma g + \sigma gy + \sigma e) \times h^2_{bs}$

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

Where,

σg = genotypic standard deviation

σgy = genotypic environmental standard deviation

σe = error standard deviation

For categorizing the magnitude of different parameters, the following limits were used:

PCV and GCV

> 30%	High
10-30%	Moderate

	< 10%	Low
Heritability in broad sense		
	> 60%	High
	30-60%	Moderate
	< 30%	Low
Genetic advance		
	> 30%	High
	10-30%	Moderate
	< 10%	Low

Test of Homogeneity

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

$$F = \frac{S_{12}}{S_{22}}$$

Where,

S_{12} = large estimate of variance

S_{22} = smaller estimate of variance

and $S_{12} > S_{22}$

at $v_1 = n_1 - 1$ and $v_2 = n_2 - 1$ degrees of freedom

Where,

v_1 = degrees of freedom for sample having larger variance

v_2 = degrees of freedom for sample having smaller variance

n_1 = sample size having large variance

n_2 = sample size having smaller variance

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

3.4.6 Correlation coefficients

For computing phenotypic, genotypic and environmental correlation coefficients, analysis of co-variance were carried out in all possible pairs of combinations of the characters studied.

Analysis of co-variance

Source	Degree of freedom	Mean Sum of Product	F- value	Expected Mean Sum of Product
Replications	(r–1)	Mr_{xy}	Mr_{xy} /Me_{xy}	σ_{exy} + g σ_{rxy}
Genotypes	(g–1)	Mg_{xy}	Mg_{xy} /Me_{xy}	σ_{exy} + r σ_{gxy}
Error	(r-1) (g-1)	Me_{xy}	----	σ_{exy}

Where,

r = number of replications

g = number of genotypes

σ_{gxy} = genotypic co-variance between characters x and y = (Mg_{xy} – Me_{xy})/r

σ_{exy} = environmental co-variance between characters x and y = Me_{xy}

σ_{pxy} = phenotypic co-variance between characters x and y = σ_{gxy} + σ_{exy}

Mg_{xy} = mean sum of squares due to genotypes from the analysis of co-variance between characters x and y

Me_{xy} = mean sum of squares due to error from the analysis of co-variance between characters x and y

The phenotypic, genotypic and environmental coefficients of correlation were calculated as suggested by Al-Jibouri *et al.* (1958).

Phenotypic coefficient of correlation (rp_{xy})

$$rp_{xy} = \frac{\sigma_{pxy}}{(\sigma_{2px} \times \sigma_{2py})^{1/2}}$$

where,

σ_{pxy} = phenotypic co-variance between characters x and y

σ_{2px} = phenotypic variance of character x

σ_{2py} = phenotypic variance of character y

Genotypic coefficient of correlation (rg_{xy})

$$rg_{xy} = \frac{\sigma_{gxy}}{(\sigma_{2gx} \times \sigma_{2gy})^{1/2}}$$

where,

σ_{gxy} = genotypic co-variance between characters x and y

σ_{2gx} = genotypic variance of character x

σ_{2gy} = genotypic variance of character y

Environmental coefficient of correlation (re_{xy})

$$re_{xy} = \frac{\sigma_{exy}}{(\sigma_{2ex} \times \sigma_{2ey})^{1/2}}$$

where,

σ_{exy} = environmental co-variance between characters x and y

σ^2_{ex} = environmental variance of character x

σ^2_{ey} = environmental variance of character y

Test of significance

The significance of phenotypic coefficient of correlation at (g–2) degrees of freedom and environmental coefficient of correlation at [(r–1) (g–1) –1] degrees of freedom, where r and g stand for number of replications and number of genotypes, respectively, were tested at 5 per cent level of significance against the table values of correlation coefficient (Fisher and Yates 1963).

To test the significance of genotypic coefficient of correlation, the F value was calculated using:

$$F = [(g–2)\ r^2]/\ (1–r^2)$$

and compared with the F-distribution at 1 and (g–2) degrees of freedom, where 'g' and 'r' stand for number of genotypes and genotypic coefficient of correlation, respectively (Mead and Curnow 1983).

3.4.7 Path coefficient analysis

Path coefficient is a standardized partial regression coefficient which permits the partitioning of the correlation coefficients into direct and indirect effects. The path coefficient analysis of important horticultural traits with marketable yield per plant was worked out following Al-Jibouri *et al.* (1958) and Dewey and Lu (1959). This was done by solving a set of equations of the form:

$$Py_1 + Py_2r_{12} + Py_3r_{13} + \ldots\ldots\ldots\ldots\ldots\ldots + Py_nr_{1n} = ry_1$$

$$Py_1r_{12} + Py_2 + Py_3r_{23} + \ldots\ldots\ldots\ldots\ldots\ldots + Py_nr_{2n} = ry_2$$

$Py_1r_{13} + Py_2r_{23} + Py_3 + \ldots\ldots\ldots\ldots\ldots\ldots + Py_nr_{3n} = ry_3$

$Py_1r_{n1} + Py_2r_{n2} + Py_3r_{n3} + \ldots\ldots\ldots\ldots\ldots\ldots + Py_n = ry_n$

Where,

Py_1, Py_2, Py_3, ……., Py_n are the direct path effects of 1, 2, 3,……., n variables on the dependent variable 'y'.

r_{12}, r_{13}, …… $r_{(n-1)n}$ are the possible coefficients of correlation between various independent variables and

ry_1, ry_2, ……., ry_n are the coefficients of correlation of independent variables with dependent variable 'y'.

The variation in the dependant variable which remained undetermined by including all variables was assumed to be due to the variable(s) not included in the present investigation. The degree of the determination (P_2× R) of such variables was calculated as follows:

Residual effect = $(1 - R_2)^{½}$

$R_2 = Py_1ry_1 + Py_2ry_2 + \ldots\ldots\ldots\ldots + Py_nry_n$

Where,

R_2 is the square multiple correlation coefficient and is the amount of variation in yield that can be attributed to the variable(s) not included in present study

4. RESULTS AND DISCUSSION

The present investigation entitled “Genetic evaluation of sprouting broccoli hybrids under mid hills of Himachal Pradesh” was undertaken in two environments *viz.,* environment I (*Rabi*, 2010-11) and environment II (*Rabi*, 2011-12). The experiments were conducted in Randomized Complete Block Design with three replications at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSKHPKV Palampur, with a view to assess genetic variability among different genotypes of sprouting broccoli and find out associations of different characters with marketable yield per plant. The results on various aspects of the present study are presented and discussed under following heads:

4.1 Studies on genetic variability

4.1.1 Analysis of variance

4.1.2 Mean performance of genotypes

4.1.3 Genetic parameters of variability

4.2 Correlation coefficient analysis

4.3 Path coefficient analysis

4.1 Studies on genetic variability

4.1.1 Analysis of variance

The analysis of variance (ANOVA) for environment I and environment II presented in Table 4.1 indicated that in both of the environments, mean squares due to genotypes were significant for all characters *viz*., days to first harvest, marketable yield per plant, terminal head weight per plant, gross weight per plant, number of spears per plant, head size index, plant frame, leaf size with leaf stalk, leaf size without leaf stalk, plant height up to longest leaf, plant height up to head, stalk length, weight of spears per plant and harvest index indicating thereby a wide range of genetic variability in the material under study.

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Table 4.1 Analysis of variance for different characters of broccoli in environment I (2010-11) and environment II (2011-12)

Sr. No.	Characters	Source	Mean Sum of Squares					
			Replication		Genotypes		Error	
			Environment I	Environment II	Environment I	Environment II	Environment I	Environment II
		d.f.	2		15		30	
1.	Days to first harvest		27.90	299.01	158.80*	425.29*	13.23	26.88
2.	Marketable yield/plant (g)		159.39	914.02	28177.00*	24685.72*	874.41	1016.73
3.	Terminal head weight/plant (g)		370.08	820.89	31661.15*	24453.78*	704.17	941.22
4.	Gross weight/plant (g)		10368.75	62659.39	38818.88*	66957.72*	7075.97	9876.19
5.	Number of spears/plant		0.23	0.70	14.88*	13.59*	0.28	0.38
6.	Head size index (cm_2)		1291.72	2069.00	3502.73*	3874.38*	908.68	1041.42
7.	Plant frame (cm_2)		18396.72	2550174.00	950545.94*	1002219.17*	213727.32	216443.05
8.	Leaf size with leaf stalk (cm_2)		985.86	8621.71	37588.85*	29117.77*	2969.44	4596.57
9.	Leaf size without leaf stalk (cm_2)		293.90	15917.26	8535.83*	28594.18*	1340.35	1966.10
10.	Plant height up to longest leaf (cm)		78.28	599.99	39.84*	52.70*	11.93	14.43
11.	Plant height up to head (cm)		12.41	32.63	46.66*	41.75*	8.69	15.92
12.	Stalk length (cm)		0.03	0.02	0.20*	0.15*	0.02	0.02
13.	Weight of spears/plant (g)		347.41	260.94	4889.01*	4382.15*	200.34	271.55
14.	Harvest index (%)		7.39	16.09	206.65*	123.44*	13.57	11.34

*Significant at P≤ 0.05

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Table 4.2 Analysis of variance for different characters of broccoli in pooled over the environments

Sr. No.	Characters	Source	Mean Sum of Squares				F-Test (Test of Homogeneity)
			Genotypes	Environments	Genotype × Environment (g × e)	Pooled error	
		d.f.	15	1	15	60	
1.	Days to first harvest		494.95*	743.70*	89.15*	20.05	4.12+
2.	Marketable yield/plant (g)		51660.71*	1971.09	1202.02	945.57	1.35
3.	Terminal head weight/plant (g)		54682.17*	1759.59	1432.77	822.70	1.78
4.	Gross weight/plant (g)		94587.86*	240500.26*	11188.74	8476.08	1.94
5.	Number of spears/plant		25.48*	7.36	3.00*	0.33	1.84
6.	Head size index (cm_2)		6085.89*	590.19	1291.18	975.05	1.31
7.	Plant frame (cm_2)		1709313.49*	1847728.22*	243451.62	215085.19	1.02
8.	Leaf size with leaf stalk (cm_2)		60778.59*	154496.50*	5928.03	3783.00	2.39
9.	Leaf size without leaf stalk (cm_2)		22846.53	59946.51	14283.49*	1653.22	2.15
10.	Plant height up to longest leaf (cm)		74.11*	537.65*	18.43	13.18	1.46
11.	Plant height up to head (cm)		74.74*	484.38*	13.67	12.95	3.35+
12.	Stalk length (cm)		0.31	0.006	0.37	6.02	1.00
13.	Weight of spears/plant (g)		8186.72*	6147.20*	1084.43*	235.94	1.83
14.	Harvest index (%)		308.84*	106.70*	23.25*	12.46	1.43

*Significant at P≤ 0.05

+ Significant at P≤ 0.05 when tested against v_1 and v_2 (v_1= d.f. for sample having larger variance and v_2= d.f. for sample having smaller variance)

Earlier researchers namely, Shakuntla (1996), Gautam (2001), Kalia and Shakuntla (2002) and Gautam *et al*. (2004) have also reported a wide range of variability in the genetic stocks of broccoli.

The pooled analysis of variance over the environments (Table 4.2) revealed that mean squares due to genotypes were significant when tested against mean squares due to genotype × environment (g × e) interactions for all the characters except leaf size without leaf stalk and stalk length. The presence of g x e interactions influenced the variation due to genotypes to the extent that genotypic differences recorded in individual environment vanished for these characters.

The g × e interactions were significant for days to first harvest, number of spears per plant, leaf size without leaf stalk, weight of spears per plant and harvest index when tested against mean squares due to pooled error indicating that performance of genotypes was greatly influenced by environment for these characters. Further, the study also revealed that mean squares due to environments were significant for characters *viz*., days to first harvest, gross weight per plant, plant frame, leaf size with leaf stalk, plant height up to longest leaf, plant height up to head, weight of spears per plant and harvest index when tested against mean squares due to g × e interactions. The F-test of homogeneity over environments showed significant differences for days to first harvest and plant height up to head. Non significant differences were observed for marketable yield per plant, terminal head weight per plant, gross weight per plant, number of spears per plant, head size index, plant frame, leaf size with leaf stalk, leaf size without leaf stalk, plant height up to longest leaf, stalk length, weight of spears per plant and harvest index thereby, the results for these characters were interpreted on the basis of pooled data over the environments.

4.1.2 Mean performance of genotypes

Mean values of sixteen sprouting broccoli genotypes along with their standard error, critical difference, coefficient of variation and range in environment I, environment II and pooled over the environments are given in Appendix III, IV and V, respectively. The salient features of mean estimates are described as below:

4.1.2.1 Days to first harvest

In environment I, days to first harvest of different genotypes varied between 97.67-125.66 with an average of 112.10 days. Genotype Indica (97.67 days) took minimum number of days to first harvest followed by CBH-1 (98.33 days) and both were found to be significantly superior to the early maturing check Palam Samridhi (105.53 days). In environment II and pooled over the environments the ranges for this character varied from 88.00-132.33 and 93.46-129.00 with an average values of 106.54 days and 109.32 days, respectively. Only one genotype *i.e.* CBH-1 (88.00 days, 93.46 days) took minimum number of days to first harvest and was significantly superior to the best (early maturing) check Palam Samridhi (96.66 days, 101.10 days) in environment II and pooled over the environments, respectively.

4.1.2.2 Marketable yield per plant

The estimates of mean values in environment I revealed that marketable yield per plant varied from 126.33-536.66 with an average value of 312.22 g. The highest marketable yield per plant was recorded by Altar (536.66 g) followed by Green Magic (399.33 g) which were significantly superior to the best check Palam Haritika (331.33 g). In environment II, marketable yield per plant of various genotypes ranged from 155.00-546.00 with an average value of 321.29 g. The genotype Altar (546.00 g) recorded the highest marketable yield per plant and appeared to be significantly superior to the best check Palam Haritika (382.00 g). However, in pooled over the environments, the range for marketable yield per

plant varied from 140.66-541.33 with an average of 316.76 g. The genotype Altar (541.33 g) recorded significantly highest marketable yield per plant in comparison to the best check Palam Haritika (356.66 g).

Altar

Green Magic

Palam Haritika (check)

Plate II: The best performing genotypes for marketable yield per plant

CBH-1

Palam Samridhi (check)

Plate III: Early maturing genotypes

4.1.2.3 Terminal head weight per plant

In environment I, the range of different genotypes for terminal head weight per plant varied from 71.33-523.33 with an average value of 291.83 g. The highest terminal head weight per plant was recorded for Altar (523.33 g) followed by Green Magic (384.66 g), BR-70 (346.00 g), Lucky (345.66 g) and Supreme (342.66 g) which were significantly superior to the best check Palam Haritika (298.00 g). In environment II, terminal head weight per plant varied from 126.66-527.66 with an average value of 300.39 g. Genotype Altar (527.66 g) recorded the highest terminal head weight per plant and was found to be significantly superior to the best check Palam Haritika (326.66 g). However, in pooled over the environments the range for this character varied between 99.00-525.50 with an average of 296.11 g. The genotype Altar (525.50 g) followed by Green Magic (369.66 g) and Lucky (348.83 g) showed significantly high terminal head weight per plant in comparison to the best check Palam Haritika (312.33 g).

4.1.2.4 Gross weight per plant

In environment I, gross weight per plant varied between 658.33-1041.66 with an average value of 835.00 g. The highest gross weight per plant was recorded in genotype Green Magic (1041.66 g) followed by Altar (1005.00 g), Fiesta (960.00 g), BR-70 (913.33 g) and Supreme (891.66 g) which were found to be significantly superior to the best check Palam Haritika (731.66 g). On the other hand, the differences between the genotypes for this character in environment II varied from 703.00-1237.33 with an average of 935.10 g. Only one genotype *i.e.* Altar (1237.33 g) recorded significantly high gross weight per plant to the best check Palam Haritika (984.33 g). In pooled over the environments, the range for gross weight per plant varied from 680.66-1121.16 with an average value of 858.05 g. Genotype Altar (1121.16 g) recorded highest gross weight per plant followed by Green Magic (1048.00 g), BR-70 (994.50 g) and Fiesta (970.00 g) and were significantly superior to the best check Palam Haritika (858.00 g).

4.1.2.5 Number of spears per plant

Number of spears per plant among different genotypes in environment I varied between 1.33-9.73 with an average value of 4.92. The maximum number of spears per plant were produced by the genotype Kendi (9.73) most closely followed by Indica (9.26) and both of them were found to be significantly superior to the best check Palam Samridhi (5.46). In environment II the range for this character varied from 1.50-10.66 with an average values of 5.47. Genotype Indica (10.66) recorded maximum number of spears per plant and it was found to be significantly superior to best check Palam Samridhi (6.73). However, in pooled over the environments, the range for number of spears per plant varied from 1.41-9.96 with an average value of 5.20. Genotypes, Indica (9.96) and Kendi (8.36) recorded maximum number of spears per plant and appeared to be significantly superior to the best check Palam Samridhi (6.10).

