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Genetic analysis of quantitative and quality traits in bacterial wilt resistant genotypes of bell pepper under sub-temperate conditions of north-western Himalayas

Minakshi Thakur, Sonia Sood and Nivedita Gupta

Abstract
The present investigation was carried out to generate information on variability for quantitative and quality traits in bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.). The experiment material consisted of 46 genotypes of bell pepper that were evaluated in randomized complete block design during *kharif*, 2016. The observations were recorded on days to 50 per cent flowering, days to first picking, plant height (cm), primary branches per plant, harvest duration (days), fruit length (cm), fruit width (cm), pericarp thickness (mm), lobes per fruit, average fruit weight (g), fruit yield per plant (g), fruits per plant, marketable fruit yield per plant (g), marketable fruits per plant, capsanthin content (ASTA units), TSS (ºBrix) and ascorbic acid content (mg/100g). Significant differences were observed among the genotypes for all the traits, indicated presence of sufficient variation for all the traits. Among all, genotypes DPCBWR-14-39 (644.29 g), DPCBWR-14-36 (610.17 g), DPCBWR-14-31 (601.96 g), DPCBWR-14-35 (517.88 g), DPCBWR-14-11 (510.34 g), DPCBWR-14-7 (510.14 g) and DPCBWR-14-29 (499.47 g) were the highest yielders and these were also among the top genotypes for economic traits *viz*., marketable fruits per plant, fruit yield per plant, fruits per plant and average fruit weight. The PCV was invariably higher than their corresponding GCV for most of the characters, indicated close association between phenotype and genotype. High PCV as well as GCV was observed for fruit yield per plant, fruits per plant, marketable fruit yield per plant, marketable fruits per plant, capsanthin content and ascorbic acid depicting the presence of substantial variability and would respond better to selection. High heritability alongwith high genetic advance was observed for fruit yield per plant, fruits per plant, marketable fruit yield per plant, marketable fruits per plant, capsanthin content, TSS and ascorbic acid, respectively revealing the importance of additive gene action for the inheritance of these traits, and further improvement could be done through phenotypic selection.

Keywords: Bell pepper, PCV, GCV, heritability, genetic advance

Introduction

Bell pepper (*Capsicum annuum* L. var. *grossum* Sendt.; 2n=2x=24) is a cultivar group of the species *Capsicum annuum*, which belongs to family Solanaceae, is commonly known as sweet pepper or green pepper or capsicum and is looked as luxury vegetable in the world. It is native to Mexico with secondary centre of origin in Guatemala (Bukasov, 1930) [6]. Bell pepper was introduced in India by the Britishers in the 19th century in Shimla hills, is also popularly known as "Shimla Mirch". It holds a very coveted position as a leading off-season vegetable during summer-rainy season in Himachal Pradesh, generating cash revenues to the farmers by selling the produce in the neighbouring states and metropolitan cities. In recent years, its demand has increased tremendously with the emergence of pizza industry (Sood *et al*., 2011) [37]. Besides, it also has medicinal properties and hence, recommended for the treatment of dropsy, colic, toothache and cholera (Peirce, 1987) [24]. Bell pepper is an excellent source of ascorbic acid and a fair source of pro-vitamin A carotenoids (Haytowitz and Matthews, 1984) [12]. In addition, peppers are rich in flavonoids (Lee *et al*., 1995) [18] and other phytochemicals (Duke, 1992) [10]. Presently, it is extensively grown in Himachal Pradesh, Uttarakhand, Jammu and Kashmir, Arunachal Pradesh and Darjeeling and in some parts of West Bengal during summer months and as an autumn crop in Maharashtra, Karnataka, Tamil Nadu and Bihar. Bell pepper transported to distant market in the plains bringing handsome returns to the small and marginal farmers. Inspite of its importance a few varieties are grown commercially. California Wonder an old introduction being grown extensively throughout the country. Also, the average yield is low due to unsuitable cultivars/hybrids, biotic and abiotic stresses, genetic drift in cultivars, and development of new races of pathogens. Among diseases, bacterial wilt, caused by *Ralstonia solanacearum*, is one of the most important disease in humid tropical and subtropical areas causing huge crop losses. To enhance productivity genetic restructuring of bell pepper germplasm is needed to develop high yielding varieties/hybrids.

To develop superior and disease resistant cultivars of bell pepper, assessment of genetic diversity in the available gene pool is of utmost importance (Maric *et al.*, 2004) [19]. Parameters like phenotypic and genotypic coefficient of variation (PCV and GCV) are useful in detecting the amount of variability present in the available genotypes and for framing of breeding strategies. The usefulness of selection depends on the amount of genetic variation present (Adunga and Labuschangne, 2003) [3]. A large amount of variability increases the chance of selecting desired types (Vavilov, 1951). Most traits of interest to plant breeders are quantitative in nature and influenced by environment for their expression. According to Fisher (1918) [11], quantitative traits exhibiting continuous variation are under control of heritable and non-heritable factors. Response to selection depends on the relative proportion of the heritable component in the continuous variation. The heritable component is due to genotype, whereas the non-heritable portion is mainly due to environmental factors. Assessment of genotypes is possible through assessment of phenotypic expression, the results of genotype, and the environmental expression. Heritability and genetic advance help in determining the influence of the environment in the expression of the characters and extent to which improvement is possible through selection (Robinson *et al.*, 1949) [29]. Higher the heritable variation, greater will be the possibility of fixing the characters by selection methods. Therefore, the present investigation was undertaken to assess the genetic variability for important quantitative and quality traits for genetic improvement of bell pepper.

Material and methods

The present investigation was envisaged to gather information about the potential and characteristics of the experimental material of bell pepper at the Experimental Farm, Department of Vegetable Science and Floriculture, College of Agriculture, CSK Himachal Pradesh Agricultural University, Palampur (HP) during summer-rainy season of 2016.

Experimental site

Location

The experimental site is located at an altitude of about 1290.8 m above mean sea level. Geographic position of the experimental site lies between 32º6' N latitude and 76º3’ E longitude under mid hill zone of Himachal Pradesh, India.

