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Variability, Association and Path Coefficient Analysis of Green Pod Yield and Yield Components of Hot pepper (*Capsicum annuum L.)* Landraces at Mereb Lehke, Northern Ethiopia

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Understanding the genetic variability and diversity of crops is the basis for breeding and improving of crops. Sixty four Ethiopian hot pepper genotypes were evaluated in 8×8 simple lattice design for genetic variability in green fruit yield and yield related traits at Axum Agricultural Research Center during 2018/2019 under irrigation. Data were collected on green pod yield and yield related characters. The analysis of variance showed significant amount of variations among genotypes in their mean performances of studied traits. High heritability and genetic advance were observed for average fruit weight (145.03, 97.11), fruit length (97.43,98.62), number of fruits per plant (78.54,95.78), number of branches per plant (77.65, 98.64), green pod yield per plant (74.26,99.80) and fruit pericarp thickness (63.61,97.76), respectively. This indicates that these traits are predominantly governed by additive gene action. From correlation study fruit yield per plant exhibited highly significant positive association with average fruit weight (0.72, 0.71), fruit length (0.69, 0.68) and fruit diameter (0.61, 0.60)) at both genotypic and phenotypic levels, respectively. Fruit length had the highest direct effect (0.46) on fruit yield per plant, followed by average fruit weight (0.36). In general, result of this study indicated that average fruit weight, fruit length, fruit diameter and fruit pericarp thickness showed high heritability, genetic advance, positive correlation and high positive direct effects. Hence, these traits can be used as indirect selection criteria for hot pepper yield improvement program.

Key words: GCV, genetic advance, heritability, PCV, pod yield, variability.

INTRODUCTION

The genus Capsicum belongs to the family Solanaceace and it includes 30 species, including five domesticated and commercially cultivated species (*Capsicum annuum* L., *Capsicum baccatum* L., *Capsicum chinensis* Jacq., *Capsicum frutescence* L. and *Capsicum pubescence*)

(Dagnoko et al., 2013). Among them, *C. annuum* L. is the most widely cultivated species worldwide (Pickersgill, 1997). It is the world's most important vegetable after tomato and used as fresh, dried or processed products, as vegetables and spices or condiments (Berhanu et al.,

2011a). Nutritionally, hot pepper like any other *Capsicum* species is rich in vitamin A and C, calcium, phosphorus and potassium. It has been reported that peppers are highly appreciated for their spicy flavor and nutritional value (Amare, 2013). Currently, it is produced in many parts of the country, because food is tasteless without hot pepper for most Ethiopians. In addition, Capsicum species have been used as medicines and lachrymatory agents (Shimeles, 2018). In Ethiopia, it is a high value crop due to its high pungency which serves as food consumption and source of cash earning for smallholder farmers in both green and dry form (Amare, 2013).

According to CSA (2017), the national average yields of hot pepper are 6.3 t ha^{-1} for green pod and 1.8 t ha^{-1} for the dry pod, which is far below the dry pod yield (2.5-3.7 t ha^{-1}) of improved varieties harvested at research fields of Ethiopia (MoANR, 2016) and world average yield of 3 - 4 t ha^{-1} (FAO, 2015). At farmers level the green pod yield is less than 5-6 t ha^{-1}. The gap between research plot yield and farmer's field yield could be associated with many biotic and abiotic factors such as lack of high yielding varieties, non-availability of quality seeds, imbalanced fertilizer use, lack of irrigation facilities, lack of proper disease and insect pest management and other agronomic practices, low storability, and lack of proper marketing facilities (Shimeles, 2018).This calls for urgent breeding work in order to develop varieties with better yield potential. For efficient and effective breeding work investigation and better understanding of the variability of existing genotypes is essential.