4.1.2.6 Head size index

Head size index of different genotypes in environment I varied between 140.24-288.81 with an average value of 223.08 cm^2. Only one genotype *i.e.* BR-70 (288.81 cm^2) was found to be significantly superior to the best check Palam Haritika (228.10 cm^2). In environment II, range varied for this character between 122.10-276.73 with an average value of 228.04 cm^2. None of the genotypes could surpass the best check Palam Haritika (276.73 cm^2) for this character. However, genotype Fiesta (270.00 cm^2) followed by Kendi (245.53 cm^2), BR-70 (243.13 cm^2), BR-60 (242.06 cm^2), Altar (240.80 cm^2), Tiltest (238.73 cm^2), Green Magic (231.40 cm^2), Packman (231.23 cm^2), Pluto (228.61 cm^2) and Lucky (224.98 cm^2) were statistically at par with the best check Palam Haritika (276.73 cm^2). However, in pool over the environments, head size index for various genotypes varied between 131.17-257.38 with an average value of 225.56 cm^2. Eleven genotypes *viz*., Fiesta (257.38 cm^2), Kendi (248.20 cm^2), BR-60 (246.18 cm^2), Green Magic (244.58 cm^2), Tiltest (244.02 cm^2), Altar (236.73 cm^2), Packman (236.11 cm^2), BR-70 (235.97 cm^2), Pluto (231.51 cm^2), CBH-1 (228.84 cm^2) and Lucky (222.75 cm^2) were statistically at par with the best check Palam Haritika (252.41 cm^2).

4.1.2.7 Plant Frame

Plant frame of different genotypes in environment I varied between 2857.06-4799.73 with an average of 3681.55 cm^2. The genotype Pluto (4799.73 cm^2) showed highest plant frame and appeared to be significantly superior to the best check Palam Haritika (3747.26 cm^2). The range for this character varied between 2698.26-5239.86 with an average value of 3959.02 cm^2 in environment II. Genotype Altar (5239.86 cm^2) was found to be significantly superior to the best check Palam Haritika (4119.20 cm^2). However, in pooled over the environments, plant frame of different genotypes varied between 2777.66-4837.22 with an average of 3820.28 cm^2. Genotype Altar (4837.22 cm^2) most closely followed by

Pluto (4653.73 cm_2) recorded the highest plant frame and both of them were significantly superior to the best check Palam Haritika (3933.23 cm_2).

4.1.2.8 Leaf size with leaf stalk

In environment I, leaf size with leaf stalk of different genotypes varied from 354.95-771.21 with an average value of 584.07 cm_2. None of the genotypes had significantly higher leaf size with leaf stalk in comparison to the best check Palam Haritika (716.85 cm_2). However, five genotypes *viz*., Altar (771.21 cm_2), BR-60 (689.58 cm_2), Pluto (686.10 cm_2), BR-70 (679.90 cm_2) and Tiltest (635.82 cm_2) were at par with the best check Palam Haritika (716.85 cm_2). In environment II, the range for this character varied from 543.12-825.56 with an average value of 664.30 cm_2. Genotype Altar (825.56 cm_2) followed by BR-70 (792.01 cm_2), Pluto (773.96 cm_2), BR-60 (724.37 cm_2), Tiltest (717.57 cm_2) and Green Magic (712.09 cm_2) were found to be statistically at par with the best check Palam Haritika (806.98 cm_2). The leaf size with leaf stalk of different genotypes in pooled over the environments varied between 476.67-798.39 with an average value of 624.19 cm_2. Four genotypes *viz*., Altar (798.39 cm_2), BR-70 (735.95 cm_2), Pluto (730.03 cm_2) and BR-60 (706.97 cm_2) exhibited similar performance to the best check Palam Haritika (761.92 cm_2).

4.1.2.9 Leaf size without leaf stalk

In environment I, the differences between the genotypes for this character varied from 249.70-452.82 with an average value of 351.59 cm_2. The genotype BR-70 (452.82 cm_2) followed by Altar (445.47 cm_2) showed maximum leaf size without leaf stalk and they appeared to be significantly superior to the best check Palam Haritika (377.22 cm_2). The range for this character in environment II varied from 304.04-470.31 with an average value of 382.50 cm_2. Nine genotypes *viz*., Pluto (470.31 cm_2), Altar (454.19 cm_2), Tiltest (412.57 cm_2), CBH-1 (412.01 cm_2), Green Magic (411.61 cm_2), BR-70 (407.28 cm_2), Fiesta

(396.81 cm_2), BR-60 (383.26 cm_2) and Lucky (358.16 cm_2) were found to be statistically at par with the best check Palam Haritika (429.89 cm_2). The leaf size without leaf stalk of different genotypes in pooled over the environments varied between 297.10-449.83 with an average of 367.04 cm_2. Twelve genotypes namely, Altar (449.83 cm_2), BR-70 (430.05 cm_2), Pluto (408.57 cm_2), Green Magic (397.77 cm_2), BR-60 (387.37 cm_2), Tiltest (385.44 cm_2), CBH-1 (371.06 cm_2), Green Beauty (352.52 cm_2), Fiesta (351.77 cm_2), Packman (347.28 cm_2), Kendi (331.32 cm_2) and Indica (329.91 cm_2) were statistically at par with the best check Palam Haritika (403.55 cm_2).

4.1.2.10 Plant height up to longest leaf

Plant height up to longest leaf of various genotypes in environment I ranged from 41.60-54.93 with an average value of 46.82 cm. Genotypes Altar (52.80 cm) and Pluto (50.86 cm) were statistically at par with best check, Palam Haritika (54.93 cm). In environment II, the range for this character varied between 45.26-59.00 with an average of 51.55 cm. Genotype Tiltest (59.00 cm) appeared to be significantly tallest in comparison to the best check Palam Haritika (51.36 cm). In pooled over the environments, the differences between the genotypes for this character ranged from 44.23-53.61 with an average value of 49.18 cm. None of the genotypes surpassed significantly the best check Palam Haritika (53.15 cm) for plant height up to longest leaf. However, eight genotypes *viz*., Tiltest (53.61 cm), Altar (53.33 cm), Pluto (53.16 cm), Indica (52.95 cm), BR-70 (51.50 cm), BR-60 (51.26), Green Magic (49.33 cm) and Supreme (48.83 cm) were found to be statistically at par with the best check Palam Haritika (53.15 cm).

4.1.2.11 Plant height up to head

In environment I, plant height up to head of various genotypes ranged from 24.53-40.36 with an average of 29.31 cm. Plant height up to head in environment II, ranged from 30.00-45.56 with an average value of 33.81 cm. In

pooled over the environments, range for this character varied between 27.36-42.96 with an average of 31.56 cm. Genotype Indica (40.36 cm, 45.56 cm and 42.96 cm) exhibited significantly maximum plant height up to head in comparison to the best check Palam Haritika (31.96 cm, 36.86 cm and 34.41 cm) in environment I, II and pooled over the environments, respectively.

4.1.2.12 Stalk length

Stalk length of various genotypes in environment I ranged from 2.08-3.25 with an average of 2.48 cm. In environment II, range for this character varied between 2.12-3.17 with an average of 2.50 cm. In pooled over the environments, stalk length ranged from 2.10-3.21 with an average of 2.49 cm. Genotype Indica (3.25 cm, 3.17 cm and 3.21 cm) recorded significantly maximum stalk length to the best check Palam Samridhi (2.53 cm, 2.59 cm and 2.56 cm) in environment I, environment II and pooled over the environments, respectively.

4.1.2.13 Weight of spears per plant

Weight of spears per plant of different genotypes in environment I and pooled over the environments varied between 15.00-173.00 and 20.83-156.66 with an average value of 93.95 g and 101.96 g, respectively. Two genotypes *viz*., Indica (173.00 g, 156.66 g) and Kendi (156.00g, 150.40 g) recorded highest weight of spears per plant and both appeared to be significantly superior to the best check Palam Haritika (110.66 g, 118.99 g) in environment I and pooled over the environments, respectively. In environment II, the range for this character varied between 26.66-157.00 with an average value of 109.96 g. Only one genotype *i.e.* Pluto (157.00 g) was found to be significantly superior to the best check Palam Haritika (127.33 g).

4.1.2.14 Harvest index

In environment I, harvest index of various genotypes ranged from 18.37-51.77 with an average value of 36.65 %. On the other hand in environment II, the range for this character varied from 19.19-46.70 with an average of 34.54 %. However, in pooled over the environments, harvest index ranged between 19.54-

49.23 with an average value of 35.59 %. Genotype Altar (51.77 %, 46.70 % and 49.23 %) recorded significantly highest harvest index to the best check Palam Haritika (43.25 %, 38.99 % and 41.12 %) in both of the environments and pooled over the environments, respectively.

High yield is the basic objective of all crop improvement programme. It is of immense importance to develop a genotype which has a potential to surpass commercially adopted cultivar(s). The perusal of data revealed that amongst sixteen genotypes of sprouting broccoli evaluated in the present investigation, the highest marketable yield per plant was recorded for two genotypes namely, Altar (536.66g, 546.00g and 541.33 g in environment I, II and pooled over the environments, respectively) and Green Magic (399.33 g in environment I) which were significantly superior over the best check Palam Haritika (331.33 g, 382.00 g and 356.66 g in environment I, II and pooled over the environments, respectively). In addition to this, genotype Altar was found to be significantly superior for five characters *viz*., terminal head weight per plant (environment I, II and pooled over the environments), gross weight per plant (environment I, II and pooled over the environments), plant frame (environment II and pooled over the environments), leaf size without leaf stalk (environment I) and harvest index (environment I, II and pooled over the environments). On the other hand, genotype Green Magic was significantly superior for the characters namely, terminal head weight per plant and gross weight per plant (environment I and pooled over the environments).

Earliness is one of the desirable traits as the market prices are invariably high early in the season. Results of the present study revealed significant differences for days to first harvest. Two genotypes *viz*., CBH-1 (98.33 days, 88.00 days and 93.46 days in environment I, II and pooled over the environments, respectively) and Indica (97.67 days in environment I) took minimum number of days to first harvest in comparison to early maturing check Palam Samridhi (105.53 days, 96.66 days and 101.10 days in environment I, II and pooled over the environments, respectively).

4.1.3 Genetic parameters of variability

The environment–wise estimates of genetic parameters of variability *viz*., phenotypic, genotypic and environmental coefficients of variation (PCV, GCV and ECV, respectively) along with heritability in broad sense (h^2_{bs}) and genetic advance (GA) expressed as per cent of mean for different characters have been presented in Tables 4.3, 4.4 and 4.5. The results pertaining to these parameters are briefly presented below:

4.1.3.1 Estimates of parameters of variability in environment I

The knowledge of phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) is helpful in predicting the amount of variation present in the given genetic stock which in turn helps in formulating an efficient breeding programme. In the present investigation, the PCV had greater values than their corresponding GCV values for all the characters which indicated that the apparent variation is not only due to genotypes, but, also due to the influence of environment. Therefore, caution has to be exercised in making selection for these characters on the basis of phenotype alone as environmental variation is unpredictable in nature. Jamwal *et al*. (1992), Radhakrishna 1992, Kalia and Shakuntla (2002), Kanwar and Korla (2002), Gautam *et al*. (2004), Jindal and Thakur (2004), Kumar 2010 and Kumar *et al*. (2011) also found higher PCV values than their GCV values.

A wide range of variability was observed for all the characters studied. Phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) were found to be high (>30%) for number of spears per plant (46.07%, 44.79 %), weight of spears per plant (44.69 %, 42.07 %), terminal head weight per plant (35.97 %, 34.80%) and marketable yield per plant (31.98 %, 30.55%). These high estimates suggest substantial variability for the characters thereby ensuring ample scope for improvement of these characters through selection.

Table 4.3 Estimates of different parameters of variability for various characters of broccoli in environment I (2010-2011)

Sr. No.	Characters	PCV (%)	GCV (%)	ECV (%)	h^2_{bs} (%)	GA (%)
1.	Days to first harvest	7.01	6.21	3.24	78.57	11.34
2.	Marketable yield/plant (g)	31.98	30.55	9.47	91.23	60.11
3.	Terminal head weight/plant (g)	35.97	34.80	9.09	93.61	69.37
4.	Gross weight/plant (g)	15.91	12.31	10.07	59.93	19.64
5.	Number of spears/plant	46.07	44.79	10.77	94.53	89.72
6.	Head size index (cm^2)	18.87	13.18	13.51	48.76	18.96
7.	Plant frame (cm^2)	18.40	13.46	12.55	53.47	20.27
8.	Leaf size with leaf stalk (cm^2)	20.62	18.39	9.33	79.53	33.78
9.	Leaf size without leaf stalk (cm^2)	17.39	13.92	10.41	64.15	22.98
10.	Plant height up to longest leaf (cm)	9.84	6.51	7.37	43.81	8.88
11.	Plant height up to head (cm)	15.76	12.13	10.06	59.26	19.24
12.	Stalk length (cm)	11.38	9.85	5.71	74.84	17.55
13.	Weight of spears/plant (g)	44.69	42.07	15.06	88.64	81.60
14.	Harvest index (%)	24.18	22.00	10.05	82.73	41.22

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

Shakuntla 1996 and Kalia and Shakuntla (2002) reported high estimates of PCV and GCV for terminal head weight per plant, mean spears weight per plant and number of spears per plant. Jamwal *et al*. (1992), Khar (1995), Gautam (2001), Kumar (2002), Pathania (2003), Sharma *et al*. (2006) and Kumar (2010) also reported high PCV and GCV for marketable yield per plant.

The moderate estimates (10-30 %) of PCV were recorded for the characters such as harvest index (24.18 %), leaf size with leaf stalk (20.62 %), head size index (18.87 %), plant frame (18.40 %), leaf size without leaf stalk (17.39 %), gross weight per plant (15.91 %), plant height up to head (15.76 %) and stalk length (11.38 %). Moderate estimates of GCV were observed for harvest index (22.00 %), leaf size with leaf stalk (18.39 %), leaf size without leaf stalk (13.92 %), plant frame (13.46 %), head size index (13.18 %), gross weight per plant (12.31 %) and plant height up to head (12.13 %). These moderate estimates suggested that direct selection for these characters should be considered cautiously. Similar results of moderate estimates of PCV and GCV for various characters were reported by different workers *viz.,* Gautam (2001) for harvest index, Khar (1995) and Kumar *et al*. (2006) for leaf size index, Khar (1995) for curd size index and Kalia (1995) and Kalia and Shakuntla (2002) for plant height up to head and head size index.

Low estimates of PCV and GCV (<10 %) were observed for days to first harvest (7.01 %, 6.21 %) and plant height up to longest leaf (9.84 %, 6.51 %). GCV was found to be low for stalk length (9.85%). Jamwal *et al*. (1992), Kalia (1995), Gautam (2001), Kalia and Shakuntla (2002), Jindal and Thakur (2004) and Kumar *et al*. (2006) reported low PCV and GCV for days to first harvest. Kumar *et al*. (2006) observed low estimates of PCV and GCV for stalk length. Low to moderate environmental coefficients of variation (ECV) for all the characters indicated the existence of inherent genetic variability for most of the characters under study.

A useful measure of considering the ratio of genetic variance to the total phenotypic variance is heritability. The information on heritability estimates is helpful in studying the inheritance of quantitative characters as well as for planning breeding programmes with desired degree of expected genetic advance. The heritability estimates in broad sense comprise both additive and non additive gene effects and in narrow sense, include only additive gene effects (Johnson *et al*. 1955). Knowledge of heritability of a trait is an essential tool which can be employed by the breeders in improving the traits under the specified situation.

In the present study, the heritability estimates were high (>60 %) for number of spears per plant (94.53 %), terminal head weight per plant (93.61 %), marketable yield per plant (91.23 %), weight of spears per plant (88.64 %), harvest index (82.73 %), leaf size with leaf stalk (79.53 %), days to first harvest (78.57 %), stalk length (74.84 %) and leaf size without leaf stalk (64.15 %). The high heritability estimates for these characters revealed lesser influence of the environment and greater role of genetic component of variation. Therefore, the selection for these characters on the basis of phenotypic expression would be more effective and can be relied upon.

The results pertaining to high heritability are in accordance with the findings of earlier researchers for number of spears per plant (Shakuntla 1996; Kalia and Shakuntla 2002), terminal head weight per plant (Khattra *et al*. 1997; Kalia and Shakuntla 2002), marketable yield per plant (Dutta 1991; Shakuntla 1996; Gautam 2001; Kalia and Shakuntla 2002; Sharma *et al*. 2006; Dhatt and Garg 2008; Kumar 2010), weight of spears per plant (Shakuntla 1996; Khattra *et al*. 1997; Kalia and Shakuntla 2002), harvest index (Kanwar and Korla2002; Jindal and Thakur 2004; Kumar 2010), leaf size (Jamwal *et al*. 1992; Shakuntla 1996; Kumar 2010) and days to first harvest (Dhiman 1979; Radhakrishna 1992; Radhakrishna and Korla 1994; Khattra *et al*. 1997; Gautam 2001; Kanwar and Korla 2002; Kumar 2002; Kumar 2010).