Climate

The climate is humid sub-temperate. The mean monthly minimum and maximum temperature varied between 2.0 to 22.0 and 9.5 to 34.5 ºC, respectively during the cropping season. The experimental site experienced average rainfall of 250 cm annually, out of which about 80 % is received during monsoon period. Monsoon arrives in the second fortnight of June and ends in September. The summer is mild and winter is very severe.

Soil

The soil of the experimental block was acidic with pH ranging from 5.0 to 5.6 and soil texture is silty clay to silty loam.

Experimental materials

The experimental materials comprised of 46 genotypes of which 42 are advanced breeding lines (F_6) of bell pepper resistant to bacterial wilt disease derived from intervarietal crosses, susceptible check (California Wonder), moderately resistant check (Kandaghat Selection) and two resistant checks (EC-464107) and EC-464115) (Table 1).

Nursery sowing

The seeds were sown on January 28, 2016 in plug trays under polyhouse at Experimental Farm of Vegetable Science at CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (HP). Healthy and disease free seedlings of 46 genotypes including susceptible, moderately resistant and resistant checks to bacterial wilt disease were transplanted on April 11, 2016.

Experimental design and layout plan

The trial was laid out on April 11, 2016 comprising of 42 bacterial wilt resistant genotypes, one each of susceptible, moderately resistant and two resistant checks and transplanted in Randomized Block Design (RBD) with three replications in plot size of 3.6 × 2.7 m. The parents were spaced at 60 cm between row to row and 45 cm plant to plant. The experimental field was prepared by ploughing twice with power tiller upto a depth of 20 cm followed by levelling. The farm yard manure (20 t/ha) was mixed in the soil at the time of field preparation with first ploughing. The chemical fertilizer (90 kg N, 75 kg P_2O_5 and 50 kg K_2O/ha) were applied as basal dose at the time of final field preparation. One third of N, full dose of P_2O_5 and K_2O is applied at the time of final field preparation. Remaining two third of N was top dressed in two equal amounts and added after 30 and 45 days of transplanting respectively. The observations were recorded on five randomly selected plants for days to 50 per cent flowering, days to first picking, plant height (cm), primary branches per plant, harvest duration (days), fruit length (cm), fruit width (cm), pericarp thickness (mm), lobes per fruit, average fruit weight (g), fruit yield per plant (g), fruits per plant, marketable fruit yield per plant (g), marketable fruits per plant.

Capsanthin content (ASTA units) from the ripened fruit sample was estimated by the method as described by AOAC (1980) [55]. Total Soluble Solids (ºBrix) was estimated by Hand Refractometer. Ascorbic acid content (mg/100g fresh weight) from the crushed fruit sample was estimated by the method as described by Sadasivam and Manickam (1991) [30].

The mean values of the data collected were used for analysis of variance (Table 3) for RBD was estimated (Panse and Sukhtame 1989) [27].

The phenotypic, genotypic and environmental coefficients of variation were estimated following Burton and De Vane (1953) [7] as follows:

$$\text{Phenotypic coefficient of variation (PCV)\%} = \frac{\sigma p}{\bar{\bar{X}}} \times 100$$

$$\text{Genotypic coefficient of variation (GCV)\%} = \frac{\sigma g}{\bar{\bar{X}}} \times 100$$

where σp, σg and $\bar{X}$ are phenotypic standard deviation, genotypic standard deviation, grand mean, respectively.

Heritability in broad sense (h^2_{bs}) was calculated as per the following formula given by Burton and De Vane (1953) [7] and Johnson *et al.* (1955) [14].

$$\text{Heritability } (h^2_{bs}) = \frac{\sigma^2 g}{\sigma^2 g + \sigma^2 e} \times 100$$

where σ^2g, σ^2e and σ^2g + σ^2e are genotypic variance, environmental variance and phenotypic variances, respectively.

The expected genetic advance (GA) resulting from the selection of 5 % superior individuals was calculated as per Burton and De Vane (1953) [7] and Johnson *et al.* (1955) [14].

$$GA = K.\sigma p.h^2_{bs}$$

where K = 2.06 (selection differential at 5 % selection intensity), σp = phenotypic standard deviation and h^2_{bs} = heritability (broad sense), respectively.

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

Limits used for categorizing the magnitude of different parameters are presented in Table 2.

Table 1: Magnitude of differences for parameters

	High (%)	Moderate (%)	Low (%)
PCV and GCV	More than 20	10-20	Less than 10
Heritability (%)	More than 60	30-60	Less than 30
Genetic advance	More than 30	10-30	Less than 10

Statistical analysis

The mean values of different genotypes for various traits were statistically analysed using OPSTAT programme. OPSTAT (developed by CCS Haryana Agricultural University, Hisar, India) software was used for statistical analysis.

Results and discussions

Analysis of Variance

The analysis of variance revealed that mean squares due to genotypes were significant for all the traits (Table 3) indicating the presence of good amount of genetic variability and considerable scope for improvement. Sufficient genetic variability for many of the traits had also been reported by earlier workers with different genetic material under their environmental conditions (Sharma *et al.*, 2010; Sood *et al.*, 2011; Ahmed *et al.*, 2012; Afroza *et al.*, 2013a; Afroza *et al.*, 2013b; Devi *et al.*, 2015; Rana *et al.*, 2015; Thakur *et al.*, 2017 [33, 36, 4, 1, 2, 9, 28, 38]. The extent of variability present in the bell pepper genotypes was measured in terms of mean, range, phenotypic (PCV) and genotypic (GCV) coefficients of variation, heritability (broad sense), genetic advance as per cent of mean for all the traits are presented in Tables 4, 5 and 6.