The first step in the development of varieties is assessing the genetic variability of available genotypes for the characters of interest (Rosmaina et al., 2016).Naturally, the genetic variation or diversity for most of the yield attributes is considerably high in pepper. There is a need for improvement in complex quantitative trait such as yield. The wide range of distribution of peppers has created an opportunity for local germplasm leading to varieties and landraces to exist. Landraces are important genetic resources because they have unique gene pools and serve as important reservoirs of genetic diversity for breeding and conserving biodiversity (Shimeles, 2018). The use of morphological characterization for studying genetic diversity of local pepper germplasm, including landraces, accessions and cultivated varieties, has long been used for identifying the potential for breeding to meet desirable traits. High genetic advancement coupled with high heritability estimates offers the most suitable condition for selection (Johnson et al., 1955).The presence of variability, heritability and genetic advance in different yield related characters of hot pepper has been reported by Berhanu et al. (2011a), Birhanu (2017) and Shimeles (2018). However, no variability studies have been conducted on hot pepper in the study area.

Fruit yield is a complex trait and highly influenced by many genetic factors and environmental fluctuations whereas yield component traits are less complex in inheritance and influenced by the environment to a lesser extent. In plant breeding programme, direct selection for fruit yield as such could be misleading (Abrham et al., 2017). A successful selection depends upon the information on the genetic variability and association of morpho-agronomic traits with fruit yield. Correlation studies along with path coefficient analysis can provide a better understanding of the association of different traits with fruit yield. Path coefficient analysis separates the direct effects from the indirect effects through other related traits by partitioning the correlation coefficient (Berhanu et al., 2011b). Hence, the present study was undertaken with the objectives to estimate phenotypic and genotypic variations, heritability and expected genetic advance of agronomically important traits in the hot pepper genotypes and to assess the extent of associations among yield and yield related traits and to identify traits for indirect selection criteria for hot pepper breeding program in the study area.

MATERIALS AND METHODS

Experimental site

The field experiment was conducted at Rama in Mereb Leke District of Central Administrative Zone of Tigray region, northern Ethiopia, during the 2018/2019 cropping season under irrigation. Rama is located at 14° 22'25" N latitude and 038°47'32" E longitude at an elevation of 1390 meters above sea level. It lies in the dry agro-ecological zone and its soil is sandy clay loam. The mean annual rainfall in the area ranges from 400 to 600 mm and the rainfall distribution is mono-modal with an erratic distribution beginning late in June and ending in the last week of August. The mean maximum and minimum temperatures of Rama during the 2018/2019 growing season were 33.9 and 18.7°C, respectively.

Experimental materials and design

Sixty-three local hot pepper Ethiopian landraces along with one released variety Mareko fana as a check were used in this study. The landraces were collected from farmer's fields in major hot pepper growing regional states of Ethiopia, namely Amhara, B/Gumuz, Oromiya, SNNPRS and Tigray varying in altitude, rainfall, temperature, and soil form and from Shire-Maitsebri Agricultural Research Center and Ethiopian Biodiversity Institute (EBI). The accession numbers and sources of the genotypes are shown in Tables 1 and 2.

The experiment was laid out in 8×8 simple lattice design with two replications. The seeds of 64 genotypes were sown in plastic plug trays containing mixture of soil, filter cake, compost and sand in the ratio of 2:2:1:1by volume, respectively inside the naturally ventilated polyhouse. The seedlings were transplanted into the main field 38 days after sowing when the seedlings attained 15 cm height. The plot size of each genotype was 8.4 m^2 (3 m x 2.8 m) planted with inter and intra-row spacing of 0.7 m and 0.3 m. Fertilizer, Di-ammonium phosphate (DAP) as a source of Phosphorus was applied at the rate of 200 kg ha^{-1} during planting and nitrogen fertilizer was applied in the form of Urea at the rate of 150 kg ha^{-1} in split half during transplanting and the rest as side dressing at 45 days after transplanting. Furrow irrigation method scheduled at 7 days interval (AxARC, 2016) was used. Weeding, hoeing and other

Table 1. List of qualitative characters considered with their codes and descriptions as per IPGRI (1995) *Capsicum annum* descriptor.