Heritability estimates were moderate (30-60 %) for characters namely, gross weight per plant (59.93 %), plant height up to head (59.26 %), plant frame (53.47 %), head size index (48.76 %) and plant height up to longest leaf (43.81 %). Moderate estimates of heritability have also been reported by earlier workers for gross weight per plant (Gautam 2001), plant height (Jindal and Thakur 2004) and plant frame (Jindal and Thakur 2004).

For an effective selection programme, knowledge of estimates of heritability alone is not sufficient and genetic advance, if studied along with heritability, is more useful. Genetic advance may or may not be in proportion to genetic variability and heritability estimates because both high heritability and high genetic variability are important to obtain higher genetic gain.

In the present study, the results revealed that the response to selection for different characters which showed high heritability need to be given due emphasis for effective selection and suggested that these characters were under genetic control. However, high heritability does not necessarily mean high genetic gain and alone is not sufficient to make improvement through simple phenotypic selection. The heritability estimates become more beneficial when used to estimate genetic advance (Johnson *et al*. 1955).

The high expected genetic advance (>30%) expressed as percentage of mean was observed for number of spears per plant (89.72 %), weight of spear per plant (81.60 %), terminal head weight per plant (69.37 %), marketable yield per plant (60.11 %), harvest index (41.22 %) and leaf size with leaf stalk (33.78 %). Earlier workers also reported high genetic advance for number of spears per plant (Shakuntla 1996; Kalia and Shakuntla 2002), weight of spears per plant (Shakuntla 1996; Khattra *et al*. 1997; Kalia and Shakuntla 2002), terminal head weight per plant (Shakuntla 1996; Kalia and Shakuntla 2002), marketable yield per plant (Dhiman 1979; Jamwal *et al*. 1992; Shakuntla 1996; Gautam 2001; Kalia and Shakuntla 2002; Kumar 2002; Sharma *et al*. 2006; Dhatt and Garg 2008; Kumar 2010), harvest index (Jindal and Thakur 2004) and leaf size (Kumar 2010). The characters showing high genetic advance indicated that these

characters are governed by additive gene action and selection will be more rewarding for the improvement of such characters.

The estimates of genetic advance were moderate (10-30 %) for leaf size without leaf stalk (22.98 %), plant frame (20.27 %), gross weight per plant (19.64 %), plant height up to head (19.24 %), head size index (18.96 %), stalk length (17.55 %) and days to first harvest (11.34 %). Low expected genetic advance (<10 %) was exhibited by plant height up to longest leaf (8.88 %). Khattra *et al*. (1997) and Jindal and Thakur (2004) also observed low genetic advance for plant height.

For predicting reliable estimates of additive and non additive effects, heritability should be considered in conjugation with genetic advance (Johnson *et al*. 1955). On this consideration, high heritability coupled with high genetic advance were observed for number of spears per plant (94.53 %, 89.72 %), terminal head weight per plant (93.61%, 69.37 %), marketable yield per plant (91.23 %, 60.11 %), weight of spears per plant (88.64 %, 81.60 %), harvest index (82.73 %, 41.22 %) and leaf size with leaf stalk (79.53 %, 33.78 %). The results indicated that most likely the heritability is due to additive gene effects and direct selection may be effective for these characters. Shakuntla (1996) and Kalia and Shakuntla (2002) also reported the similar findings for number of spears per plant, terminal head weight per plant, mean spears weight per plant and leaf size. High heritability accompanied with high genetic advance for marketable yield per plant was reported by Dutta (1991), Jamwal *et al*. (1992), Khar (1995), Shakuntla (1996), Pathania (2003), Gautam *et al*. (2004), Kumar *et al*. (2006), Sharma *et al*. (2006) and Kumar (2010).

High heritability along with moderate genetic advance were observed for days to first harvest (78.57 %, 11.34 %), stalk length (74.84 %, 17.55 %) and leaf size without leaf stalk (64.15 %, 22.98 %). The results of present study indicated the presence of additive and non-additive gene action, providing scope for improvement of these characters through hybridization and selection. Similar

findings have also been reported for leaf size (Dhatt and Garg 2008) and stalk length (Kanwar and Korla 2002). On the other hand, gross weight per plant (59.93 %, 19.64 %), plant height up to head (59.26 %, 19.24 %), plant frame (53.47 %, 20.27 %) and head size index (48.76 %, 18.96 %) had shown moderate heritability coupled with moderate genetic advance. These estimates indicated the role of dominance and epistasis hence, these characters could be improved through hybridization/ recombination breeding.

Moderate heritability coupled with low genetic advance was found for plant height up to longest leaf (43.81 %, 8.88 %). The characters with low heritability could be improved through hybridization (Liang and Walter 1969).

4.1.3.2 Estimates of parameters of variability in environment II

The perusal of data in environment II revealed that values of phenotypic coefficients of variation (PCV) were higher than their respective genotypic coefficients of variation (GCV) indicating considerable influence of environment on the performance of genotypes. Similar findings with respect to PCV and GCV have also been reported earlier by Jamwal *et al*. (1992), Radhakrishna (1992), Kalia and Shakuntla (2002), Kanwar and Korla (2002), Gautam *et al*. (2004), Jindal and Thakur (2004), Kumar (2010) and Kumar *et al*. (2011). The high PCV and GCV (>30 %) values were observed for number of spears per plant (39.94 %, 38.30 %) and weight of spears per plant (36.84 %, 33.66 %). High PCV value was recorded for terminal head weight per plant (31.19 %). Shakuntla (1996) and Kalia and Shakuntla (2002) also observed high PCV and GCV for number of spears per plant and mean spears weight per plant.

The estimates of PCV were moderate (10-30 %) for marketable yield per plant (29.37 %), leaf size without leaf stalk (25.93 %), harvest index (20.20 %), head size index (19.54 %), gross weight per plant (18.18 %), plant frame (17.47 %), leaf size with leaf stalk (17.01 %), plant height up to head (14.65 %), days to first harvest (11.86 %) and stalk length (10.38 %). The moderate (10-30 %) GCV values were noticed for terminal head weight per plant (29.47 %), marketable yield per plant (27.64 %), leaf size without leaf stalk (23.46 %), harvest index

(17.69 %), gross weight per plant (14.75 %), leaf size with leaf stalk (13.60 %), head size index (13.47 %), plant frame (12.92 %) and days to first harvest (10.81 %). The moderate estimates of PCV and GCV have also been reported by Khar (1995) and Kumar *et al*. (2006) for leaf size index, Gautam *et al*. (2004) for harvest index and Kalia and Shakuntla (2002) for plant height up to head and head size index.

The low estimates of PCV (<10 %) were observed for plant height up to longest leaf (9.11 %). Low GCV (<10 %) was recorded for characters namely, plant height up to head (8.67 %), stalk length (8.38 %) and plant height up to longest leaf (6.92 %). Kumar *et al*. (2006) reported low estimates of PCV and GCV for stalk length. Low to moderate environmental coefficient of variation (ECV) for all the characters indicated the existence of inherent genetic variability for most of the characters under study.

Table 4.4 Estimates of different parameters of variability for various characters of broccoli in environment II (2011-2012)

Sr. No.	Characters	PCV (%)	GCV (%)	ECV (%)	h^2_{bs} (%)	GA (%)
1.	Days to first harvest	11.86	10.81	4.86	83.17	20.32
2.	Marketable yield/plant (g)	29.37	27.64	9.92	88.58	53.60
3.	Terminal head weight/plant (g)	31.19	29.47	10.21	89.28	57.36
4.	Gross weight/plant (g)	18.18	14.75	10.62	65.83	24.65
5.	Number of spears/plant	39.94	38.30	11.32	92.01	75.66
6.	Head size index (cm_2)	19.54	13.47	14.15	47.55	19.14
7.	Plant frame (cm_2)	17.47	12.92	11.75	54.75	19.70

8.	Leaf size with leaf stalk (cm_2)	17.01	13.60	10.20	64.01	22.42
9.	Leaf size without leaf stalk (cm_2)	25.93	23.46	11.04	81.87	43.72
10.	Plant height up to longest leaf (cm)	9.11	6.92	7.36	46.92	9.77
11.	Plant height up to head (cm)	14.65	8.67	11.80	35.09	10.59
12.	Stalk length (cm)	10.38	8.38	6.12	65.21	13.95
13.	Weight of spears/plant (g)	36.84	33.66	14.98	83.46	63.35
14.	Harvest index (%)	20.20	17.69	9.75	76.70	31.92

PCV, GCV and ECV represent phenotypic, genotypic and environmental coefficients of variations, respectively; h_{2bs}: Heritability in broad sense; GA (%): Genetic advance (%) of mean

High heritability estimates (>60 %) were observed for number of spears per plant (92.01%), terminal head weight per plant (89.28 %), marketable yield per plant (88.58%), weight of spears per plant (83.46 %), days to first harvest (83.17 %), leaf size without leaf stalk (81.87 %), harvest index (76.70 %), gross weight per plant (65.83 %), stalk length (65.21 %) and leaf size with leaf stalk (64.01 %). Earlier researchers also revealed high heritability estimates for number of spears per plant (Shakuntla 1996; Kalia and Shakuntla 2002), terminal head weight per plant (Shakuntla 1996 ; Khattra *et al*. 1997), marketable yield per plant (Dutta 1991; Shakuntla 1996; Gautam 2001; Kalia and Shakuntla 2002; Sharma *et al*. 2006; Dhatta and Garg 2008; Kumar 2010), weight of spears per plant (Shakuntla 1996; Khattra *et al*. 1997; Kalia and Shakuntla 2002), days to first harvest (Dhiman 1979; Radhakrishna 1992; Radhakrishna and Korla 1994; Khattra *et al*. 1997; Gautam 2001; Kanwar and Korla 2002; Kumar 2002; Kumar 2010), harvest index (Kanwar and Korla 2002; Jindal and Thakur 2004; Kumar 2010) and leaf size (Jamwal *et al*. 1992; Shakuntla 1996; Kumar 2010).

Moderate heritability (30-60 %) was recorded for plant frame (54.75 %), head size index (47.55 %), plant height up to longest leaf (46.92 %) and plant height up to head (35.09 %). Jindal and Thakur (2004) reported moderate heritability for plant frame.

Expected genetic advance expressed as percentage of mean was recorded high (>30 %) for number of spears per plant (75.66 %), weight of spear per plant (63.35 %), terminal head weight per plant (57.36 %), marketable yield per plant (53.60%), leaf size without leaf stalk (43.72%) and harvest index (31.92 %). High estimates of genetic advance were observed by earlier researchers for number of spears per plant (Shakuntla 1996; Kalia and Shakuntla 2002), weight of spears per plant (Shakuntla 1996; Khattra *et al*. 1997; Kalia and Shakuntla 2002), terminal head weight per plant (Shakuntla 1996; Kalia and Shakuntla 2002), marketable yield per plant (Dhiman 1979; Jamwal *et al*. 1992; Shakuntla 1996; Gautam 2001; Kalia and Shakuntla 2002; Kumar 2002; Sharma *et al*. 2006; Dhatt and Garg 2008; Kumar 2010), harvest index (Jindal and Thakur 2004) and leaf size (Kumar 2010). The estimates were moderate (10-30 %) for gross weight per plant (24.65 %), leaf size with leaf stalk (22.42 %), days to first harvest (20.32 %), plant frame (19.70 %), head size index (19.14 %), stalk length (13.95 %) and plant height up to head (10.59). The expected genetic advance was low (<10%) for plant height up to longest leaf (9.77 %).

Based on the present study, high heritability along with high genetic advance were observed for number of spears per plant (92.01 %, 75.66 %), terminal head weight per plant (89.28 %, 57.36 %), marketable yield per plant (88.58 %, 53.60 %), weight of spears per plant (83.46 %, 63.35 %), leaf size without leaf stalk (81.87%, 43.72 %) and harvest index (76.70 %, 31.92 %). Kalia and Shakuntla (2002) reported high heritability coupled with high genetic advance for number of spears per plant, terminal head weight per plant, mean weight of spears per plant and leaf size. High heritability accompanied with high genetic advance for marketable yield per plant was reported by Dutta (1991), Jamwal *et al*. (1992), Khar (1995), Shakuntla (1996), Gautam *et al*. (2004), Kumar *et al*. (2006), Sharma *et al*. (2006) and Kumar (2010). On the other hand,

high heritability coupled with moderate genetic advance were recorded for days to first harvest (83.17 %, 20.32 %), gross weight per plant (65.83 %, 24.65 %), stalk length (65.21 %, 13.95 %) and leaf size with leaf stalk (64.01 %, 22.42 %). Similar findings have also been reported for stalk length by Kanwar and Korla (2002).

Moderate heritability along with moderate genetic advance were observed for plant frame (54.75 %, 19.70 %), head size index (47.55 %, 19.14 %) and plant height up to head (35.09 %, 10.59 %) whereas moderate heritability coupled with low genetic advance was recorded for plant height up to longest leaf (46.92 %, 9.77 %).

4.1.3.3 Estimates of parameters of variability in pooled over the environments

In pooled over the environments, the PCV values were higher than their corresponding GCV values for all the characters studied which indicated that the apparent variation is not only due to genotypes, but, also due to the influence of environment. Similar findings with respect to PCV and GCV have also been reported earlier by Radhakrishna (1992), Kalia and Shakuntla (2002), Kanwar and Korla (2002), Gautam *et al*. (2004), Kumar (2020) and Kumar (2010).

Table 4.5 Estimates of different parameters of variability for various characters of broccoli in pooled over the environments

Sr. No.	Characters	PCV (%)	GCV (%)	ECV (%)	h^2_{bs} (%)	GA (%)
1.	Days to first harvest	9.62	8.01	5.32	69.40	13.76
2.	Marketable yield/plant (g)	30.67	29.01	9.96	89.44	56.51
3.	Terminal head weight/plant (g)	33.60	31.96	10.38	90.46	62.61
4.	Gross weight/plant (g)	17.23	13.49	10.73	61.26	21.75

5.	Number of spears/plant	42.85	38.93	17.89	82.56	72.86
6.	Head size index (cm_2)	19.22	12.85	14.28	44.76	17.72
7.	Plant frame (cm_2)	17.92	13.03	12.29	52.92	19.53
8.	Leaf size with leaf stalk (cm_2)	18.71	15.55	10.39	69.12	26.64
9.	Leaf size without leaf stalk (cm_2)	22.67	14.81	17.16	42.67	19.93
10.	Plant height up to longest leaf (cm)	10.00	6.42	7.67	41.22	8.49
11.	Plant height up to head (cm)	15.17	10.19	11.24	45.15	14.11
12.	Stalk length (cm)	10.89	8.86	6.34	66.11	14.84
13.	Weight of spears/plant (g)	40.46	35.31	19.75	76.17	63.50
14.	Harvest index (%)	22.41	19.67	10.74	77.03	35.35

PCV, GCV and ECV represent phenotypic, genotypic and environmental coefficients of variations, respectively; h_{2bs}: Heritability in broad sense; GA (%): Genetic advance (%) of mean

The high estimates (>30 %) of PCV and GCV were observed for number of spears per plant (42.85 %, 38.93 %), weight of spears per plant (40.46 %, 35.31 %) and terminal head weight per plant (33.60%, 31.96%). High PCV was recorded for marketable yield per plant (30.67 %). The moderate estimates (10-30 %) of PCV were observed for leaf size without leaf stalk (22.67 %), harvest index (22.41 %), head size index (19.22 %), leaf size with leaf stalk (18.71 %), plant frame (17.92 %), gross weight per plant (17.23 %), plant height up to head (15.17 %), stalk length (10.89 %) and plant height up to longest leaf (10.00 %). Estimates of GCV were moderate for marketable yield per plant (29.01 %), harvest index (19.67 %), leaf size with leaf stalk (15.55 %), leaf size without leaf

stalk (14.81 %), gross weight per plant (13.49 %), plant frame (13.03 %), head size index (12.85 %) and plant height up to head (10.19 %). Similar results of moderate PCV and GCV for various characters were reported by different workers *viz.,* Gautam *et al*. (2004) for harvest index, Khar (1995) and Kumar *et al*. (2006) for leaf size index and Kalia and Shakuntla (2002) for plant height up to head and head size index. Low estimates (<10 %) of PCV were observed for days to first harvest (9.62 %). Estimates of GCV were low for stalk length (8.86 %), days to first harvest (8.01 %) and plant height up to longest leaf (6.42 %). Low to moderate environmental coefficient of variation (ECV) for all the characters indicated the existence of inherent genetic variability for most of the characters under study.