Mean Performance of Genotypes

Genotypes influenced some qualitative and quality traits (Table 4 and 6). Days to 50 per cent flowering and first picking are the trait which determines the earliness of a variety and consequently help in capturing early market which fetches high price in markets, whereas fruits per plant, fruit length, fruit width and weight are the major yield contributing traits. Based on mean values, progenies *viz.*, DPCBWR-14-29 (32.67 days), DPCBWR-14-37 (34.67 days), DPCBWR-14-43 (34.67 days), DPCBWR-14-42 (35.00 days) and DPCBWR-14-39 (35.33 days) were early in bearing 50 per cent flowering and progenies *viz.*, DPCBWR-14-15 (48.00 days), DPCBWR-14-21 (48.00 days), DPCBWR-14-29 (48.00 days), DPCBWR-14-37 (48.00 days) and DPCBWR-14-39 (48.00 days) took less number of days to first picking. These results are in consonance with the findings of Sharma *et al.* (2013) [32], Devi *et al.* (2015) [9] and Rana *et al.* (2015) [28] for days to 50 per cent flowering, whereas Sharma *et al.* (2010) [33] and Sood *et al.* (2011) [36], Afroza *et al.* (2013b) [2] for days to first picking.

Bell pepper is grown during the rainy season, taller plants are preferred to prevent diseases because fruits tend to rot in plants which are short statured. In the present study maximum plant height was found in DPCBWR-14-11 (61.17 cm) followed by DPCBWR-14-10 (58.47 cm), DPCBWR-14-40 (56.57 cm), DPCBWR-14-12 (56.47 cm) and DPCBWR-14-25 (55.00 cm). Among these DPCBWR-14-11 also produced high marketable fruits and yield per plant. Higher fruit yield per plant in taller plants could be attributed to production of more number of flowers. More primary branches per plant are preferred for getting more fruits per plant and ultimately higher marketable fruit yield. DPCBWR-14-36 (4.77) had maximum number of primary branches per plant followed by DPCBWR-14-35 (4.47), DPCBWR-14-16 (4.20), DPCBWR-14-8 (4.13) and DPCBWR-14-42 (4.07). Among these DPCBWR-14-36 (610.17 g) and DPCBWR-14-35 (517.88 g) also exhibited high marketable fruit yield per plant. These results are in broad confirmity with the findings of Sharma *et al.* (2013) [32] and Rana *et al.* (2015) [28] for both plant height and primary branches per plant.

Genotypes having long harvest duration are generally preferred in the present marketing system under Indian conditions because it not only avoids the glut in the market but off-season value of the crop is also maintained. Genotypes with long harvest duration, in general, produced more fruits and high fruit yield per plant. In the present study, progeny DPCBWR-14-39 offered promise for more marketable fruits per plant (16.80) and marketable fruit yield per plant (644.29 g) and thus suitable for long harvest duration (49.67 days). Similar findings were also reported by Sood *et al.* (2011) [36] and Devi *et al.* (2015) [9].

In present market, medium sized blocky fruits are preferred over large sized fruits. DPCBWR-14-31 had maximum fruit length (7.78 cm) followed by DPCBWR-14-36 (7.07 cm) and DPCBWR-14-43 (6.85 cm). These progenies had fruit width of 5.08, 5.46 and 5.12 cm; and pericarp thickness of 3.98, 4.22 and 4.03 mm, respectively. Fruit width is a desirable trait for obtaining blocky fruits and DPCBWR-14-36 (5.46 cm) excelled for fruit width. Pericarp thickness of fruits is an important parameter which is suitable for long storage and distance transportation. Among the progenies, DPCBWR-14-7 (6.49 mm) exerted maximum pericarp thickness followed by DPCBWR-14-30 (5.20 mm) and DPCBWR-14-39 (5.17 mm). These progenies also showed good marketable fruit yield per plant. DPCBWR-14-2 (4.22) excelled for lobes per fruit whereas in all the progenies a narrow range of lobes per fruit (2.17 to 4.11) was observed. Sood *et al.* (2007b) [35] and Rana *et al.* (2015) [28] also reported similar results.

Higher fruit yield is the prime objective of all the crop improvement programmes. The progenies DPCBWR-14-39 (644.29 g), DPCBWR-14-36 (610.17 g), DPCBWR-14-31 (601.96 g), DPCBWR-14-35 (517.88 g), DPCBWR-14-11 (510.34 g), DPCBWR-14-7 (510.14 g) and DPCBWR-14-29

(499.47 g) were the highest yielders. These progenies were also among the top progenies for other economic traits *viz*., marketable fruits per plant, fruit yield per plant, fruits per plant and average fruit weight. The higher yield obtained in these progenies were mainly on account of inherent ability to produce more fruits per plant, more average fruit weight, more marketable fruits per plant, harvest duration, early flowering and picking, which were the main component traits contributed towards increased fruit yield. In general, fruits per plant is an important parameter which directly influences the yield. Maximum fruits per plant (17.07) and marketable fruits per plant (16.80) were harvested from DPCBWR-14-39. The highest average fruit weight was obtained from DPCBWR-14-36 (45.52 g) followed by DPCBWR-14-17 (42.35 g) and DPCBWR-14-21 (41.31 g). These results are in close confirmity with the findings of Kumari (2013) [17], Rana *et al.* (2015) [28] and Thakur *et al.* (2017) [38] using different genetic material and in different environments.

Among the quality traits, maximum capsanthin and ascorbic acid were recorded in DPCBWR-14-11 and DPCBWR-14-3 (150.88 ASTA units and 146.59 mg/100g, respectively). Capsanthin is a neutral pigment gains great attention because it used world widely in the food, cosmetic and dye industries and metabolized in the body. Its functions are antioxidative, anti-tumor, anti-cancer and have inhibitory effects on colon carcinogenesis in the human body (Shaha *et al.*, 2013) [31]. Therefore, bell pepper fruits with high capsanthin content are preferred. Ascorbic acid (Vitamin C) has unique antioxidant properties and also strengthens the immune system of the body against diseases.

TSS directly influence flavour and is an important biochemical trait required in the processing industry. High TSS adds to the quality of fruits and result in higher recovery of processed products. Bell pepper having TSS 3.3 ºBrix or higher are always desired in the processing industries for the preparation of different processed products. DPCBWR-14-4 had maximum TSS (6.07 ºBrix) followed by DPCBWR-14-42 (5.40 ºBrix), DPCBWR-14-1 (5.00 ºBrix) and DPCBWR-14-7 (5.00 ºBrix).