S/N	Character	Description and code
1	Plant growth habit	Prostrate (3), Compact (5) and Erect (7)
2	Leaf color	Yellow (1), Light green (2), Green (3), Dark green (4), light purple (5), Purple (6), Variegated(7)
3	Branching habit	Sparse (3), compact (5), Dense (7)
4	Tillering	Sparse (3), Intermediate (5), Dense (7)
5	Leaf density	Sparse (3), Intermediate (5), Dense (7)
6	Fruit set	Low(3) Intermediate(5) High(7)
7	Fruit colour at mature stage	Orange (6), Light red (7), Red (8), Dark red (9), Purple (10), Brown(11), Black (12)
8	Fruit Shape	Elongate (1), Almost round (2), Triangular (3),Campanulate (4), Blocky (5)
9	Fruit shape at pedicel attachment	Acute (1), Obtuse (3), Truncate (5), Cordate (7), Lobate (9)
10	Fruit shape at blossom end	Pointed(1) Blunt(2) Sunken(3) Sunken and pointed(4)

field management and crop protection activities were done as required.

Data recording

Data were collected on days to germination, flowering and fruiting and total fruit yield t ha^{-1} on plot basis. Five randomly selected plants from the central rows of each plot were used for data collection on plant height, canopy width, stem diameter(mm), number of flowers, leaves, branches and pods per plant, pod weight(g) and green pod yield(g) per plant. The pod length (cm) and width (cm) and pericarp thickness (mm) were measured from 10 pods harvested from each plot following the method adapted from IPGRI (1995).

Data analysis

Data for quantitative characters were subjected to analysis of variances (ANOVA) for simple lattice design using proc lattice procedure of SAS version 9.2(SAS Institute Inc., 2010) to test the presence of significant differences among genotypes; mean separations were estimated using Tukey Test at 5% probability level.

Genotypic and phenotypic variance and coefficient of variation

The variability present in the population was estimated by simple measure, namely range, mean, phenotypic and genotypic variance and coefficient of variation. The phenotypic and genotypic variance and coefficient of variation was estimated according to the method suggested by Burton and DeVane (1953) as follows: Genotypic Variance $(\sigma^2 g) = \frac{MSg - MSe}{r}$,Phenotypic variance $(\sigma^2 p) = [\sigma^2 g + (\sigma^2 e/r)]$, Phenotypic coefficient of variation (PCV) $= \frac{\sqrt{\sigma 2p}}{\bar{x}} * 100$,

Genotypic coefficient of variation (GCV) $= \frac{\sqrt{\sigma 2g}}{\bar{x}} * 100$, where, r = number of replication; MSg = mean square of genotypes and Mse = mean square of error, $\sigma^2 p$ = phenotypic variance, $\sigma^2 g$ = genotypic variance and $\bar{x}$ = grand mean of the character under consideration. Both phenotypic and genotypic coefficients of variations were categorized depending up on cut points suggested by Deshmukh et al. (1986) as low (<10%), moderate (10-20%) and high (>20%).

Estimate of broad sense heritability

(H^2) of all traits were calculated according to the formula as described by Allard (1960) as follows: $h^2_{bs}= [(\sigma^2 G) / (\sigma^2 P)] \times 100$. According to Singh (2001) that heritability values ≥80% were very high, values from 60-79% were moderately high, values from 40-59% were medium and values less than 40% were low.

Genetic Advance (GA) for selection intensity (K) at 5% was computed according to Allard (1960) as given:

$$GA = K*\sigma p*H^2$$

Where, K = the standardized selection differential at 5% selection intensity (K = 2.063), σp = is phenotypic standard deviation on mean basis and H^2 = heritability in the broad sense.

The genetic advance as percentage of population means (GAM) was also estimated with the methods described by Johnson et al. (1955). Genetic advance as % of mean (GAM) was computed as:GAM $= \frac{GA}{\bar{x}} * 100$

Where, $\bar{x}$ = mean of the population. According to Johson et al. (1955) genetic advance as percent of mean was classified as low (<10%), moderate (10-20%) and high (>20%).