Estimates of heritability were high (>60 %) for terminal head weight per plant (90.46 %), marketable yield per plant (89.44 %), number of spears per plant (82.56 %), harvest index (77.03 %), weight of spears per plant (76.17 %), days to first harvest (69.40 %), leaf size with leaf stalk (69.12 %), stalk length (66.11 %) and gross weight per plant (61.26 %). The results pertaining to high heritability were in accordance with the findings of earlier research workers for terminal head weight per plant (Shakuntla 1996; Khattra *et al*. 1997), marketable yield per plant (Dutta 1991; Shakuntla 1996; Gautam 2001; Kalia and Shakuntla 2002; Dhatt and Garg 2008; Kumar 2010), number of spears per plant (Shakuntla 1996; Kalia and Shakuntla 2002), harvest index (Jindal and Thakur 2004; Kumar 2010), weight of spears per plant (Shakuntla 1996; Khattra *et al*. 1997; Kalia and Shakuntla 2002), days to first harvest (Dhiman 1979; Radhakrishna 1992; Radhakrishna and Korla 1994; Khattra *et al*. 1997; Gautam 2001; Kanwar and Korla 2002; Kumar 2010) and leaf size (Jamwal *et al*. 1992; Shakuntla 1996; Kumar 2010). However, heritability estimates were moderate (30-60 %) for rest of the characters *viz*., plant frame (52.92 %), plant height up to head (45.15 %), head size index (44.76 %), leaf size without leaf stalk (42.67 %) and plant height up to longest leaf (41.22 %). These moderate estimates of heritability have also been reported for plant frame by Jindal and Thakur (2004).

Expected genetic advance expressed as percentage of mean was high (>30 %) for number of spears per plant (72.86 %), weight of spear per plant (63.50 %), terminal head weight per plant (62.61 %), marketable yield per plant (56.51%) and harvest index (35.35 %). High estimates of genetic advance were observed by earlier workers for number of spears per plant (Shakuntla 1996; Kalia and Shakuntla 2002), weight of spears per plant (Shakuntla 1996; Khattra *et al.* 1997; Kalia and Shakuntla 2002), terminal head weight per plant (Shakuntla 1996; Kalia and Shakuntla 2002), marketable yield per plant (Dhiman 1979; Jamwal *et al*. 1992; Shakuntla 1996; Gautam 2001; Kalia and Shakuntla 2002; Sharma *et al*. 2006; Dhatt and Garg 2008; Kumar 2010) and harvest index (Jindal and Thakur 2004). The estimates were moderate (10-30 %) for leaf size with leaf stalk (26.64 %), gross weight per plant (21.75 %), leaf size without leaf stalk (19.93 %), plant frame (19.53 %), head size index (17.72 %), stalk length (14.84 %), plant height up to head (14.11 %) and days to first harvest (13.76 %). The expected genetic advance was found to be low (<10 %) for plant height up to longest leaf (8.49 %).

High heritability along with high genetic advance were recorded for terminal head weight per plant (90.46 %, 62.61 %), marketable yield per plant (89.44 %, 56.51 %), number of spears per plant (82.56 %, 72.86 %), harvest index (77.03 %, 35.35 %) and weight of spears per plant (76.17 %, 63.50 %). Kalia and Shakuntla (2002) also reported the similar findings for number of spears per plant, terminal head weight per plant and mean spears weight per plant. High heritability accompanied with high genetic advance for marketable yield per plant were reported by Dutta (1991), Jamwal *et al*. (1992), Khar (1995), Shakuntla (1996), Pathania (2003), Gautam *et al*. (2004), Kumar *et al*. (2006), Sharma *et al*. (2006) and Kumar (2010). High heritability coupled with moderate genetic advance were recorded for days to first harvest (69.40 %, 13.76 %), leaf size with leaf stalk (69.12 %, 26.64 %), stalk length (66.11 %, 14.84 %) and gross weight per plant (61.26 %, 21.75 %). Kanwar and Korla (2002) observed high heritability with moderate genetic advance for stalk length. Moderate

heritability accompanied with moderate genetic advance were recorded for plant frame (52.92 %, 19.53 %), plant height up to head (45.15 %, 14.11 %), head size index (44.76 %, 17.72 %) and leaf size without leaf stalk (42.67 %, 19.93 %). On the other hand, moderate heritability coupled with low genetic advance were noticed for plant height up to longest leaf (41.22 %, 8.49 %).

Besides this, the breeder's interest lies in assessing the performance of an individual genotype with respect to economic characters under selection. In the present investigations, genotypes Altar and Green Magic showed high yield potential and other desirable economic characters. The superior performance of these genotypes for terminal head weight per plant, gross weight per plant, harvest index resulted in high yield since these characters also exhibited high to moderate phenotypic and genotypic coefficients of variation, heritability and genetic advance.

4.2 Correlation coefficient analysis

Yield is a complex character and is a function of several component characters and their interaction with environment. Direct selection based on yield alone will not be very effective in breeding programme. The effectiveness of any breeding/selection programme depends upon the nature and association between yield and other component characters, as more directly and positively a character is associated with yield in desirable direction, more will be the success of the selection programme. Therefore, besides getting information on the nature and magnitude of variation, it is also important to have knowledge on the association of marketable yield with other characters and among themselves and their basis to identify characters for increasing the efficiency of both direct and indirect selection and thereby defining an ideal plant type. Based on the estimates of genotypic and phenotypic correlations, the breeder can decide the method of breeding to be followed to exploit the useful correlation. The results on correlations computed at phenotypic and genotypic levels for all possible paired

combinations in environment I, environment II and pooled over the environments are presented in Tables 4.6, 4.7 and 4.8, respectively.

4.2.1 Estimates of correlation coefficients at phenotypic (P) and genotypic (G) levels in environment I

At phenotypic level, marketable yield per plant had significant and positive association with terminal head weight per plant, harvest index, gross weight per plant, head size index, days to first harvest, leaf size without leaf stalk and leaf size with leaf stalk indicating that these characters have effectively contributed towards increase in the marketable yield per plant. These findings are in consonance with those of earlier research workers who found significant and positive association of marketable yield per plant with terminal head weight per plant (Shakuntla 1996; Shakuntla *et al*. 1999; Khattra *et al*. 2001), harvest index (Dutta 1991; Khar 1995; Shakuntla 1996; Kumar 1999; Kanwar and Korla 2002; Kumar 2010; Kumar *et al*. 2011), gross weight per plant (Dhiman 1979; Thamburaj *et al*. 1982; Dhiman *et al*. 1983; Dutta 1991; Jamwal *et al*. 1992; Radhakrishna 1992; Khar 1995; Radhakrishna and Korla 1995; Kumar 1999; Shakuntla 1996; Shakuntla *et al*. 1999; Kanwar and Korla 2002; Gautam *et al*. 2004; Kumar *et al*. 2004; Kumar *et al*. 2005; Sharma *et al.* 2006; Kumar 2010), head size index (Dhiman 1979; Dhiman *et al*. 1983; Dutta 1991; Jamwal *et al*. 1992; Khar 1995; Shakuntla 1996; Shakuntla *et al*. 1999; Garg and Lal 2004; Gautam *et al*. 2004; Rattan *et al*. 2006; Sharma *et al.* 2006; Kumar 2010), days to first harvest (Dutta 1991; Radhakrishna 1992; Radhakrishna and Korla 1995; Shakuntla 1996; Dhatt and Garg 2008) and leaf size index (Sharma *et al*. 1982; Kumar 1999; Gautam *et al*. 2004; Kumar *et al*. 2005; Dhatt and Garg 2008). On the other hand, marketable yield per plant showed significant negative association with plant height up to head, stalk length, number of spears per plant and weight of spears per plant. Negative association of marketable yield per plant with stalk length was also observed by Kumar (2010).

Tables 4.6 Estimates of phenotypic (P) and genotypic (G) correlation coefficients for different characters of broccoli in environment I (2010-2011)

Characters		Marketable yield/plant (g)	Days to first harvest	Terminal head weight/plant (g)	Gross weight/ plant (g)	Number of spears/ plant	Head size index (cm_2)	Plant frame (cm_2)	Leaf size with leaf stalk (cm_2)	Leaf size without leaf stalk (cm_2)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/ plant (g)
Days to first harvest	P	0.5238*												
	G	0.6072*												
Terminal head weight/plant (g)	P	0.9194*	0.5202*											
	G	1.0032*	0.6389*											
Gross weight/plant (g)	P	0.5807*	0.2865*	0.6250*										
	G	0.8179*	0.4773*	0.8115*										
Number of spears/plant	P	-0.5147*	-0.5854*	-0.5094*	-0.3527*									
	G	-0.5406*	-0.6557*	-0.5604*	-0.5261*									
Head size index (cm_2)	P	0.5686*	0.3004*	0.4658*	0.2330	-0.1938								
	G	0.7501*	0.2787	0.7842*	0.6331*	-0.2662								
Plant frame (cm_2)	P	0.1084	0.2631	0.1140	0.1958	-0.3884*	-0.0678							
	G	0.1636	0.5648*	0.1020	0.3815*	-0.5916*	-0.2077							
Leaf size with leaf stalk (cm_2)	P	0.2965*	0.3543*	0.3270*	0.2652	-0.2766	0.0434	0.2099						
	G	0.3509*	0.4020*	0.3697*	0.3646*	-0.3157*	0.1018	0.3601*						
Leaf size without leaf stalk (cm_2)	P	0.3006*	0.3662*	0.3121*	0.2500	-0.2018	0.1367	0.0683	0.5795*					
	G	0.3531*	0.3865*	0.4053*	0.5204*	-0.2063	0.1164	0.1124	0.7622*					
Plant height up to longest leaf (cm)	P	0.2175	0.2399	0.1926	0.0535	-0.2085	0.0025	0.3822*	0.5757*	0.3694*				
	G	0.3132*	0.5726*	0.2403	0.1297	-0.3779*	0.0041	0.2191	1.0310*	0.7668*				
Plant height up to head (cm)	P	-0.5609*	-0.6559*	-0.6076*	-0.4107*	0.6275*	-0.3250*	-0.1709	-0.2038	-0.2780	0.1535			
	G	-0.7855*	-	-0.8197*	-	0.8266*	-	-	-0.2574	-0.3121*	-0.2685			

			0.8449*		0.8111*		0.6961*	0.6015*						
Stalk length (cm)	P	-0.5150*	-0.5279*	-0.5359*	-0.4052*	0.4174*	-0.4302*	-0.1831	-0.2369	-0.2202	0.0038	0.6013*		
	G	-0.5868*	-0.7308*	-0.6242*	-0.6651*	0.4765*	-0.6927*	-0.0890	-0.3205*	-0.3611*	0.0403	0.8746*		
Weight of spears/plant (g)	P	-0.4444*	-0.3512*	-0.4003*	-0.2925*	0.8234*	-0.1243	-0.4514*	-0.1643	-0.0940	-0.0580	0.5000*	0.2901*	
	G	-0.4554*	-0.4004*	-0.4561*	-0.4392*	0.8748*	-0.2213	-0.7854*	-0.1839	-0.0755	-0.1365	0.7056*	0.3929*	
Harvest index (%)	P	0.8639*	0.6012*	0.8307*	0.2938*	-0.4488*	0.4695*	0.0806	0.2438	0.1569	0.1663	-0.5468*	-0.5048*	-0.3442*
	G	0.9228*	0.7173*	0.9492*	0.5803*	-0.4959*	0.6508*	0.0951	0.3014*	0.1885	0.3049*	-0.7741*	-0.5915*	-0.3505*

*Significant at P≤ 0.05

Among other characters, days to first harvest had significant positive correlation with harvest index, terminal head weight per plant, leaf size without leaf stalk, leaf size with leaf stalk, head size index and gross weight per plant while, it showed significant and negative association with plant height up to head, number of spears per plant, stalk length and weight of spears per plant. Shakuntla (1996) noticed significant and positive association of days to first harvest with terminal head weight per plant whereas Kanwar and Korla (2002) observed significant negative association of days to first harvest with stalk length.

Terminal head weight per plant showed significant and positive association with harvest index, gross weight per plant, head size index, leaf size with leaf stalk and leaf size without leaf stalk whereas it exhibited significant negative correlation with plant height up to head, stalk length, number of spears per plant and weight of spears per plant. Guan *et al*. (1995) observed significant and positive correlation of terminal head weight with plant weight. Significant and positive association of terminal head weight per plant with gross weight per plant, head size index and leaf size was also reported by Shakuntla (1996). Gross weight per plant was significantly and positively correlated with harvest index whereas it showed significant and negative association with plant height up to head, stalk length, number of spears per plant and weight of spears per plant. Kumar (2010) observed significant and positive association of gross weight per plant with harvest index.

Number of spears per plant were significantly and positively associated with weight of spears per plant, plant height up to head and stalk length and negatively associated with harvest index and plant frame. Significant and positive correlation of head size index was observed with harvest index whereas it exhibited significant and negative correlation with stalk length and plant height up to head. Plant frame exhibited significant and positive association with plant height up to longest leaf and significant negative association with weight of spears per plant.

Leaf size with leaf stalk and leaf size without leaf stalk, both were found to be significantly and positively associated with plant height up to longest leaf. In addition, leaf size with leaf stalk had significant and positive correlation with leaf size without leaf stalk. Significant positive associations were observed for plant height up to head with stalk length and weight of spears per plant. Stalk length was significantly and positively correlated with weight of spears per plant. Plant height up to head, stalk length and weight of spears per plant were significantly and negatively correlated with harvest index.

In general, values of genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients for most of the characters studied, suggesting strong inherent relationship between the various characters. Similar results have also been reported by earlier researchers (Dhiman *et al*. 1983; Shakuntla *et al*. 1999; Kumar *et al*. 2004). It was also found that the general trend of associations among various characters at genotypic level remained the same as that at phenotypic level *viz*., the positive phenotypic correlation coefficient values were positive at genotypic levels and vice-versa.

4.2.2 Estimates of correlation coefficients at phenotypic (P) and genotypic (G) levels in environment II

At phenotypic level, marketable yield per plant had significant and positive association with terminal head weight per plant, gross weight per plant, harvest index, head size index, days to first harvest, leaf size with leaf stalk and plant frame indicating that selection on the basis of these traits will lead to higher marketable yield. However, marketable yield per plant showed significant and negative correlation with number of spears per plant, weight of spear per plant, stalk length and plant height up to head. Earlier many research workers have also reported significant and positive association of marketable yield per plant with terminal head weight per plant (Shakuntla 1996; Shakuntla *et al*. 1999; Khattra *et al*. 2001), gross weight per plant (Dhiman 1979; Thamburaj *et al.* 1982; Dhiman *et al*. 1983; Dutta 1991; Jamwal *et al*. 1992; Radhakrishna 1992; Khar 1995; Radhakrishna and Korla 1995; Kumar 1999; Shakuntla 1996; Shakuntla *et*

al. 1999; Kanwar and Korla 2002; Gautam *et al*. 2004; Kumar *et al*. 2004; Kumar *et al*. 2005; Sharma *et al.* 2006; Kumar 2010), harvest index (Dutta 1991; Khar 1995; Shakuntla 1996; Kumar 1999; Kanwar and Korla 2002; Kumar 2010; Kumar *et al*. 2011), head size index (Dhiman 1979; Dhiman *et al*. 1983; Dutta

Tables 4.7 Estimates of phenotypic (P) and genotypic (G) correlation coefficients for different characters of broccoli in environment II (2011-2012)

Characters		Marketable yield/plant (g)	Days to first harvest	Terminal head weight/plant (g)	Gross weight/ plant (g)	Number of spears/ plant	Head size index (cm_2)	Plant frame (cm_2)	Leaf size with leaf stalk (cm_2)	Leaf size without leaf stalk (cm_2)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/ plant (g)
Days to first harvest	P	0.4792*												
	G	0.5604*												
Terminal head weight/plant (g)	P	0.9887*	0.4229*											
	G	0.9917*	0.5022*											
Gross weight/plant (g)	P	0.7995*	0.4333*	0.7968*										
	G	0.9535*	0.6178*	0.9487*										
Number of spears/plant	P	-0.5580*	-0.3231*	-0.5836*	-0.4939*									
	G	-0.6008*	-0.4138*	-0.6266*	-0.0613									
Head size index (cm_2)	P	0.5312*	0.3310*	0.5131*	0.3535*	-0.3258*								
	G	0.6257*	0.5118*	0.6192*	0.3520*	-0.5100*								
Plant frame (cm_2)	P	0.3989*	0.3498*	0.3699*	0.4070*	-0.2975*	-0.0316							
	G	0.4448*	0.6558*	0.3952*	0.7345*	-0.4034*	-0.1431							
Leaf size with leaf stalk (cm_2)	P	0.4607*	0.1769	0.3964*	0.3677*	-0.1071	0.2498	0.3606*						
	G	0.5982*	0.3042*	0.5261*	0.5211*	-0.1481	0.5007*	0.5175*						
Leaf size without leaf stalk (cm_2)	P	0.1558	-0.0505	0.1460	0.0230	-0.1522	0.1693	0.1826	0.4974*					
	G	0.1542	0.0224	0.1355	-0.0163	-0.1566	0.2470	0.1379	0.5206*					
Plant height up to longest leaf (cm)	P	-0.0189	-0.0278	-0.0513	-0.0071	0.2211	-0.1104	0.3763*	0.4764*	0.4516*				
	G	-0.0583	-0.0826	-0.1098	-0.0128	0.3040*	-0.4141*	0.3680*	0.7854*	0.7466*				
Plant height up to head (cm)	P	-0.3356*	0.1155	-0.3853*	-0.2910*	0.5272*	-0.1700	-0.0072	-0.1392	-0.1695	0.1770			
	G	-0.6656*	-0.0284	-0.7066*	-0.5415*	0.8589*	-0.9132*	0.2586	-0.1672	-0.2014	0.1970			
Stalk length (cm)	P	-0.4590*	-0.3647*	-0.4693*	-0.3297*	0.5032*	-0.4880*	-0.0910	-0.1600	-0.0684	0.2138	0.3763*		
	G	-0.6544*	-0.4826*	-0.6531*	-0.6346*	0.6655*	-0.9936*	-0.1704	-0.3460*	-0.0054	0.3637*	0.8223*		

Weight of spears/plant (g)	P	-0.5125*	-0.4761*	-0.5315*	-0.4704*	0.7058*	-0.1432	-0.2798	0.0576	0.2119	0.2250	0.2134	0.4450*	
	G	-0.5728*	-0.5234*	-0.6014*	-0.5899*	0.8199*	-0.1999	-0.5084*	0.0520	0.2050	0.3747*	0.4397*	0.4933*	
Harvest index (%)	P	0.7899*	0.4655*	0.7735*	0.4683*	-0.4778*	0.5620*	0.1917	0.3951*	0.1404	-0.0365	-0.2905*	-0.6040*	-0.3662*
	G	0.9163*	0.4921*	0.9134*	0.7846*	-0.5730*	0.8408*	0.2929*	0.5229*	0.2099	-0.1052	-0.9808*	-0.8024*	-0.4791*

*Significant at P≤ 0.05

1991; Jamwal *et al*. 1992; Khar 1995; Shakuntla 1996; Shakuntla *et al*. 1999; Garg and Lal 2004; Gautam *et al*. 2004; Sharma *et al.* 2006; Kumar 2010), days to first harvest (Dutta 1991; Radhakrishna 1992; Dhatt and Garg 2008), leaf size index (Gautam *et al*. 2004; Kumar *et al*. 2005; Dhatt and Garg 2008) and plant frame (Kumar 1999; Garg and Lal 2004; Kumar *et al*. 2005; Rattan *et al.* 2006; Dhatt and Garg 2008). Negative association of marketable yield per plant with stalk length was earlier observed by Kumar (2010).