Besides, highest yielder progenies DPCBWR-14-11 and DPCBWR-14-7 also exhibited excellent quality traits *viz*., capsanthin content (150.88 and 110.21 ASTA units), TSS (3.96 and 5.00 ºBrix) and ascorbic acid content (109.60 and 102.25 mg/100g). These results are in close confirmity with those of earlier workers for capsanthin (Choudhary *et al.*, 2011; Misra *et al.*, 2011; Kumar, 2013) [8, 21, 15], TSS (Islam and Singh, 2006; Afroza *et al.*, 2013a) [13, 1] and ascorbic acid (Sharma *et al.*, 2010; Sharma *et al.*, 2013; Kumar *et al.*, 2015) [33, 32, 16].

Parameters of Variability

Variability was partitioned into genotypic and environmental components. The estimates of PCV were higher than corresponding GCV for all the characters studied (Table 5) which indicated that the apparent variation is not only due to genotypes but also due to the influence of environment. However, the differences between the genotypic and phenotypic variances were relatively low for most of the traits studied. This indicated highly heritable and comparatively stable nature of the characters and thus, the selection based on phenotypic performance would be quite effective in the improvement of these traits.

The magnitude of PCV and GCV were high for fruit yield per plant (22.90 % and 20.92 %), fruits per plant (21.08 % and 20.16 %), marketable fruit yield per plant (24.16 % and 21.33 %), marketable fruits per plant (21.63 % and 20.34 %), capsanthin content (23.77 % and 23.16 %) and ascorbic acid (21.57 % and 21.00 %). These high estimates indicated that there is substantial variability ensuring ample scope for improvement of these traits through selection. Sood *et al.* (2011) [36], Ahmed *et al.* (2012) [4], Kumari (2013) [17], Rana *et al.* (2015) [28] and Thakur *et al.* (2017) [38] have also reported high PCV and GCV for fruit yield per plant; Sood *et al.* (2011) [36] and Kumari (2013) [17] for fruits per plant; Sood *et al.* (2007a) [34] for marketable fruit yield per plant; Sood *et al.* (2007b) [35] for marketable fruits per plant; Islam and Singh (2006) [13] and Sharma *et al.* (2010) [33] for ascorbic acid content using different genetic material and in different environments.

The moderate estimates of PCV and GCV were recorded for plant height (13.89 % and 11.55 %), primary branches per plant (14.65 % and 12.74 %), harvest duration (15.25 % and 14.39 %), fruit length (16.36 % and 15.12 %), pericarp thickness (15.44 % and 13.73 %), lobes per fruit (13.58 % and 11.38 %) and TSS (18.96 % and 17.02 %). However, for average fruit weight PCV was observed to be moderate, while GCV was low. The moderate estimates suggested cautions approach while following direct selection for these traits. Such moderate estimates have also been reported by earlier research workers for plant height (Sharma *et al.*, 2010; Ahmed *et al.*, 2012) [33, 4], primary branches per plant (Ahmed *et al.*, 2012; Rana *et al.*, 2015) [4, 28], harvest duration (Sharma *et al.*, 2010; Sood *et al.*, 2011) [33, 36], fruit length (Sood *et al.*, 2011; Ahmed *et al.*, 2012; Kumari, 2013; Rana *et al.*, 2015; Thakur *et al.*, 2017) [36, 4, 17, 28, 38], pericarp thickness (Sood *et al.*, 2011; Ahmed *et al.*, 2012) [36, 4], lobes per fruit (Sood *et al.*, 2009; Sood *et al.*, 2011) [37, 36] and TSS (Sood *et al.*, 2007a) [34].

The rest of the traits namely, days to 50 per cent flowering (8.38 % and 6.83 %), days to first picking (8.73 % and 7.06 %) and fruit width (8.15 % and 5.47 %) showed low PCV and GCV estimates. These traits can be improved through hybridization. The low estimates have also been reported by Sharma *et al.* (2010) [33], Kumar *et al.* (2015) [16] and Rana *et al.* (2015) [28] for days to 50 per cent flowering and Sood *et al.* (2011) [36] and Kumar *et al.* (2015) [16] for days to first picking, who used different genetic material and were in different environments, indicating the possibility for improvement through hybridization for these traits.

Heritability and Genetic Advance

Heritability in broad sense is a parameter of tremendous significance to the breeders as its magnitude indicates the reliability with which a genotype can be recognized by its phenotypic expression.

Most of the traits studied showed high (>60 %) to moderate (30-60 %) heritability. The heritability estimates were recorded to be high for capsanthin content (94.87 %), ascorbic acid (94.74 %), fruits per plant (91.43 %), harvest duration (89.07 %), marketable fruits per plant (88.44 %), fruit length (85.42 %), fruit yield per plant (83.41 %), TSS (80.56 %), pericarp thickness (79.04 %), marketable fruit yield per plant (77.89 %), primary branches per plant (75.63 %), lobes per fruit (70.15 %), plant height (69.07 %), days to 50 per cent flowering (66.53 %) and days to first picking (65.30 %) indicating that these traits were less influenced by environment. This suggested that large proportion of phenotypic variation has been attributed to the genotypic variance and hence, reliable selection could be made for these traits on the basis of phenotypic expression. In bell pepper similar results with high broad sense heritability was also recorded by earlier workers for ascorbic acid (Sharma *et al.*, 2010; Afroza *et al.*, 2013a) [33, 1], fruit length, fruit yield per plant and fruits per plant (Sood *et al.*, 2011; Kumari, 2013; Rana *et al.*, 2015) [36, 17, 28], harvest duration (Sood *et al.*, 2007b; Sood *et al.*, 2009) [35], TSS (Sharma *et al.*, 2010; Afroza *et al.*, 2013a) [33, 1], pericarp thickness (Sood *et al.*, 2011; Kumari, 2013) [36, 17], marketable fruit yield per plant (Sood *et al.*, 2007a) [34], primary branches per plant (Mishra *et al.*, 2005), lobes per fruit (Sood *et al.*, 2011) [36], plant height (Ahmed *et al.*, 2012; Kumari, 2013; Rana *et al.*, 2015) [4, 17, 28], days to 50 per cent flowering (Rana *et al.*, 2015) [28] and days to first picking (Islam and Singh, 2006) [13].