Character association

Character associations at genotypic and phenotypic levels were calculated from the genotypic, phenotypic and environmental covariance according to Singh and Chaundhary (1985). In Path analysis, yield per plant was taken as dependent variable while the rest of the characters was considered as independent variables. The direct and indirect effects of the independent characters on fruit yield per plant were estimated by the simultaneous solution of the formula suggested by Dewey and Lu (1959).

Frequency distribution and Shannon-Weaver Diversity Index (H')

Frequency distribution is a systematic way of ordering a set of data

Table 2. Pepper accessions used in the study.

S/N	Accession Name	Origin	Region	Taxonomy	No.	Accession name	Origin	Region	Taxonomy
1	Acc-1	Tselemti	Tigray	*Capsicum annuum L.*	33	Acc-33	Semien Gonder	Amhara	*Capsicum annuum L.*
2	Acc-2	Tanqua Abergelle	Tigray	*Capsicum annuum L.*	34	Acc-34	Ahferom	Tigray	*Capsicum annuum L.*
3	Acc-3	Welkait(Mygiba)	Tigray	*Capsicum annuum L.*	35	Acc-35	Bale	Oromiya	*Capsicum annuum L.*
4	Acc-4	Mekelle	Tigray	*Capsicum annuum L.*	36	Acc-36	Mirab Shewa	Amhara	*Capsicum annuum L.*
5	Acc-5	Ofla(Zata)	Tigray	*Capsicum annuum L.*	37	Acc-37	Semien Gonder	Amhara	*Capsicum annuum L.*
6	Acc-6	Ahferom	Tigray	*Capsicum annuum L.*	38	Acc-38	Mirab Gojam	Amhara	*Capsicum annuum L.*
7	Acc-7	Welkait	Tigray	*Capsicum annuum L.*	39	Acc-39	Mirab Gojam	Amhara	*Capsicum annuum L.*
8	Acc-8	Kilte Awulalo	Tigray	*Capsicum annuum L.*	40	Acc-40	Mirab Gojam	Amhara	*Capsicum annuum L.*
9	Acc-9	Kola Temben	Tigray	*Capsicum annuum L.*	41	Acc-41	Semien Shewa	Amhara	*Capsicum annuum L.*
10	Acc-10	Abergelle	Tigray	*Capsicum annuum L.*	42	Acc-42	Bale	Amhara	*Capsicum annuum L.*
11	Acc-11	Alamata	Tigray	*Capsicum annuum L.*	43	Acc-43	Metekel	B/Gumz	*Capsicum annuum L.*
12	Acc-12	Wojirat	Tigray	*Capsicum annuum L.*	44	Acc-44	Mirab Gojam	Amhara	*Capsicum annuum L.*
13	Acc-13	Welkait	Tigray	*Capsicum annuum L.*	45	Acc-45	Mirab Gojam	Amhara	*Capsicum annuum L.*
14	Acc-14	Embalaje	Tigray	*Capsicum annuum L.*	46	Acc-46	Misrak Gojam	Amhara	*Capsicum annuum L.*
15	Acc-15	Welkait Tsegede	Tigray	*Capsicum annuum L.*	47	Acc-47	Mirab Gojam	Oromiya	*Capsicum annuum L.*
16	Acc-16	Mereb Lehke	Tigray	*Capsicum annuum L.*	48	Acc-48	Guragae	SNNPRS	*Capsicum annuum L.*
17	Acc-17	Illubabor	Oromiya	*Capsicum annuum L.*	49	Acc-49	Guragae	SNNPRS	*Capsicum annuum L.*
18	Acc-18	Misrak Harerge	Oromiya	*Capsicum annuum L.*	50	Acc-50	Mirab Gojam	Amhara	*Capsicum annuum L.*
19	Acc-19	Illubabor	Oromiya	*Capsicum annuum L.*	51	Acc-51	Guragie	SNNPRS	*Capsicum annuum L.*
20	Acc-20	Semien Gonder	Amhara	*Capsicum annuum L.*	52	Acc-52	Mirab Gojam	Amhara	*Capsicum annuum L.*
21	Acc-21	Kembata Alaba	SNNPRS	*Capsicum annuum L.*	53	Acc-53	Mirab Gojam	Amhara	*Capsicum annuum L.*
22	Acc-22	Semien Gonder	Amhara	*Capsicum annuum L.*	54	Acc-54	Mirab Gojam	Amhara	*Capsicum annuum L.*
23	Acc-23	Semien Gonder	Amhara	*Capsicum annuum L.*	55	Acc-55	Mirab Gojam	Amhara	*Capsicum annuum L.*
24	Acc-24	Illubabor	Oromiya	*Capsicum annuum L.*	56	Acc-56	Mirab Gojam	Amhara	*Capsicum annuum L.*
25	Acc-25	Semen Omo	SNNPRS	*Capsicum annuum L.*	57	Acc-57	Butajira	SNNPRS	*Capsicum annuum L.*
26	Acc-26	Misrak Gojam	Amhara	*Capsicum annuum L.*	58	Acc-58	Mereb Lehke	Tigray	*Capsicum annuum L.*
27	Acc-27	Mirab Gojam	Amhara	*Capsicum annuum L.*	59	Acc-59	Abi Adi	Tigray	*Capsicum annuum L.*
28	Acc-28	Semien Gonder	Oromiya	*Capsicum annuum L.*	60	Acc-60	Mirab Gojam	Amhara	*Capsicum annuum L.*
29	Acc-29	Mirab Shewa	Oromiya	*Capsicum annuum L.*	61	Acc-61	Mereb Lehke	Tigray	*Capsicum annuum L.*
30	Acc-30	Illubabor	Oromiya	*Capsicum annuum L.*	62	Acc-62	Mereb Lehke	Tigray	*Capsicum annuum L.*
31	Acc-31	Mirab Shewa	Oromiya	*Capsicum annuum L.*	63	Acc-63	Melkassa	Oromiya	*Capsicum annuum L.*
32	Acc-32	Semien Gonder	Oromiya	*Capsicum annuum L.*	64	Acc-64	Melkassa	Oromiya	*Capsicum annuum L.*