Among other characters, significant and positive correlation was observed for days to first harvest with harvest index, gross weight per plant, terminal head weight per plant, plant frame and head size index while it showed significant negative association with number of spears per plant, weight of spears per plant and stalk length. Terminal head weight per plant showed significant and positive correlation with gross weight per plant, harvest index, head size index, leaf size with leaf stalk and plant frame. Significant and positive correlation of terminal head weight per plant with plant weight was also reported by Guan *et al.* (1995). Gross weight per plant was significantly and positively correlated with harvest index, plant frame, leaf size with leaf stalk and head size index. Terminal head weight per plant and gross weight per plant both, exhibited significant and negative association with number of spears per plant, weight of spears per plant, stalk length and plant height up to head. Kumar (2010) observed significant and positive association of gross weight per plant with harvest index. Number of spears per plant exhibited significant and positive association with weight of spears per plant, plant height up to head and stalk length whereas significant negative correlation with harvest index, head size index and plant frame. Head size index was found to be significantly and positively correlated with harvest index whereas it showed significant and negative association with stalk length.

Significant and positive correlations were observed for plant frame, leaf size with leaf stalk and leaf size without leaf stalk with plant height up to longest leaf. In addition to this, plant frame was significantly and positively correlated with

leaf size with leaf stalk. Leaf size with leaf stalk had significant and positive correlation with harvest index and leaf size without leaf stalk.

Plant height up to head and stalk length were significantly and positively associated with stalk length and weight of spears per plant, respectively. The characters *viz*., plant height up to head, stalk length and weight of spears per plant had significant and negative association with harvest index.

At genotypic level, the estimates of correlation coefficients were generally similar to those observed at phenotypic level for most of the characters. However, the magnitude of genotypic correlation coefficients was higher than their corresponding phenotypic ones indicating the inherent association among the various characters studied. The results are in conformity with the earlier findings (Dhiman *et al*. 1983; Shakuntla *et al*. 1999; Kumar *et al*. 2004).

4.2.3 Estimates of correlation coefficients at phenotypic (P) and genotypic (G) levels in pooled over the environments

At phenotypic level, significant positive correlation of marketable yield per plant was observed with terminal head weight per plant, harvest index, gross weight per plant, head size index, days to first harvest, leaf size with leaf stalk, plant frame and leaf size without leaf stalk indicating that selection based on these characters will be effective in selecting genotypes with high marketable yield. These findings are in consonance with those of earlier research workers who found significant and positive association of marketable yield per plant with terminal head weight per plant (Shakuntla 1996; Shakuntla *et al*. 1999; Khattra *et al*. 2001), harvest index (Dutta 1991; Khar 1995; Shakuntla 1996; Kumar 1999; Kanwar and Korla 2002; Kumar 2010; Kumar *et al*. 2011), gross weight per plant (Dhiman 1979; Thamburaj *et al.* 1982; Dhiman *et al*. 1983; Dutta 1991; Jamwal *et al*. 1992; Radhakrishna 1992; Khar 1995; Radhakrishna and Korla 1995; Kumar 1999; Shakuntla 1996; Shakuntla *et al*. 1999; Kanwar and Korla 2002; Gautam *et al*. 2004; Kumar *et al*. 2004; Kumar *et al*. 2005; Sharma *et al.* 2006; Kumar 2010), head size index (Dhiman *et al*. 1983; Jamwal *et al*. 1992; Shakuntla 1996; Shakuntla *et al*. 1999; Garg and Lal 2004; Gautam *et al*. 2004;

Sharma *et al.* 2006; Kumar 2010), days to first harvest (Dutta 1991; Radhakrishna 1992; Dhatt and Garg 2008), leaf size index (Gautam *et al*. 2004; Kumar *et al*. 2005; Dhatt and Garg 2008) and plant frame (Kumar 1999; Garg

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Tables 4.8 Estimates of phenotypic (P) and genotypic (G) correlation coefficients for different characters of broccoli in pooled over the environments

Characters		Marketable yield/plant (g)	Days to first harvest	Terminal head weight/plant (g)	Gross weight/ plant (g)	Number of spears/ plant	Head size index (cm_2)	Plant frame (cm_2)	Leaf size with leaf stalk (cm_2)	Leaf size without leaf stalk (cm_2)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/ plant (g)
Days to first harvest	P	0.4805*												
	G	0.5736*												
Terminal head weight/plant (g)	P	0.9507*	0.4440*											
	G	0.9967*	0.5472*											
Gross weight/plant (g)	P	0.6925*	0.3830*	0.7052*										
	G	0.8826*	0.5532*	0.8867*										
Number of spears/plant	P	-0.5353*	-0.4130*	-0.5433*	-0.4264*									
	G	-0.5992*	-0.6064*	-0.6137*	-0.5485*									
Head size index (cm_2)	P	0.5490*	0.3132*	0.4870*	0.3010*	-0.2602*								
	G	0.7193*	0.4068*	0.7347*	0.4447*	-0.4594*								
Plant frame (cm_2)	P	0.2505*	0.3094*	0.2354*	0.3134*	-0.3432*	-0.0490							
	G	0.3142*	0.5941*	0.2744*	0.5378*	-0.4885*	-0.1512							
Leaf size with leaf stalk (cm_2)	P	0.3736*	0.2392*	0.3585*	0.3173*	-0.1960	0.1459	0.2833*						
	G	0.4996*	0.4053*	0.4676*	0.4501*	-0.2403*	0.2979*	0.4326*						
Leaf size without leaf stalk (cm_2)	P	0.2029*	0.0609	0.2017*	0.0936	-0.1647	0.1536	0.1366	0.5075*					
	G	0.3191*	0.1706	0.2957*	0.2205*	-0.2626*	0.2704*	0.2281*	0.8063*					
Plant height up to longest leaf (cm)	P	0.0950	0.0662	0.0696	0.0176	0.0156	-0.0590	0.3785*	0.5223*	0.4156*				
	G	0.1462	0.2307*	0.0932	0.1245	0.0168	-0.1709	0.3565	0.9754	0.8746*				

								*	*					
Plant height up to head (cm)	P	-0.4466*	-0.1646	-0.4968*	-0.3402*	0.5757*	-0.2426*	-0.0854	-0.1710	-0.2029*	0.1663			
	G	-0.7689*	-0.4901*	-0.8185*	-0.7629*	0.8635*	-0.9170*	-0.1911	-0.2713*	-0.2107*	0.1270			
Stalk length (cm)	P	-0.4890*	-0.4148*	-0.5059*	-0.3595*	0.4575*	-0.4576*	-0.1384	-0.2013*	-0.0423	0.1102	0.4882*		
	G	-0.6184*	-0.5744*	-0.6534*	-0.6372*	0.6585*	-0.8826*	-0.2005	-0.3715*	-0.3722*	0.1166	0.9295*		
Weight of spears/plant (g)	P	-0.4769*	-0.4142*	-0.4606*	-0.3870*	0.7667*	-0.1337	-0.3661*	-0.0589	0.0926	0.0894	0.3538*	0.3627*	
	G	-0.5363*	-0.4360*	-0.5443*	-0.5219*	0.9388*	-0.2421*	-0.5653*	-0.0632	0.0323	0.1710	0.7048*	0.4735*	
Harvest index (%)	P	0.8290*	0.4940*	0.8056*	0.3704*	-0.4590*	0.5061*	0.1290	0.3069*	0.1373	0.0696	-0.4245*	-0.5449*	-0.3519*
	G	0.9319*	0.6376*	0.9470*	0.7314*	-0.5945*	0.8337*	0.2335*	0.4619*	0.2671*	0.1103	-0.8087*	-0.6733*	-0.4662*

*Significant at P≤ 0.05

and Lal 2004; Kumar *et al*. 2005; Rattan *et al.* 2006; Dhatt and Garg 2008). Marketable yield per plant showed significant and negative association with number of spears per plant, stalk length, weight of spears per pant and plant height up to head.

Among other characters, significant and positive correlation was observed for days to first harvest with harvest index, terminal head weight per plant, gross weight per plant, head size index, plant frame and leaf size with leaf stalk while it showed significant negative association with stalk length, number of spears per plant and weight of spears per plant. Terminal head weight per plant exhibited significant and positive correlation with harvest index, gross weight per plant, head size index, leaf size with leaf stalk, plant frame and leaf size without leaf stalk whereas significant and negative association with number of spears per plant, stalk length, plant height up to head and weight of spears per plant. Significant and positive associations of terminal head weight per plant with gross weight per plant, head size index and leaf size were also reported by Shakuntla (1996).

Gross weight per plant was significantly and positively associated with harvest index, leaf size with leaf stalk, plant frame and head size index whereas it showed significant and negative correlation with number of spears per plant, weight of spears per plant, stalk length and plant height up to head. Number of spears per plant had significant and positive correlation with weight of spears per plant, plant height up to head and stalk length. Contrary to this, number of spears per plant were significantly and negatively associated with harvest index, plant frame and head size index. Head size index exhibited significant and positive correlation with harvest index whereas significant and negative association with stalk length and plant height up to head. Plant frame showed significant and positive correlation with plant height up to longest leaf and leaf size with leaf stalk whereas significant and negative association with weight of spears per plant.

Significant and positive association was observed for leaf size with leaf stalk with plant height up to longest leaf, leaf size without leaf stalk and harvest index. Leaf size without leaf stalk was significantly and positively associated with plant height up to longest leaf whereas leaf size with leaf stalk and leaf size without leaf stalk were significantly and negatively associated with stalk length and plant height up to head, respectively. Plant height up to head exhibited significant and positive correlation with stalk length and weight of spears per plant. A significant and positive association was observed for stalk length with weight of spears per plant. The characters namely, plant height up to head, stalk length and weight of spears per plant were significantly and negatively associated with harvest index.

In general, values of genotypic correlation coefficients were higher than the corresponding phenotypic correlation coefficients for most of the characters studied suggesting strong inherent relationship between the various characters. Similar results have also been reported by earlier researchers (Dhiman *et al*. 1983; Shakuntla *et al*. 1999; Kumar *et al*. 2004). It was also found that the general trend of associations among various traits at genotypic level remained the same as that at phenotypic level *viz*., the positive phenotypic correlation coefficient values were positive at genotypic levels and vice-versa.

A perusal of Tables 4.6, 4.7 and 4.8 revealed that the terminal head weight per plant, harvest index, gross weight per plant, days to first harvest, head size index and leaf size with leaf stalk have shown stable significant positive association with marketable yield per plant. On the basis of correlation studies and their coefficients of determination, it can be concluded that the selection on the basis of high terminal head weight per plant along with high harvest index, high gross weight per plant, high head size index, late maturity, more leaf size with leaf stalk and plant frame will be rewarding in broccoli for getting high marketable yield per plant.

4.3 Path coefficient analysis

Even though, the correlation coefficients are helpful in determining the components of a complex trait like marketable yield, an exact picture of the relative importance of direct and indirect influence of each trait is not provided by such studies as these estimates provide nature and magnitude but, not the cause. The path coefficient analysis allows partitioning of correlation coefficients into direct and indirect effects of various traits towards dependent variable and thus, helps in assessing the cause effect relationships as well as effective selection. It plays an important role in determining the degree of relationship between yield and its component effects and also permits critical examination of specific factors that provide a given correlation. The effects of yield components *via* path analysis were examined for significant correlated characters with marketable yield per plant.

4.3.1 Estimates of direct and indirect effects of different characters on marketable yield per plant

In order to understand direct and indirect effects of different characters towards marketable yield per plant, the path coefficient analysis was done separately for environment I, environment II and pooled over the environments and the results obtained are presented in Tables 4.9, 4.10 and 4.11, respectively.

4.3.1.1 Estimates of direct and indirect effects at phenotypic (P) and genotypic (G) levels in environment I

At phenotypic level, marketable yield per plant showed significant and positive correlation with seven characters *viz*., days to first harvest, terminal head weight per plant, gross weight per plant, head size index, leaf size with leaf stalk, leaf size without leaf stalk and harvest index while it showed significant negative association with number of spears per plant, plant height up to head, stalk length and weight of spears per plant.