Johnson *et al.* (1955) [14] stressed that for estimating the real effects of selection, heritability alone is not sufficient and genetic advance along with heritability is more useful.

High heritability alongwith high genetic advance was observed for fruit yield per plant (83.41 % and 39.35 %), fruits per plant (91.43 % and 39.70 %), marketable fruit yield per plant (77.89 % and 38.77 %), marketable fruits per plant (88.44 % and 39.41 %), capsanthin content (94.87 % and 46.46 %), TSS (80.56 % and 31.46 %) and ascorbic acid (94.74 % and 42.10 %. Earlier researchers have also found similar results for fruit yield per plant (Sood *et al.*, 2011; Kumari, 2013; Pandey *et al.*, 2013; Rana *et al.*, 2015; Thakur *et al.*, 2017) [36, 17, 25, 28, 38], fruits per plant (Sood *et al.*, 2011; Kumari, 2013; Pandey *et al.*, 2013) [36, 17, 25], marketable fruit yield per plant (Sood *et al.*, 2007a) [34], TSS (Naik *et al.*, 2014) [22] and ascorbic acid content (Islam and Singh, 2006; Sharma *et al.*, 2010) [13, 33]. In contrary, fruit yield per plant (Pandey *et al.*, 2013) [25] and ascorbic acid (Kumar *et al.*, 2015) [16] showed high heritability coupled with moderate genetic advance.

High heritability coupled with moderate genetic advance for days to 50 per cent flowering (66.53 % and 11.48 %), days to first picking (65.30 % and 11.75 %), plant height (69.07 % and 19.77 %), primary branches per plant (75.63 % and 22.83 %), harvest duration (89.07 % and 27.98 %), fruit length (85.42 % and 28.80 %), pericarp thickness (79.04 % and 25.14 %) and lobes per fruit (70.15 % and 19.63 %). High to moderate heritability coupled with high to moderate genetic advance indicates the importance of additive effects for these traits and their possible improvement through selection. Similar results have also been observed for days to 50 per cent flowering (Rana *et al.*, 2015) [28], plant height and primary branches per plant (Mishra *et al.*, 2005) and fruit length (Sood *et al.*, 2011; Kumari, 2013; Rana *et al.*, 2015) [36, 17, 28].

Moderate heritability with moderate to low genetic advance was noticed for average fruit weight (47.36 % and 12.81 %) and fruit width (44.91 % and 7.55 %), respectively (Table 5). The association of high to moderate heritability with low genetic advance revealed that inheritance of these characters was under the control of non-additive gene effects and these can be improved through hybridization (Panse, 1957) [26]. Improvement of these traits through straight selection might not give desirable results. Similar findings were also reported by Kumar *et al.* (2015) [16] for fruit width using different genetic material and under different environmental conditions.

Table 2: List of bell pepper genotypes and their sources

S. No.	Genotypes	Source	S. No.	Genotypes	Source
1.	DPCBWR-14-1	Department of Vegetable Science & Floriculture, CSK HPKV, Palampur (HP)	24.	DPCBWR-14-24	Department of Vegetable Science & Floriculture, CSK HPKV, Palampur (HP)
2.	DPCBWR-14-2	-do-	25.	DPCBWR-14-25	-do-
3.	DPCBWR-14-3	-do-	26.	DPCBWR-14-26	-do-
4.	DPCBWR-14-4	-do-	27.	DPCBWR-14-27	-do-
5.	DPCBWR-14-5	-do-	28.	DPCBWR-14-28	-do-
6.	DPCBWR-14-6	-do-	29.	DPCBWR-14-29	-do-
7.	DPCBWR-14-7	-do-	30.	DPCBWR-14-30	-do-
8.	DPCBWR-14-8	-do-	31.	DPCBWR-14-31	-do-
9.	DPCBWR-14-9	-do-	32.	DPCBWR-14-32	-do-
10.	DPCBWR-14-10	-do-	33.	DPCBWR-14-34	-do-
11.	DPCBWR-14-11	-do-	34.	DPCBWR-14-35	-do-
12.	DPCBWR-14-12	-do-	35.	DPCBWR-14-36	-do-
13.	DPCBWR-14-13	-do-	36.	DPCBWR-14-37	-do-
14.	DPCBWR-14-14	-do-	37.	DPCBWR-14-38	-do-
15.	DPCBWR-14-15	-do-	38.	DPCBWR-14-39	-do-
16.	DPCBWR-14-16	-do-	39.	DPCBWR-14-40	-do-
17.	DPCBWR-14-17	-do-	40.	DPCBWR-14-41	-do-
18.	DPCBWR-14-18	-do-	41.	DPCBWR-14-42	-do-
19.	DPCBWR-14-19	-do-	42.	DPCBWR-14-43	-do-
20.	DPCBWR-14-20	-do-	43.	EC-464107 (R)	AVRDC, Taiwan
21.	DPCBWR-14-21	-do-	44.	EC-464115 (R)	AVRDC, Taiwan
22.	DPCBWR-14-22	-do-	45.	Kandaghat Selection	RRS, Kandaghat, UHF, Solan (HP)
23.	DPCBWR-14-23	-do-	46.	California Wonder	IARI, Regional Research Station, Katrain (Kullu), HP

Table 3: Analysis of variance for quantitative and quality traits in bell pepper genotypes

S. No.	Sources of variation → Traits df→	Replication 2	Genotypes 45	Error 90	CD (5%)
I.	**Quantitative traits**				
a)	**Phenological and structural traits**				
	Days to 50 per cent flowering	48.20	24.83*	3.57	3.07
	Days to first picking	0.20	50.08*	7.54	4.46
	Plant height (cm)	19.13	102.19*	13.28	5.92
	Primary branches per plant	0.24	0.65*	0.06	0.41

	Harvest duration (days)	4.96	111.83*	4.39	3.41
b)	**Fruit yield traits**				
	Fruit length (cm)	0.03	2.24*	0.12	0.56
	Fruit width (cm)	0.31	0.30*	0.09	0.48
	Pericarp thickness (mm)	0.32	1.17*	0.10	0.50
	Lobes per fruit	0.02	0.48*	0.06	0.40
	Average fruit weight (g)	122.67	41.72*	11.28	5.37
	Fruit yield per plant (g)	7205.41	25015.65*	1,555.71	65.74
	Fruits per plant	0.51	18.04*	0.55	1.20
	Marketable fruit yield per plant (g)	12134.15	24986.09*	2,159.91	75.23
	Marketable fruits per plant	0.66	17.53*	0.73	1.39
II.	**Quality traits**				
	Capsanthin content (ASTA units)	5.81	1552.24*	27.49	8.52
	Total soluble solids (°Brix)	0.33	1.49*	0.11	0.54
	Ascorbic acid content (mg/100g)	34.43	1294.28*	23.53	7.88
III.	**Disease reaction**				
	Plant survival rate (%)	519.89	1008.92*	95.19	15.85

*Significant at 5% level

Table 4: Estimates of mean values for quantitative and quality traits in bell pepper genotypes

Genotypes/Traits	**Quantitative traits**														**Quality traits**		
	Phenological and structural traits					**Fruit yield traits**											
	DF	**DFP**	**PL (cm)**	**PBL**	**HD (days)**	**FL (cm)**	**FW (cm)**	**PT (mm)**	**LPP**	**AFW (g)**	**FYP (g)**	**FPP**	**MFYP (g)**	**MFP**	**CC (ASTA units)**	**TSS (ºBrix)**	**AA (mg/100g)**
DPCBWR-14-1	41.33	57.00	45.33	3.40	35.33	5.23	4.63	4.19	3.83	36.61	335.40	9.13	325.47	8.87	78.72	5.00	109.29
DPCBWR-14-2	39.33	51.00	50.33	3.73	46.00	5.44	5.40	3.77	4.22	36.70	435.60	12.07	422.94	11.53	75.77	3.80	87.48
DPCBWR-14-3	38.67	54.00	42.12	3.15	41.00	5.58	4.42	3.88	3.11	34.91	372.20	10.40	353.56	10.13	91.84	3.60	146.59
DPCBWR-14-4	39.00	57.00	49.07	3.60	36.67	5.09	4.30	4.71	3.22	33.70	312.15	9.13	285.48	8.87	95.12	6.07	63.93
DPCBWR-14-5	41.33	57.00	43.27	3.33	36.67	5.23	4.72	5.01	3.55	36.80	420.58	11.40	409.84	11.13	71.18	4.67	71.63
DPCBWR-14-6	36.33	54.00	44.40	3.47	41.00	4.80	4.47	4.92	3.45	37.67	430.99	11.27	416.18	11.07	81.02	4.83	102.50
DPCBWR-14-7	39.00	54.00	42.33	3.73	41.00	5.10	4.72	6.49	3.17	38.28	524.47	13.40	510.14	13.33	110.21	5.00	102.25
DPCBWR-14-8	40.67	57.00	51.33	4.13	36.67	6.61	4.67	4.73	3.78	36.96	413.39	10.80	377.62	10.20	86.26	3.87	71.62
DPCBWR-14-9	40.67	57.00	47.40	3.60	36.67	5.78	5.20	5.05	4.11	39.35	483.83	12.13	473.11	12.00	76.43	3.60	120.56
DPCBWR-14-10	39.33	54.00	58.47	3.13	41.00	5.86	5.13	4.46	3.78	35.17	382.30	10.73	370.99	10.53	92.19	4.53	95.41
DPCBWR-14-11	37.00	54.00	61.17	3.95	43.67	5.61	4.89	3.71	3.22	33.00	522.34	15.67	510.34	15.47	150.88	3.96	109.60
DPCBWR-14-12	37.33	57.00	56.47	3.73	39.00	5.74	5.33	4.19	3.11	34.26	363.37	10.73	352.53	10.27	141.04	3.53	73.37
DPCBWR-14-13	38.67	54.00	38.73	4.00	41.00	4.52	4.72	4.86	3.00	37.13	470.72	12.67	455.45	12.27	90.87	3.03	99.81
DPCBWR-14-14	35.33	48.00	45.93	3.40	49.67	6.80	5.18	4.18	2.83	36.76	419.08	11.40	405.63	11.00	86.92	4.25	89.16
DPCBWR-14-15	36.33	48.00	47.27	3.33	49.67	4.44	4.92	4.96	3.56	31.55	463.57	14.80	451.65	14.33	82.67	4.25	101.09
DPCBWR-14-16	36.67	51.00	45.53	4.20	45.33	4.88	4.50	4.47	3.44	35.54	462.10	13.00	456.07	12.87	81.02	3.80	103.23
DPCBWR-14-17	38.00	51.00	44.73	2.68	44.00	6.61	4.85	4.30	3.50	42.35	416.54	9.87	398.44	9.40	82.00	4.47	103.93
DPCBWR-14-18	36.00	48.00	39.47	2.93	48.33	5.78	4.97	2.83	3.56	34.83	337.54	8.93	303.70	8.73	114.81	4.30	93.70
DPCBWR-14-19	39.67	51.00	46.40	3.27	44.00	5.45	5.06	2.91	3.56	40.19	394.30	9.40	372.57	9.27	98.62	4.56	116.97
DPCBWR-14-20	44.00	57.00	42.13	2.87	36.67	6.08	4.67	4.63	3.33	41.13	374.36	9.00	367.59	8.93	71.18	4.08	88.45
DPCBWR-14-21	37.00	48.00	46.92	2.93	48.33	5.71	4.36	4.99	3.00	41.31	458.58	10.93	447.86	10.80	90.87	4.04	75.19
DPCBWR-14-22	42.67	54.00	47.28	2.87	41.00	4.59	4.12	4.20	3.00	33.39	386.28	11.33	376.83	11.27	80.04	4.90	112.90
DPCBWR-14-23	43.33	54.00	37.07	2.67	41.00	5.72	4.96	4.28	3.11	36.91	354.34	9.60	339.13	9.20	76.43	4.08	67.88
DPCBWR-14-24	39.67	51.00	41.23	2.80	45.33	4.90	5.06	4.58	3.00	31.65	406.11	12.93	394.79	12.47	91.84	2.63	120.64
DPCBWR-14-25	39.67	54.00	55.00	3.13	41.00	4.38	4.68	4.35	3.72	30.98	464.65	15.00	450.23	14.53	79.05	4.05	106.54
DPCBWR-14-26	43.33	54.00	41.80	3.40	39.33	5.32	5.31	4.47	3.28	32.64	393.53	11.80	376.20	11.53	115.07	3.30	95.24
DPCBWR-14-27	44.00	54.00	42.10	3.42	39.33	5.22	4.72	3.59	3.78	31.56	400.10	12.47	392.18	12.40	95.12	3.07	98.21
DPCBWR-14-28	36.00	48.00	52.13	3.47	49.67	6.06	4.74	4.40	2.89	30.12	385.48	12.87	373.06	12.40	108.24	3.60	69.83
DPCBWR-14-29	32.67	48.00	51.53	3.27	49.67	5.73	4.87	4.31	3.11	32.37	515.34	15.93	499.47	15.33	131.20	3.93	57.58
DPCBWR-14-30	39.67	57.00	45.40	3.67	36.67	5.42	4.50	5.20	2.17	34.82	450.50	13.07	421.68	12.13	145.96	3.50	95.67
DPCBWR-14-31	40.00	53.67	51.67	3.67	44.33	7.78	5.08	3.98	2.17	40.03	615.27	15.33	601.96	15.00	92.83	3.63	128.31
DPCBWR-14-32	37.00	64.67	48.80	3.20	36.33	5.29	4.67	4.52	3.33	34.02	501.23	14.53	475.30	13.93	143.23	3.80	114.02
DPCBWR-14-34	40.00	61.33	38.98	3.43	34.33	5.28	4.88	4.95	3.11	36.75	375.55	10.27	357.69	9.73	134.48	3.13	94.00
DPCBWR-14-35	44.33	64.33	53.07	4.47	36.67	6.03	4.91	4.05	3.00	34.07	542.23	15.67	517.88	15.20	126.72	4.20	55.36
DPCBWR-14-36	44.33	57.00	51.80	4.77	36.67	7.07	5.46	4.22	3.56	45.52	624.95	13.73	610.17	13.40	71.18	2.90	104.55
DPCBWR-14-37	34.67	48.00	35.40	3.20	48.33	4.69	4.86	4.14	3.17	39.43	461.01	11.60	449.94	11.40	85.56	2.90	82.34
DPCBWR-14-38	40.00	57.00	54.47	3.97	36.67	3.92	4.89	4.67	3.39	29.24	401.18	13.40	379.69	13.00	122.13	3.60	111.50
DPCBWR-14-39	35.33	48.00	52.67	3.47	49.67	4.72	4.74	5.17	3.00	38.56	665.12	17.07	644.29	16.80	83.65	3.20	101.75
DPCBWR-14-40	39.33	51.00	56.57	3.73	45.33	4.57	4.83	4.41	2.83	32.02	485.30	14.93	467.67	14.60	125.30	3.80	125.18
DPCBWR-14-41	42.00	51.00	44.13	3.33	45.33	4.67	4.42	3.88	3.00	27.23	341.41	12.60	319.23	11.80	78.43	4.77	59.26
DPCBWR-14-42	35.00	51.00	45.53	4.07	45.33	5.29	4.25	3.16	3.22	31.60	389.11	11.20	341.65	10.87	78.39	5.40	106.30
DPCBWR-14-43	34.67	51.00	50.07	3.73	45.33	6.85	5.12	4.03	3.17	32.51	365.45	11.07	349.39	10.80	101.68	4.20	123.28
EC-464107(R)	37.67	51.00	49.27	3.77	45.33	7.20	4.94	3.96	3.44	31.84	399.66	11.93	368.90	11.67	77.08	4.70	104.39
EC-464115(R)	39.00	51.00	49.10	3.67	44.00	7.53	5.37	4.15	3.33	33.17	366.13	10.80	352.01	10.67	70.58	3.33	115.50
Kandaghat selection	40.00	51.00	45.87	3.47	39.67	5.16	4.99	4.31	3.33	34.37	412.29	12.13	386.58	11.27	116.53	3.70	126.37