The highest positive direct effects on marketable yield per plant were recorded by harvest index followed by terminal head weight per plant, gross weight per plant and head size index. On the other hand, negative direct effects

were recorded by weight of spears per plant. Earlier research workers have also reported direct and positive effects of harvest index (Dutta 1991; Khar 1995; Reddy and Varalakshmi 1995; Shakuntla 1996; Kumar 1998; Gautam 2001; Kanwar and Korla 2002; Kumar *et al* 2004; Kumar *et al*. 2005), terminal head weight per plant (Shakuntla 1996; Shakuntla *et al*. 1999; Khattra 2001), gross weight per plant (Thamburaj *et al*. 1982; Dutta 1991; Radhakrishna 1992; Khar

Table 4.9 Estimates of direct and indirect effects of different characters on marketable yield per plant at phenotypic (P) and genotypic (G) levels in environment I (2010-2011)

Characters		Days to first harvest	Terminal head weight/ plant (g)	Gross weight/ plant (g)	Number of spears/ Plant	Head size index (cm_2)	Plant frame (cm_2)	Leaf size with leaf stalk (cm_2)	Leaf size without leaf stalk (cm_2)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/ plant (g)	Harvest index (%)
Days to first harvest	P	**-0.0663**	-0.0345	-0.0190	0.0388	-0.0199	-0.0174	-0.0235	-0.0243	-0.0159	0.0435	0.0350	0.0233	-0.0399
	G	**-0.5962**	-0.3809	-0.2846	0.3909	-0.1661	-0.3367	-0.2397	-0.2304	-0.3413	0.5037	0.4357	0.2387	-0.4277
Terminal head weight/plant (g)	P	0.1406	**0.2702**	0.1689	-0.1377	0.1259	0.0308	0.0884	0.0843	0.0521	-0.1642	-0.1448	-0.1082	0.2245
	G	-0.0303	**-0.0474**	-0.0385	0.0266	-0.0372	-0.0048	-0.0175	-0.0192	-0.0114	0.0389	0.0296	0.0216	-0.0450
Gross weight/plant (g)	P	0.0655	0.1428	**0.2285**	-0.0806	0.0533	0.0448	0.0606	0.0571	0.0122	-0.0939	-0.0926	-0.0668	0.0671
	G	0.0335	0.0569	**0.0701**	-0.0369	0.0444	0.0267	0.0256	0.0365	0.0091	-0.0568	-0.0466	-0.0308	0.0407
Number of spears/plant	P	-0.0343	-0.0298	-0.0206	**0.0585**	-0.0113	-0.0227	-0.0162	-0.0118	-0.0122	0.0367	0.0244	0.0482	-0.0263
	G	0.0422	0.0360	0.0338	**-0.0643**	0.0171	0.0380	0.0203	0.0133	0.0243	-0.0532	-0.0306	-0.0563	0.0319
Head size index (cm_2)	P	0.0479	0.0743	0.0372	-0.0309	**0.1596**	-0.0108	0.0069	0.0218	0.0004	-0.0519	-0.0687	-0.0198	0.0749
	G	-0.0105	-0.0297	-0.0239	0.0101	**-0.0378**	0.0079	-0.0038	-0.0044	0.0002	0.0263	0.0262	0.0084	-0.0246
Plant frame (cm_2)	P	-0.0197	-0.0085	-0.0147	0.0291	0.0051	**-0.0750**	-0.0157	-0.0051	-0.0287	0.0128	0.0137	0.0338	-0.0060
	G	0.0517	0.0093	0.0349	-0.0541	-0.0190	**0.0915**	0.0329	0.0103	0.0200	-0.0550	-0.0081	-0.0719	0.0087
Leaf size with leaf stalk (cm_2)	P	-0.0254	-0.0234	-0.0190	0.0198	-0.0031	-0.0150	**-0.0717**	-0.0415	-0.0413	0.0146	0.0170	0.0118	-0.0175
	G	-0.0004	-0.0003	-0.0003	0.0003	-0.0001	-0.0003	**-0.0009**	-0.0007	-0.0009	0.0002	0.0003	0.0002	-0.0003
Leaf size without leaf stalk (cm_2)	P	0.0298	0.0254	0.0203	-0.0164	0.0111	0.0056	0.0471	**0.0813**	0.0300	-0.0226	-0.0179	-0.0076	0.0128
	G	0.0186	0.1139	0.1463	-0.0580	0.0327	0.0316	0.2142	**0.2810**	0.2155	-0.0877	-0.1051	-0.0212	0.0530
Plant height up to longest leaf (cm)	P	0.0307	0.0247	0.0068	-0.0267	0.0003	0.0489	0.0737	0.0473	**0.1280**	0.0197	0.0005	-0.0074	0.0213
	G	-0.0286	-0.0120	-0.0065	0.0189	0.0002	-0.0109	-0.0515	-0.0383	**-0.0500**	0.0134	-0.0020	0.0068	-0.0152
Plant height up to head (cm)	P	0.0049	0.0045	0.0031	-0.0047	0.0024	0.0013	0.0015	0.0021	-0.0011	**-0.0075**	-0.0045	-0.0037	0.0041
	G	0.5174	0.5020	0.4968	-0.5063	0.4263	0.3684	0.1576	0.1912	0.1645	**-0.6124**	-0.5356	-0.4322	0.4741
Stalk length (cm)	P	-0.0151	-0.0153	-0.0116	0.0119	-0.0123	-0.0052	-0.0068	-0.0063	0.0001	-0.0172	**0.0286**	0.0083	-0.0145
	G	-0.1186	-0.1013	-0.1079	0.0773	-0.1124	-0.0144	-0.0520	-0.0586	0.0065	0.1419	**0.1623**	0.0638	-0.0960
Weight of spears/plant (g)	P	0.0646	0.0737	0.0538	-0.1516	0.0229	0.0831	0.0302	0.0173	0.0107	-0.0920	-0.0534	**-0.1841**	0.0633
	G	-0.0644	-0.0734	-0.0707	0.1408	-0.0356	-0.1264	-0.0296	-0.0121	0.0220	0.1136	0.0632	**0.1609**	-0.0564
Harvest index (%)	P	0.3006	0.4153	0.1469	-0.2244	0.2348	0.0403	0.1219	0.0785	0.0832	-0.2734	-0.2524	-0.1721	**0.5000**

	G	0.7028	0.9300	0.5685	-0.4858	0.6376	0.0932	0.2953	0.1847	0.2987	-0.7584	-0.5795	-0.3434	**0.9797**
Correlation with marketable yield per plant	P	0.5238*	0.9194*	0.5807*	-0.5147*	0.5686*	0.1084	0.2965*	0.3006*	0.2175	-0.5609*	-0.5150*	-0.4444*	0.8639*
	G	0.6072*	1.0032*	0.8179*	-0.5406*	0.7501*	0.1636	0.3509*	0.3531*	0.3132*	-0.7855*	-0.5868*	-0.4554*	0.9228*

Residual effect (P): 0.25; (G): 0.17 *Significant at P≤0.05 **The bold values indicate direct effects**

1995; Gautam 2001; Kanwar and Korla 2002; Sharma *et al*. 2006; Dhatt and Garg 2008) and head size index (Shakuntla 1996; Gautam 2001; Garg and Lal 2004) on marketable yield per plant.

The significant positive association of days to first harvest with marketable yield per plant was mainly contributed by its high positive indirect effects *via* harvest index followed by terminal head weight per plant and weight of spears per plant, though, its own negative direct effect counter balanced the positive indirect effect *via* gross weight per plant to a greater extent.

The significant positive correlation of terminal head weight per plant with marketable yield per plant was due to its positive direct effect and high positive indirect effects *via* harvest index followed by gross weight per plant and head size index.

The significant positive association of gross weight per plant with marketable yield per plant was mainly due to its high positive direct effect. It also contributed towards marketable yield per plant indirectly *via* terminal head weight per plant followed by harvest index and weight of spears per plant.

The significant positive correlation of head size index with marketable yield per plant was due to its positive direct effect and high positive indirect effects *via* harvest index followed by terminal head weight per plant and gross weight per plant.

The significant positive association of leaf size with leaf stalk with marketable yield per plant was mainly due to its high positive indirect effects *via* harvest index followed by terminal head weight per plant and gross weight per plant. However, its own negative direct effect counter balanced the positive indirect effect *via* plant height up to longest leaf to a greater extent.

The significant positive association of leaf size without leaf stalk with marketable yield per plant was due to its positive direct and indirect effects *via*

terminal head weight per plant followed by harvest index and gross weight per plant.

The significant positive correlation of harvest index with marketable yield per plant was mainly due to its high positive direct and small indirect effects *via* terminal head weight per plant followed by head size index and gross weight per plant.

The significant negative correlation of number of spears per plant with marketable yield per plant was mainly due to its high negative indirect effects *via* harvest index followed by weight of spears per plant and terminal head weight per plant.

The significant negative association of plant height up to head with marketable yield per plant was mainly due to its high negative indirect effects *via* harvest index followed by terminal head weight per plant and gross weight per plant.

The significant negative correlation of stalk length with marketable yield per plant was mainly due to its high negative indirect effects *via* harvest index followed by terminal head weight per plant and gross weight per plant.

The significant negative association of weight of spears per plant with marketable yield per plant was mainly due to its high negative direct effect and negative indirect effects *via* harvest index and terminal head weight per plant.

4.3.1.2 Estimates of direct and indirect effects at phenotypic (P) and genotypic (G) levels in environment II

At phenotypic level, marketable yield per plant showed significant and positive correlation with seven characters *viz*., days to first harvest, terminal head weight per plant, gross weight per plant, head size index, plant frame, leaf size with leaf stalk and harvest index however significant negative association with number of spears per plant, plant height up to head, stalk length and weight of spears per plant.

Estimates of direct effects indicated that terminal head weight per plant had the highest direct effect on marketable yield per plant followed by leaf size with leaf stalk, days to first harvest, harvest index and stalk length. Earlier research workers have also reported direct and positive effects of terminal head weight per

Table 4.10 Estimates of direct and indirect effects of different characters on marketable yield per plant at phenotypic (P) and genotypic (G) levels in environment II (2011-2012)

Characters		Days to first harvest	Terminal head weight/plant (g)	Gross weight/ plant (g)	Number of spears/ plant	Head size index (cm_2)	Plant frame (cm_2)	Leaf size with leaf stalk (cm_2)	Leaf size without leaf stalk (cm_2)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/ plant (g)	Harvest index (%)
Days to first harvest	P	**0.0531**	0.0225	0.0230	-0.0172	0.0176	0.0186	0.0094	-0.0027	-0.0015	0.0061	-0.0194	-0.0253	0.0247
	G	**0.0568**	0.0285	0.0351	-0.0235	0.0291	0.0372	0.0173	0.0013	-0.0047	-0.0016	-0.0274	-0.0297	0.0297
Terminal head weight/plant (g)	P	0.3766	**0.8905**	0.7096	-0.5197	0.4569	0.3294	0.3530	0.1300	-0.0457	-0.3431	-0.4180	-0.4733	0.6889
	G	0.4537	**0.9035**	0.8571	-0.5661	0.5594	0.3570	0.4753	0.1224	-0.0992	-0.6384	-0.5901	-0.5434	0.8253
Gross weight/plant (g)	P	0.0063	0.0117	**0.0147**	-0.0072	0.0052	0.0060	0.0054	0.0003	-0.0001	-0.0043	-0.0048	-0.0069	0.0069
	G	-0.0285	-0.0438	**-0.0462**	0.0278	-0.0163	-0.0339	-0.0241	0.0008	0.0006	0.0250	0.0293	0.0272	-0.0362
Number of spears/plant	P	-0.0026	-0.0047	-0.0040	**0.0080**	-0.0026	-0.0024	-0.0009	-0.0012	0.0018	0.0042	0.0040	0.0057	-0.0038
	G	0.0246	0.0372	0.0357	**-0.0594**	0.0303	0.0240	0.0088	0.0093	-0.0181	-0.0510	-0.0395	-0.0487	0.0341
Head size index (cm_2)	P	0.0092	0.0143	0.0098	-0.0091	**0.0279**	-0.0009	0.0070	0.0047	-0.0031	-0.0047	-0.0136	-0.0040	0.0157
	G	0.0393	0.0475	0.0270	-0.0392	**0.0768**	-0.0110	0.0384	0.0190	-0.0318	-0.0701	-0.0763	-0.0154	0.0646
Plant frame (cm_2)	P	0.0072	0.0077	0.0084	-0.0062	-0.0007	**0.0207**	0.0075	0.0038	0.0078	-0.0001	-0.0019	-0.0058	0.0040
	G	0.0430	0.0259	0.0482	-0.0265	-0.0094	**0.0656**	0.0340	0.0091	0.0242	0.0170	-0.0112	-0.0334	0.0192
Leaf size with leaf stalk (cm_2)	P	0.0157	0.0352	0.0326	-0.0095	0.0222	0.0320	**0.0887**	0.0441	0.0423	-0.0123	-0.0142	0.0051	0.0351
	G	0.0295	0.0511	0.0506	-0.0144	0.0486	0.0503	**0.0971**	0.0505	0.0763	-0.0162	-0.0336	0.0050	0.0508
Leaf size without leaf stalk (cm_2)	P	0.0010	-0.0028	-0.0004	0.0030	-0.0033	-0.0035	-0.0097	**-0.0194**	-0.0088	0.0033	-0.0013	-0.0041	-0.0027
	G	-0.0019	-0.0112	0.0013	0.0130	-0.0205	-0.0114	-0.0432	**-0.0829**	-0.0619	0.0167	0.0004	-0.0170	-0.0174
Plant height up to longest leaf (cm)	P	0.0006	0.0011	0.0001	-0.0046	0.0023	-0.0078	-0.0098	-0.0093	**-0.0207**	-0.0037	-0.0044	-0.0046	0.0008
	G	0.0005	0.0007	0.0001	-0.0018	0.0025	-0.0022	-0.0047	-0.0045	**-0.0060**	-0.0012	-0.0022	-0.0023	0.0006
Plant height up to head (cm)	P	0.0022	-0.0075	-0.0057	0.0103	-0.0033	-0.0001	-0.0027	-0.0033	0.0034	**0.0194**	0.0073	0.0042	-0.0057
	G	0.0001	0.0028	0.0021	-0.0034	0.0036	-0.0010	0.0007	0.0008	-0.0008	**-0.0039**	-0.0032	-0.0017	0.0038
Stalk length (cm)	P	-0.0136	-0.0174	-0.0123	0.0187	-0.0181	-0.0034	-0.0059	0.0025	0.0079	0.0140	**0.0372**	0.0165	-0.0225
	G	-0.0653	-0.0884	-0.0859	0.0901	-0.1345	-0.0231	-0.0468	-0.0007	0.0492	0.1113	**0.1354**	0.0654	-0.1086
Weight of spears/plant (g)	P	0.0011	0.0013	0.0011	-0.0017	0.0003	0.0007	-0.0001	-0.0005	-0.0005	-0.0005	-0.0011	**-0.0024**	0.0009
	G	-0.0313	-0.0359	-0.0353	0.0490	-0.0119	-0.0304	0.0031	0.0122	0.0224	0.0263	0.0289	**0.0598**	-0.0286
Harvest index (%)	P	0.0223	0.0370	0.0224	-0.0228	0.0269	0.0092	0.0189	0.0067	-0.0017	-0.0139	-0.0289	-0.0175	**0.0478**
	G	0.0398	0.0739	0.0634	-0.0463	0.0680	0.0237	0.0423	0.0170	-0.0085	-0.0793	-0.0649	-0.0387	**0.0809**
Correlation with marketable yield per plant	P	0.4792*	0.9887*	0.7995*	-0.5580*	0.5312*	0.3983*	0.4607*	0.1558	-0.0189	-0.3356*	-0.4590*	-0.5125*	0.7899*
	G	0.5604*	0.9917*	0.9535*	-0.6608*	0.6257*	0.4448*	0.5982*	0.1542	-0.0583	-0.6656*	-0.6544*	-0.5728*	0.9163*

Residual effect (P): 0.10; (G): 0.06 *Significant at P≤ 0.05 **The bold values indicate direct effects**

plant (Shakuntla 1996; Shakuntla *et al*. 1999; Khattra 2001), leaf size index (Kumar 1999; Dhatt and Garg 2008), days to first harvest (Radhakrishna 1992; Khar 1995; Shakuntla 1996), harvest index (Dutta 1991; Khar 1995; Reddy and Varalakshmi 1995; Shakuntla 1996; Kumar 1998; Gautam 2001; Kanwar and Korla 2002; Kumar *et al* 2004; Kumar *et al*. 2005) and stalk length (Kumar *et al*. 2005; Dhatt and Garg 2008) on marketable yield per plant.

The significant positive association of days to first harvest with marketable yield per plant was due to its positive direct and high positive indirect effects *via* terminal head weight per plant, harvest index and leaf size with leaf stalk.

The significant positive correlation of terminal head weight per plant with marketable yield per plant was mainly due to its high positive direct effect and small positive indirect effects *via* harvest index and leaf size with leaf stalk.

The significant positive correlation of gross weight per plant with marketable yield per plant was mainly due to its high positive indirect effects *via* terminal head weight per plant followed by leaf size with leaf stalk, days to first harvest and harvest index.

The significant positive association of head size index with marketable yield per plant was due to high positive indirect effects *via* terminal head weight per plant followed by harvest index and leaf size with leaf stalk along with own direct effect.

The significant positive correlation of plant frame with marketable yield per plant was due to its positive direct effect and high positive indirect effects *via* terminal head weight per plant and leaf size with leaf stalk.

The significant positive association of leaf size with leaf stalk with marketable yield per plant was due to its positive direct effect and high positive indirect effects *via* terminal head weight per plant and harvest index.

The significant positive association of harvest index with marketable yield per plant was due to its positive direct effect and high positive indirect effects *via* terminal head weight per plant followed by leaf size with leaf stalk.

The significant negative correlation of number of spears per plant with marketable yield per plant was mainly due to its high negative indirect effects *via* terminal head weight per plant followed by harvest index and days to first harvest.

The significant negative correlation of plant height up to head with marketable yield per plant was mainly due to its high negative indirect effect *via* terminal head weight per plant, though, counter balanced by positive indirect effect *via* stalk length up to some extent.

The significant negative association of stalk length with marketable yield per plant was mainly due to its high negative indirect effects *via* terminal head weight per plant followed by days to first harvest and leaf size with leaf stalk, though, its own positive direct effect counter balanced the negative indirect effect *via* harvest index to a greater extent.

The significant negative correlation of weight of spears per plant with marketable yield per plant was mainly due to its high negative indirect effects *via* terminal head weight per plant followed by days to first harvest and harvest index.

4.3.1.3 Estimates of direct and indirect effects at phenotypic (P) and genotypic (G) levels in pooled over the environments

At phenotypic level, marketable yield per plant showed significant and positive correlation with eight characters *viz*., days to first harvest, terminal head weight per plant, gross weight per plant, head size index, plant frame, leaf size with leaf stalk, leaf size without leaf stalk and harvest index while it showed significant negative association with number of spears per plant, plant height up to head, stalk length and weight of spears per plant.