California wonder(S)	36.33	51.00	39.20	2.60	15.00	5.80	4.78	4.12	3.39	32.57	99.15	3.07	88.74	2.73	98.40	3.76	106.71
SE(m)+	1.09	1.59	2.10	0.15	1.21	0.20	0.17	0.18	0.14	1.91	23.36	0.43	26.73	0.49	3.03	0.19	2.80
SE(d)+	1.54	2.24	2.98	0.21	1.71	0.28	0.24	0.25	0.20	2.70	33.04	0.60	37.81	0.70	4.28	0.27	3.96
C.V.	4.85	5.14	7.73	7.23	5.04	6.25	6.05	7.07	7.42	9.39	9.50	6.17	11.33	7.35	5.39	8.36	4.95
C.D.	3.07	4.46	5.92	0.41	3.41	0.56	0.48	0.50	0.40	5.37	65.74	1.20	75.23	1.39	8.52	0.54	7.88

DF-days to 50 per cent flowering, DFP-days to first picking, PH-Plant height, PBP-primary branches per plant, HD-harvest duration, FL-fruit length, FW-fruit width, PT-pericarp thickness, LPF-lobes per fruit, AFW-average fruit weight, FYP-fruit yield per plant, FPP-fruits per plant, MFYP-marketable fruit yield per plant, MFP-marketable fruits per plant, CC-capsanthin content, TSS-Total Soluble Solids, AA-Ascorbic acid, PS-plant survival

Table 5: Estimates of genetic parameters for quantitative and quality traits in bell pepper genotypes

S. No.	Traits	Grand mean + S.E.(m)	Range	PCV (%)	GCV (%)	h^2 (%)	GA	GA as % of mean
I.	**Quantitative traits Phenological and structural traits**							
a)								
	Days to 50 per cent flowering	38.96 + 1.09	32.67-44.33	8.38	6.83	66.53	4.47	11.48
	Days to first picking	53.37 + 1.59	48.00-64.67	8.73	7.06	65.30	6.27	11.75
	Plant height (cm)	47.15 + 2.10	35.40-61.17	13.89	11.55	69.07	9.32	19.77
	Primary branches per plant	3.47 + 0.15	2.60-4.77	14.65	12.74	75.63	0.79	22.83
	Harvest duration (days)	41.59 + 1.21	15.00-49.67	15.25	14.39	89.07	11.63	27.98
b)	**Fruit yield traits**							
	Fruit length (cm)	5.55 + 0.20	3.92-7.78	16.36	15.12	85.42	1.60	28.80
	Fruit width (cm)	4.83 + 0.17	4.12-5.46	8.15	5.47	44.91	0.37	7.55
	Pericarp thickness (mm)	4.36 + 0.18	2.83-6.49	15.44	13.73	79.04	1.10	25.14
	Lobes per fruit	3.28 + 0.14	2.17-4.22	13.58	11.38	70.15	0.64	19.63
	Average fruit weight (g)	35.21 + 1.91	27.23-45.52	13.13	9.04	47.36	4.34	12.81
	Fruit yield per plant (g)	425.97 + 23.36	99.15-665.12	22.90	20.92	83.41	166.37	39.35
	Fruits per plant	11.98 + 0.43	3.07-17.07	21.08	20.16	91.43	4.76	39.70
	Marketable fruit yield per plant (g)	408.74 + 26.73	88.74-644.29	24.16	21.33	77.89	158.59	38.77
	Marketable fruits per plant	11.63 + 0.49	2.73-16.8	21.63	20.34	88.44	4.58	39.41
II.	**Quality traits**							
	Capsanthin content (ASTA units)	97.36 + 3.03	70.58-150.88	23.77	23.16	94.87	45.23	46.46
	Total soluble solids (ºBrix)	3.99 + 0.19	2.63-6.07	18.96	17.02	80.56	1.25	31.46
	Ascorbic acid content (mg/100g)	98.02 + 2.80	55.36-146.59	21.57	21.00	94.74	41.27	42.10

PCV - Phenotypic coefficient of variation; GCV - Genotypic coefficient of variation; h^2 - Heritability (Broad sense); GA - Genetic advance

Table 6: Mean performance of top seven high yielding genotypes for quantitative and quality traits in bell pepper

S. No.	Trait	Mean performance of Top Ranking Progenies										
		California Wonder (S)	**Kandaghat Selection (MR)**	**EC-464107 (R)**	**EC-464115 (R)**	**DPCB WR-14-39**	**DPCB WR-14-36**	**DPCB WR-14-31**	**DPCB WR-14-35**	**DPCB WR-14-11**	**DPCB WR-14-7**	**DPCB WR-14-29**
1.	Days to 50 per cent flowering	36.33	40.00	37.67	39.00	35.33	44.33	40.00	44.33	37.00	39.00	32.67
2.	Days to first picking	51.00	51.00	51.00	51.00	48.00	57.00	53.67	64.33	54.00	54.00	48.00
3.	Plant height (cm)	39.20	45.87	49.27	49.10	52.67	51.80	51.67	53.07	61.17	42.33	51.53
4.	Primary branches per plant	2.60	3.47	3.77	3.67	3.47	4.77	3.67	4.47	3.95	3.73	3.27
5.	Harvest duration (days)	15.00	39.67	45.33	44.00	49.67	36.67	44.33	36.67	43.67	41.00	49.67
6.	Fruit length (cm)	5.80	5.16	7.20	7.53	4.72	7.07	7.78	6.03	5.61	5.10	5.73
7.	Fruit width (cm)	4.78	4.99	4.94	5.37	4.74	5.46	5.08	4.91	4.89	4.72	4.87
8.	Pericarp thickness (mm)	4.12	4.31	3.96	4.15	5.17	4.22	3.98	4.05	3.71	6.49	4.31
9.	Lobes per fruit	3.39	3.33	3.44	3.33	3.00	3.56	2.17	3.00	3.22	3.17	3.11
10.	Average fruit weight (g)	32.57	34.38	31.84	33.17	38.56	45.52	40.03	34.07	33.00	38.28	32.37
11.	Fruit yield per plant (g)	99.15	412.29	399.66	366.13	665.12	624.95	615.27	542.23	522.34	524.47	515.34
12.	Fruits per plant	3.07	12.13	11.93	10.80	17.07	13.73	15.33	15.67	15.67	13.40	15.93
13.	Marketable fruit yield per plant (g)	88.74	386.58	368.90	352.01	644.29	610.17	601.96	517.88	510.34	510.14	499.47
14.	Marketable fruits per plant	2.73	11.27	11.67	10.67	16.80	13.40	15.00	15.20	15.47	13.33	15.33
15.	Capsanthin content (ASTA units)	98.40	116.53	77.08	70.58	83.65	71.18	92.83	126.72	150.88	110.21	131.20
16.	TSS (ºBrix)	3.76	3.70	4.70	3.33	3.20	2.90	3.63	4.20	3.96	5.00	3.93
17.	Ascorbic acid (mg/100g)	106.71	126.37	104.39	115.50	101.75	104.55	128.31	55.36	109.60	102.25	57.58

Conclusion

There was adequate genetic variability within the germplasm evaluated for the improvement of marketable fruit yield and quantitative and qualitative traits. The genetic variation observed suggests that a positive response to direct selection is possible for fruit yield per plant, fruits per plant, marketable fruit yield per plant, marketable fruits per plant, capsanthin content and ascorbic acid as these traits showed high PCV, GCV, heritability and genetic advance.

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