The highest positive direct effect on marketable yield per plant was recorded by terminal head weight per plant followed by harvest index, gross weight per plant, head size index and stalk length. Negative direct effects were exhibited by weight of spears per plant and days to first harvest on marketable yield per plant. Earlier research workers have also reported positive direct effects

Table 4.11 Estimates of direct and indirect effects of different characters on marketable yield per plant at phenotypic (P) and genotypic (G) levels in pooled over the environments

Characters		Days to first harvest	Terminal head weight /plant (g)	Gross weight/ plant (g)	Number of spears/ plant	Head size index (cm_2)	Plant frame (cm_2)	Leaf size with leaf stalk (cm_2)	Leaf size without leaf stalk (cm_2)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/ plant (g)	Harvest index (%)
Days to first harvest	P	**-0.0089**	-0.0039	-0.0034	0.0037	-0.0028	-0.0027	-0.0021	-0.0005	-0.0006	0.0015	0.0037	0.0037	-0.0044
	G	**-0.0949**	-0.0519	-0.0525	0.0575	-0.0386	-0.0564	-0.0384	-0.0162	-0.0219	0.0465	0.0545	0.0414	-0.0605
Terminal head weight/plant (g)	P	0.2568	**0.5784**	0.4079	-0.3143	0.2817	0.1362	0.2074	0.1167	0.0402	-0.2874	-0.2926	-0.2664	0.4660
	G	0.0316	**0.0578**	0.0512	-0.0354	0.0424	0.0158	0.0270	0.0171	0.0054	-0.0473	-0.0377	-0.0314	0.5470
Gross weight/plant (g)	P	0.0570	0.1049	**0.1487**	-0.0634	0.0448	0.0466	0.0472	0.0139	0.0026	-0.0506	-0.0535	-0.0575	0.0551
	G	0.1328	0.2129	**0.2401**	-0.1317	0.1068	0.1291	0.1080	0.0529	0.0299	-0.1832	-0.1530	-0.1253	0.1756
Number of spears/plant	P	-0.0213	-0.0280	-0.0220	**0.0516**	-0.0134	-0.0177	-0.0101	-0.0085	0.0008	0.0297	0.0236	0.0396	-0.0237
	G	-0.2546	-0.2577	-0.2303	**0.4199**	-0.1929	-0.2051	-0.1009	-0.1103	0.0070	0.3626	0.2765	0.3942	-0.2496
Head size index (cm_2)	P	0.0369	0.0574	0.0355	-0.0306	**0.1178**	-0.0058	0.0172	0.0181	-0.0070	-0.0286	-0.0539	-0.0157	0.0596
	G	-0.3527	-0.6369	-0.3856	0.3983	**-0.8669**	0.1311	-0.2583	-0.2344	0.1481	0.7950	0.7651	0.2099	-0.7228
Plant frame (cm_2)	P	0.0045	0.0034	0.0046	-0.0050	-0.0007	**0.0146**	0.0041	0.0020	0.0055	-0.0012	-0.0020	-0.0053	0.0019
	G	-0.2665	-0.1231	-0.2412	0.2191	0.0678	**-0.4485**	-0.1940	-0.1023	-0.1599	0.0857	0.0899	0.2536	-0.1047
Leaf size with leaf stalk (cm_2)	P	0.0038	0.0057	0.0050	-0.0031	0.0023	0.0045	**0.0158**	0.0080	0.0082	-0.0027	-0.0032	-0.0009	0.0048
	G	0.0042	0.0049	0.0047	-0.0025	0.0031	0.0045	**0.0104**	0.0084	0.0102	-0.0028	-0.0039	-0.0007	0.0048
Leaf size without leaf stalk (cm_2)	P	0.0016	0.0054	0.0025	-0.0044	0.0041	0.0037	0.0137	**0.0269**	0.0112	-0.0055	-0.0011	0.0025	0.0037
	G	0.0139	0.0241	0.0180	-0.0214	0.0221	0.0186	0.0658	**0.0816**	0.0713	-0.0172	-0.0304	-0.0026	0.0218
Plant height up to longest leaf (cm)	P	0.0010	0.0010	0.0003	0.0002	-0.0009	0.0057	0.0078	0.0062	**0.0150**	0.0025	0.0017	0.0013	0.0010
	G	0.0114	0.0046	0.0061	0.0008	-0.0084	0.0176	0.0481	0.0431	**0.0493**	0.0063	0.0058	0.0084	0.0054
Plant height up to head (cm)	P	-0.0028	-0.0084	-0.0058	0.0097	-0.0041	-0.0014	-0.0029	-0.0034	0.0028	**0.0169**	0.0083	0.0060	-0.0072
	G	-0.1714	-0.2863	-0.2669	0.3020	-0.3207	-0.0669	-0.0949	-0.0737	0.0444	**0.3498**	0.3251	0.2465	-0.2829
Stalk length (cm)	P	-0.0283	-0.0345	-0.0245	0.0312	-0.0312	-0.0094	-0.0137	-0.0029	0.0075	0.0332	**0.0681**	0.0247	-0.0371
	G	0.4356	0.4955	0.4832	-0.4994	0.6693	0.1520	0.2818	0.2823	-0.0885	-0.7049	**-0.7584**	-0.3591	0.5106
Weight of spears/plant (g)	P	0.0472	0.0525	0.0441	-0.0873	0.0152	0.0417	0.0067	-0.0105	-0.0102	-0.0403	-0.0413	**-0.1139**	0.0401
	G	0.2422	0.3024	0.2899	-0.5215	0.1345	0.3140	0.0351	0.0180	-0.0950	-0.3915	-0.2630	**-0.5555**	0.2590
Harvest index (%)	P	0.1330	0.2168	0.0997	-0.1235	0.1362	0.0347	0.0826	0.0370	0.0187	-0.1143	-0.1467	-0.0947	**0.2692**
	G	0.8418	1.2504	0.9658	-0.7849	1.1009	0.3083	0.6099	0.3526	0.1457	-1.0678	-0.8890	-0.6156	**1.3204**
Correlation with marketable yield per plant	P	0.4805*	0.9507*	0.6925*	-0.5353*	0.5490*	0.2505*	0.3736*	0.2029*	0.0950	-0.4466*	-0.4890*	-0.4769*	0.8290*
	G	0.5736*	0.9967*	0.8826*	-0.5992*	0.7193*	0.3142*	0.4996*	0.3191*	0.1462	-0.7689*	-0.6184*	-0.5363*	0.9319*

Residual effect (P): 0.24; (G): 0.18 *Significant at P≤ 0.05 **The bold values indicate direct effects**

of terminal head weight per plant (Shakuntla 1996; Shakuntla *et al*. 1999; Khattra 2001), harvest index (Dutta 1991; Khar 1995; Reddy and Varalakshmi 1995; Kumar 1998; Gautam 2001; Kanwar and Korla 2002; Kumar *et al* 2004; Kumar *et al*. 2005), gross weight per plant (Thamburaj *et al*. 1982; Dutta 1991; Radhakrishna 1992; Khar 1995; Gautam 2001; Kanwar and Korla 2002; Sharma *et al*. 2006; Dhatt and Garg 2008), head size index (Gautam 2001; Garg and Lal 2004) and stalk length (Kumar *et al.* 2005; Dhatt and Garg 2008) on marketable yield per plant.

The significant positive association of days to first harvest with marketable yield per plant was due to its high positive indirect effects *via* terminal head weight per plant followed by harvest index, gross weight per plant and weight of spears per plant.

The significant positive correlation of terminal head weight per plant with marketable yield per plant was mainly due to its high positive direct effect and positive indirect effects *via* harvest index followed by gross weight per plant and weight of spears per plant.

The significant positive correlation of gross weight per plant with marketable yield per plant was due to its positive direct effect and high positive indirect effects *via* terminal head weight per plant followed by harvest index and weight of spears per plant.

The significant positive association of head size index with marketable yield per plant was due to its high positive direct and indirect effects *via* terminal head weight per plant and harvest index.

The significant positive correlation of plant frame with marketable yield per was due to its high positive indirect effects *via* terminal head weight per plant followed by gross weight per plant, weight of spears per plant and harvest index, though, its own positive direct effect was counter balanced by negative indirect effect *via* number of spears per plant to a greater extent.

The significant positive association of leaf size with leaf stalk with marketable yield per plant was due to its high positive indirect effects *via* terminal

head weight per plant followed by harvest index, gross weight per plant and head size index along with its own direct effect.

The significant positive association of leaf size without leaf stalk with marketable yield per plant was due to its positive direct effect and high positive indirect effects *via* terminal head weight per plant followed by harvest index and gross weight per plant, though, the negative indirect effect *via* weight of spears per plant counter balanced the positive indirect effect *via* head size index to a greater extent.

The significant positive correlation of harvest index with marketable yield per plant was due to its high positive direct and indirect effects *via* terminal head weight per plant and head size index.

The significant negative correlation of number of spears per plant with marketable yield per plant was mainly due to its high negative indirect effects *via* terminal head weight per plant followed by harvest index and weight of spears per plant

The significant negative association of plant height up to head with marketable yield per plant was mainly due to its high negative indirect effects *via* terminal head weight per plant followed by harvest index and gross weight per plant.

The significant negative correlation of stalk length with marketable yield per plant was due to its high indirect effects *via* terminal head weight per plant followed by harvest index and gross weight per plant. However, its own positive direct effect counter balanced the negative indirect effect *via* head size index to a greater extent.

The significant negative association of weight of spears per plant with marketable yield per plant was due to its high negative direct and indirect effects *via* terminal head weight per plant and harvest index.

The estimates of direct and indirect effects at genotypic level were generally higher in magnitude than phenotypic ones for different characters on marketable yield per plant in environment I, environment II and pooled over the environments.

The low magnitude of unexplained variation 0.25 (environment I), 0.10 (environment II) and 0.24 (pooled over the environments) at phenotypic level indicated that the characters chosen in the present study accounted for most of the variation present in the dependable variable *viz*., marketable yield per plant.

Keeping in view the direct and indirect contributions of component characters towards the marketable yield per plant, the selection on the basis of terminal head weight per plant, harvest index, gross weight per plant, head size index and leaf size with leaf stalk in the genotypes under study would be rewarding. Shakuntla *et al*. (1999) also emphasized the importance of terminal head weight per plant and harvest index in the improvement of marketable yield per plant in broccoli.

5. SUMMARY AND CONCLUSIONS

The present investigation entitled “Genetic evaluation of sprouting broccoli hybrids under mid hills of Himachal Pradesh” was undertaken to assess the nature of genetic variability, association of various characters with marketable yield and their direct and indirect effects for effective selection under two different environments *viz*., environment I (*Rabi*, 2010-2011) and environment II (*Rabi*, 2011-2011).

The experimental material comprised of sixteen genotypes of broccoli including two checks namely, Palam Haritika and Palam Samridhi. All the genotypes were raised in Randomized Complete Block Design with three replications at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSK HPKV, Palampur, during *rabi*, 2010-2011 and 2011-2012. Data were recorded on five randomly selected plants for various characters *viz*., days to first harvest, marketable yield per plant, terminal head weight per plant, gross weight per plant, number of spears per plant, head size index, plant frame, leaf size with leaf stalk, leaf size without leaf stalk, plant height up to longest leaf, plant height up to head, stalk length, weight of spears per plant and harvest index. The data were analysed as per the standard statistical procedures for parameters of genetic variability, correlation and path coefficients in environment I, environment II and pooled over the environments.

The analysis of variance indicated the presence of sufficient genetic variability for all the characters in environment I and environment II. The pooled analysis of variance over the environments revealed the presence of g×e interactions for characters namely, days to first harvest, number of spears per plant, leaf size without leaf stalk, weight of spears per plant and harvest index. The presence of g×e interactions greatly influenced the variation due to genotypes to the extent that genotypic differences recorded in individual environment vanished for these characters. On the basis of mean performance,

genotype Altar was found to be significantly superior for marketable yield per plant over the best check Palam Haritika in both of the environments and pooled over the environments. In addition, genotype Green Magic was significantly superior for marketable yield per plant to the best check Palam Haritika in environment I. The superior performance of these genotypes for terminal head weight per plant, gross weight per plant, plant frame and harvest index resulted in higher marketable yield. Genotype, CBH-1 was found to be significantly superior to the early maturing check Palam Samridhi as it took minimum number of days to first harvest in both of the environments and pooled over the environments.

The estimates of phenotypic coefficient of variation were higher than their corresponding genotypic coefficient of variation for all the characters in both of the environments and pooled over the environments. The estimates of PCV and GCV were high for number of spears per plant, weight of spears per plant and terminal head weight per plant in environment I and pooled over the environments and for number of spears per plant and weight of spears per plant in environment II indicating substantial variability and ensuring ample scope of improvement through selection. Marketable yield per plant exhibited high PCV and GCV in environment I and moderate PCV and GCV in environment II. On the other hand, moderate estimates of PCV and GCV were recorded for harvest index, head size index, plant frame, gross weight per plant, leaf size without leaf stalk and leaf size with leaf stalk in both the environments and pooled over the environments and for plant height up to head in environment I and pooled over the environments suggesting that direct selection for these characters should be considered cautiously. Moderate PCV and low GCV was recorded for stalk length in environment I, II and pooled over the environments. Days to first harvest recorded low estimates of PCV and GCV in environment I and pooled over the environments.

Heritability estimates were high for number of spears per plant, terminal head weight per plant, marketable yield per plant, weight of spears per plant, harvest index, leaf size with leaf stalk, days to first harvest and stalk length in both

the environments and pooled over the environments. High heritability was observed for leaf size without leaf stalk in environment I and environment II and for gross weight per plant in environment II and pooled over the environments. The high heritability estimates for these characters revealed the lesser influence of environment and greater role of genetic component of variation. Genetic advance expressed as percentage of mean was recorded high for number of spears per plant, weight of spears per plant, terminal head weight per plant, marketable yield per plant and harvest index in both of the environments and pooled over the environments. Leaf size with leaf stalk and leaf size without leaf stalk recorded high genetic advance in environment I and environment II, respectively.

High heritability coupled with high genetic advance was observed for number of spears per plant, terminal head weight per plant, marketable yield per plant, weight of spears per plant and harvest index in both the environments and pooled over the environments. Leaf size with leaf stalk and leaf size without leaf stalk recorded high heritability accompanied with high genetic advance in environment I and environment II, respectively indicating the predominance of additive gene action for these characters. This would be useful for effective selection in early segregating generations due to their high breeding values. High heritability along with moderate genetic advance was observed for days to first harvest and stalk length in both of the environments and pooled over the environments, whereas gross weight per plant and leaf size with leaf stalk had shown high heritability accompanied with moderate genetic advance in environment II and pooled over the environments. On the other hand, moderate heritability coupled with moderate genetic advance was recorded for plant height up to head, plant frame and head size index in environment I, II and pooled over the environments and leaf size without leaf stalk in pooled over the environments.

In general, genotypic correlation coefficients were of higher magnitude than the corresponding phenotypic ones indicating the inherent association among the various characters. Marketable yield per plant showed significant and positive correlation with terminal head weight per plant, harvest index, gross weight per plant, head size index, days to first harvest and leaf size with leaf stalk in both the

environments and pooled over the environments and with plant frame in environment II and pooled over the environments. Leaf size without leaf stalk exhibited significant and positive association with marketable yield per plant in environment I and pooled over the environments. Selection on the basis of these characters shall lead to higher marketable yield.

Path coefficient analysis revealed the high positive direct effects of terminal head weight per plant, harvest index, gross weight per plant and head size index in environment I and pooled over the environments. In environment II, terminal head weight per plant, leaf size with leaf stalk, days to first harvest and harvest index had the maximum positive direct effect on marketable yield per plant. Terminal head weight per plant, harvest index, gross weight per plant and leaf size with leaf stalk had maximum indirect contribution for enhancing the magnitude of association for majority of the characters with marketable yield per plant. On the basis of direct and indirect contributions of component characters towards the marketable yield per plant, the selection based on terminal head weight per plant, harvest index, gross weight per plant, head size index and leaf size with leaf stalk in the genotypes under study would be rewarding.

Conclusions

Sufficient genetic variability was observed for all the characters in environment I and environment II. Genotypes, Altar and Green Magic were observed to be promising on the basis of marketable yield per plant, whereas genotype CBH-1 was found to be early maturing. High heritability coupled with high genetic advance was observed for number of spears per plant, terminal head weight per plant, marketable yield per plant, weight of spears per plant and harvest index which indicated the predominance of additive gene action, important for effective selection in early segregating generations. Based on correlation and path coefficient analysis, terminal head weight per plant, harvest index, gross weight per plant, head size index and leaf size with leaf stalk were observed to be the best selection parameters for evolving high yielding broccoli genotypes.

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*original not seen

Appendix I

Agro-ecological zones of Himachal Pradesh

Agro-ecological zones	Altitude range (m)	Rainfall (mm)
Zone 1.1	240-1000	< or =1500
Zone 1.2	240-1000	>1500
Zone 2.1	1001-1500	< or =1500
Zone 2.2	1001-1500	>1500
Zone 3.1	1501-2500	< or =1500
Zone 3.2	1501-3250	>1500
Zone 4.1	2501-3250	<700 (Dry)
Zone 4.2	3251-4250	Dry/snow
Zone 4.3	>4250	Dry/snow

Appendix II

Mean weekly weather data during the cropping season *rabi*, 2010-2011 at Palampur

Month	Temperature ^{0}C		Relative humidity (%)	Rainfall (mm)	Sunshine hours
	Maximum	Minimum			
October 2010					
40	27.2	15.0	77.4	1.8	8.64
41	26.5	14.3	67.5	2.5	9.28
42	26.7	15.0	72.6	0.0	9.00
43	23.1	14.9	74.8	0.0	8.78
November 2010					
44	23.7	10.6	63.2	0.0	8.23
45	24.5	10.6	61.8	0.0	9.37
46	23.9	9.8	52.9	1.2	9.46
47	21.2	8.4	62.4	4.0	7.03
48	20.3	7.2	71.9	0.0	8.43
December 2010					
49	19.6	5.8	55.6	0.0	8.71
50	17.7	4.7	66.1	0.0	7.00
51	18.9	4.1	52.2	0.0	8.64
52	16.8	4.6	59.1	91.2	6.14
January 2011					
1	15.7	2.9	58.7	5.8	8.53
2	17.1	4.7	53.5	0.0	7.03
3	12.0	2.4	68.2	58.2	4.17
4	16.1	3.5	63.0	0.0	8.64
5	18.1	6.5	59.4	1.0	5.00
February 2011					
6	19.1	7.6	57.3	23.0	4.00
7	14.3	6.5	77.8	108.8	2.00
8	16.8	5.9	67.3	1.0	4.50
9	15.1	6.1	76.5	38.8	2.29
March 2011					
10	19.5	7.6	54.9	7.7	7.14
11	24.4	11.2	54.0	0.0	8.79
12	24.8	11.7	49.1	0.0	8.00
13	25.9	12.2	50.1	5.4	8.21
April 2011					
14	22.7	10.5	57.3	5.0	6.14
15	24.4	12.6	64.3	5.6	5.86
16	24.0	11.8	59.6	80.1	7.14
17	28.7	17.0	55.3	0.0	10.52
18	31.6	19.2	62.1	10.0	9.71

Mean weekly weather data during the cropping season *rabi*, 2011-2012 at Palampur

Month	Temperature ^{0}C		Relative humidity (%)	Rainfall (mm)	Sunshine hours
	Maximum	Minimum			
October 2011					
40	25.5	15.8	86.5	32.2	9.00
41	27.1	14.4	72.5	0.0	8.64
42	25.9	12.5	64.5	0.0	8.13
43	24.2	11.7	63.5	2.6	8.14
44	23.4	12.6	74.0	1.8	7.07
November 2011					
45	23.6	11.5	79.5	0.0	8.64
46	23.0	10.1	79.0	0.0	7.85
47	22.8	9.7	81.0	0.0	8.00
48	20.7	7.1	76.5	0.0	8.34
December 2011					
49	21.9	8.7	88.0	6.0	8.21
50	18.5	6.6	85.5	0.0	7.85
51	17.9	3.6	88.0	0.0	7.52
52	18.1	3.8	67.5	0.0	4.70
January 2012					
1	17.1	4.6	66.8	1.7	5.64
2	11.6	1.7	65.7	10.4	1.42
3	10.1	2.8	84.4	15.7	6.57
4	15.0	3.5	63.2	0.0	7.28
5	16.3	3.0	59.1	0.1	5.42
February 2012					
6	14.3	3.2	66.6	4.6	5.42
7	13.9	4.8	71.7	5.1	3.92
8	18.2	7.6	69.1	1.5	3.78
9	19.8	8.0	47.6	0.0	8.53
March 2012					
10	18.9	6.7	53.0	2.9	5.79
11	20.8	8.4	53.1	1.7	7.63
12	25.5	11.0	53.6	0.0	7.54
13	25.9	13.5	45.2	0.0	7.21
April 2012					
14	28.3	14.8	39.6	0.5	7.35
15	25.0	12.2	61.4	2.6	6.28
16	25.5	13.8	63.0	1.0	7.55
17	26.2	12.9	54.2	3.8	7.28
18	26.9	14.4	45.2	0.0	8.14

Appendix III Estimation of mean values for marketable yield per plant and other characters of broccoli in environment I (2010-2011)

Characters / Genotypes	Days to first harvest	Marketable yield/plant (g)	Terminal head weight/ plant (g)	Gross weight /plant (g)	Number of spears/plant	Head size index (cm_2)	Plant frame (cm_2)	Leaf size with leaf stalk (cm_2)	Leaf size without leaf stalk (cm_2)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/plant (g)	Harvest index (%)
Lucky	113.60	364.00	345.66	846.66	2.48	220.51	4140.93	438.89	249.70	43.33	24.73	2.60	42.66	42.72
Fiesta	119.80	371.33	328.66	960.00	1.78	244.76	4222.33	537.69	306.74	44.60	24.53	2.08	52.00	40.42
Kendi	113.20	340.66	325.33	836.66	9.73	250.86	3393.26	475.54	312.92	41.60	30.33	2.32	156.00	41.66
Indica	97.67	126.33	71.33	668.33	9.26	140.24	3386.46	540.98	313.40	48.26	40.36	3.25	173.00	19.90
Green Magic	113.20	399.33	384.66	1041.66	4.80	257.76	2936.46	560.09	383.93	47.13	28.80	2.36	131.33	38.24
BR-70	114.06	370.66	346.00	913.33	5.46	288.81	3445.80	679.90	452.82	47.53	24.66	2.23	107.33	40.24
BR-60	112.53	264.00	292.00	825.00	4.40	250.30	3555.13	689.58	391.48	47.26	27.26	2.44	104.66	32.64
Altar	121.60	536.66	523.33	1005.00	1.33	232.66	4434.57	771.21	445.47	52.80	25.60	2.41	15.00	51.77
CBH-1	98.33	336.33	299.00	865.00	5.93	264.14	3209.86	609.85	330.11	46.10	32.46	2.57	80.66	32.53
Pluto	111.93	295.33	251.33	855.00	5.00	234.41	4799.73	686.10	346.82	50.86	29.53	2.50	78.00	35.52
Green Beauty	110.80	142.66	123.66	820.00	4.55	163.56	4409.53	540.75	372.40	44.20	30.13	2.51	59.33	18.37
Supreme	112.73	307.66	342.66	891.66	4.60	185.54	3626.93	614.86	346.48	45.26	28.73	2.48	102.66	41.61
Packman	109.53	280.33	251.33	718.33	5.26	241.00	3392.13	354.95	349.12	43.80	30.40	2.73	95.33	34.31
Tiltest	113.53	270.33	253.00	723.33	5.00	209.31	3347.33	635.82	358.31	48.23	31.62	2.27	100.66	36.22
Palam Haritika (c)	125.66	331.33	298.00	731.66	3.71	228.10	3747.26	716.85	377.22	54.93	31.96	2.46	110.66	43.25
Palam Samridhi (c)	105.53	258.66	233.33	658.33	5.46	217.36	2857.06	492.06	288.50	43.20	27.93	2.53	94.00	37.03
GRAND MEAN ($\bar{X}$)	**112.10**	**312.22**	**291.83**	**835.00**	**4.92**	**223.08**	**3681.55**	**584.07**	**351.59**	**46.82**	**29.31**	**2.48**	**93.95**	**36.65**
S.E (d)±	**2.10**	**17.07**	**15.32**	**48.56**	**0.30**	**17.40**	**266.91**	**31.46**	**21.13**	**1.99**	**1.70**	**0.08**	**8.17**	**2.12**
CD (5%)	**6.06**	**49.30**	**44.24**	**140.26**	**0.88**	**50.26**	**770.89**	**90.86**	**61.04**	**5.76**	**4.91**	**0.23**	**23.60**	**6.14**
CV (%)	**3.24**	**9.47**	**9.09**	**10.07**	**10.77**	**13.51**	**12.55**	**9.32**	**10.41**	**7.37**	**10.05**	**5.71**	**15.06**	**10.05**
Range	**97.67-125.66**	**126.33-536.66**	**71.33-523.33**	**658.33-1041.66**	**1.33-9.73**	**140.24-288.81**	**2857.06-4799.73**	**354.95-771.21**	**249.70-452.82**	**41.60-54.93**	**24.53-40.36**	**2.08-3.25**	**15.00-173.00**	**18.37-51.77**

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Appendix IV Estimation of mean values for marketable yield per plant and other characters of broccoli in environment II (2011-2012)

Characters / Genotypes	Days to first harvest	Marketable yield/plant (g)	Terminal head weight/ plant (g)	Gross weight /plant (g)	Number of spears/plant	Head size index (cm_2)	Plant frame (cm_2)	Leaf size with leaf stalk (cm_2)	Leaf size without leaf stalk (cm_2)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/ plant (g)	Harvest index (%)
Lucky	118.33	372.00	352.00	1046.66	2.33	224.98	4057.26	551.96	358.16	48.23	30.00	2.56	48.33	36.97
Fiesta	125.33	376.00	359.33	980.00	4.73	270.00	4044.06	595.12	396.81	48.00	34.53	2.12	55.83	40.93
Kendi	107.00	369.00	358.00	1078.33	7.00	245.53	4089.06	609.86	349.72	47.56	36.20	2.54	144.80	33.83
Indica	102.00	155.00	126.66	724.33	10.66	122.10	4219.60	594.43	346.41	57.63	45.56	3.17	140.33	19.19
Green Magic	107.20	378.66	354.66	1054.33	5.20	231.40	3874.13	712.09	411.61	51.53	30.13	2.62	117.33	35.89
BR-70	101.53	359.66	344.66	1075.66	5.73	243.13	3725.60	792.01	407.28	55.46	32.73	2.38	113.00	32.71
BR-60	99.93	306.00	279.33	858.33	6.06	242.06	3716.46	724.37	383.26	55.26	31.53	2.34	113.46	36.62
Altar	116.86	546.00	527.66	1237.33	1.50	240.80	5239.86	825.56	454.19	53.86	31.66	2.38	26.66	46.70
CBH-1	88.00	329.33	315.33	917.00	6.00	193.53	3168.86	590.79	412.01	49.06	31.06	2.51	123.33	35.38
Pluto	99.13	305.00	263.00	905.66	6.86	228.61	4507.73	773.96	470.31	55.46	34.26	2.52	157.00	35.64
Green Beauty	104.93	210.00	193.33	890.66	2.70	193.63	4439.86	556.13	332.65	47.73	34.53	2.42	76.66	23.80
Supreme	112.40	303.00	290.33	986.00	5.96	216.51	4202.60	636.52	304.04	52.40	31.53	2.34	120.66	39.34
Packman	91.33	238.00	229.33	740.00	5.66	231.23	3410.53	598.38	345.43	47.00	33.80	2.58	118.80	31.98
Tiltest	101.06	263.00	250.66	780.00	5.00	238.73	3831.20	717.57	412.57	59.00	32.26	2.65	153.33	32.89
Palam Haritika (c)	132.33	382.00	326.66	984.33	5.50	276.73	4119.20	806.98	429.89	51.36	36.86	2.34	127.33	38.99
Palam Samridhi (c)	96.66	248.00	235.33	703.00	6.73	249.73	2698.26	543.12	305.70	45.26	34.26	2.59	122.50	31.81
GRAND_ MEAN (X)	**106.54**	**321.29**	**300.39**	**935.10**	**5.47**	**228.04**	**3959.02**	**664.30**	**382.50**	**51.55**	**33.81**	**2.50**	**109.96**	**34.54**
S.E (d)±	**2.99**	**18.40**	**17.71**	**57.37**	**0.35**	**18.63**	**268.60**	**39.14**	**25.60**	**2.19**	**2.30**	**0.08**	**9.51**	**1.94**
CD (5%)	**8.64**	**53.17**	**51.15**	**165.71**	**1.03**	**53.81**	**775.77**	**113.05**	**73.93**	**6.33**	**6.65**	**0.25**	**27.47**	**5.61**
CV (%)	**4.86**	**9.92**	**10.21**	**10.62**	**11.32**	**14.15**	**11.75**	**10.20**	**11.04**	**7.36**	**11.80**	**6.12**	**14.98**	**9.75**
Range	**88.00-132.33**	**155.00-546.00**	**126.66-527.66**	**703.00-1237.33**	**1.50-10.66**	**122.10-276.73**	**2698.26-5239.86**	**543.12-825.56**	**304.04-470.31**	**45.26-59.00**	**30.00-45.56**	**2.12-3.17**	**26.66-157.00**	**19.19-46.70**

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Appendix V Estimation of mean values for marketable yield per plant and other characters of broccoli in pooled over the environments

Characters / Genotypes	Days to first harvest	Marketable yield/plant (g)	Terminal head weight/ plant (g)	Gross weight /plant (g)	Number of spears/ plant	Head size index (cm_2)	Plant frame (cm_2)	Leaf size with leaf stalk (cm_2)	Leaf size without leaf stalk (cm_2)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/plant (g)	Harvest index (%)
Lucky	115.96	368.00	348.83	946.66	2.40	222.75	4099.10	495.42	303.93	45.78	27.36	2.58	45.50	39.84
Fiesta	122.56	373.66	344.00	970.00	3.25	257.38	4133.20	566.40	351.77	46.30	29.53	2.10	53.91	40.67
Kendi	110.10	354.83	341.66	957.50	8.36	248.20	3741.16	542.70	331.32	44.58	33.26	2.43	150.40	37.74
Indica	99.83	140.66	99.00	696.33	9.96	131.17	3803.03	567.71	329.91	52.95	42.96	3.21	156.66	19.54
Green Magic	110.20	389.00	369.66	1048.00	5.00	244.58	3405.30	636.09	397.77	49.33	29.46	2.49	124.33	37.07
BR-70	107.80	365.16	345.33	994.50	5.60	235.97	3585.70	735.95	430.05	51.50	28.70	2.31	110.16	36.47
BR-60	106.23	285.00	285.66	841.66	5.23	246.18	3635.80	706.97	387.37	51.26	29.40	2.39	109.06	34.63
Altar	119.23	541.33	525.50	1121.16	1.41	236.73	4837.22	798.39	449.83	53.33	28.63	2.38	20.83	49.23
CBH-1	93.46	332.83	307.16	891.00	5.96	228.84	3189.36	600.32	371.06	47.58	31.76	2.54	102.00	33.96
Pluto	105.53	300.16	257.16	880.33	5.93	231.51	4653.73	730.03	408.57	53.16	31.90	2.51	117.50	35.58
Green Beauty	107.86	176.33	158.50	855.33	3.62	178.60	4424.70	548.44	352.52	45.96	32.33	2.46	68.00	21.08
Supreme	112.56	305.33	316.50	938.83	5.28	201.03	3914.76	625.69	325.26	48.83	30.13	2.41	111.66	40.47
Packman	100.43	295.16	240.33	729.16	5.46	236.11	3401.33	476.67	347.28	45.40	32.10	2.65	107.06	33.14
Tiltest	107.30	266.67	251.83	751.66	5.00	244.02	3589.26	676.70	385.44	53.61	31.94	2.46	127.00	34.55
Palam Haritika (c)	129.00	356.66	312.33	858.00	4.60	252.41	3933.23	761.92	403.55	53.15	34.41	2.40	118.99	41.12
Palam Samridhi (c)	101.10	253.33	234.33	680.66	6.10	233.55	2777.66	517.59	297.10	44.23	31.09	2.56	108.25	34.42
GRAND MEAN (X)	**109.32**	**316.76**	**296.11**	**858.05**	**5.20**	**225.56**	**3820.28**	**624.19**	**367.04**	**49.18**	**31.56**	**2.49**	**101.96**	**35.59**
S.E (d)±	**2.37**	**12.88**	**12.54**	**38.76**	**0.38**	**13.15**	**191.81**	**26.49**	**26.39**	**1.54**	**1.44**	**0.06**	**8.22**	**1.56**
CD (5%)	**6.69**	**36.31**	**35.35**	**109.22**	**1.07**	**37.06**	**540.39**	**74.64**	**74.35**	**4.33**	**4.08**	**0.18**	**23.16**	**4.39**
CV (%)	**5.32**	**9.96**	**10.37**	**10.70**	**17.89**	**14.28**	**12.29**	**10.39**	**17.16**	**7.66**	**11.23**	**6.34**	**19.75**	**10.74**
Range	**93.46-129.00**	**140.66-541.33**	**99.00-525.50**	**680.66-1121.16**	**1.41-9.96**	**131.17-257.38**	**2777.66-4837.22**	**476.67-798.39**	**297.10-449.83**	**44.23-53.61**	**27.36-42.96**	**2.10-3.21**	**20.83-156.66**	**19.54-49.23**

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Brief Biodata of the student

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10th	2004	CBSE, New Delhi	62.00	First	English, Maths, Science, Hindi & Social Studies
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B.Sc. (Agriculture)	2010	CSK Himachal Pradesh Agriculture University, Palampur (H.P.), India	79.28	First	All Agriculture and Allied subjects
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