Acc = accession; B/Gumz = Benishangul-Gumz Regional State; SNNPRS = Southern Nation; Nationalities and People's Regional State ; Acc-64; obtained from Melkassa Agricultural Research Center; Acc-64 is a standard check

Table 3. Analysis of Variance (ANOVA) for morphological and green pod yield and pod characters of 64 hot pepper genotypes.

Source	DF	DG	DIF	DFL	DFR	NFLPP	NLPP	NBPP	PHT	CW
Replication	1	0.07	84.5	40.50	2.53	17.04	0.10	1.58	551.12	19.92
Block(Rpn)	14	0.06	15.83	5.48	9.88	45.58	0.83	0.14	16.81	0.56
Genotypes(adji)	63	6.87**	50.46**	34.47**	48.39**	525.88**	2671.2**	16.17**	64.09**	52.10**
Intra block error	49	0.47	11.61	4.95	5.31	70.60	0.72	0.22	21.01	0.79
Source	**DF**	**SD**	**FL**	**FD**	**FPT**	**NFRPP**	**FW**	**GPYPP**	**TY**	
Replication	1	0.74	0.00	0.25	0.04	52.28	5.79	139.03	18699.00	
Block(Rpn)	14	1.39	0.47	0.99	0.02	11.99	1.33	22.55	341.35	
Genotypes(adji)	63	4.15**	25.47**	52.43**	0.46**	611.63**	77.97**	12541.8**	1252.7**	
Intra block error	49	1.04	0.35	1.34	0.01	25.80	2.25	25.30	285.04	

*and** = significant at 5% and 1% probability level, respectively. DF=degree of freedom, DG=days to germination, DIF= days first flowering, DFL= days to flowering, DFR= days to fruiting, NFLPP= number of flowers per plant, NLPP= number of leaves per plant, NBPP=number of branches per plant, PHT=plant height, CW=canopy width, SD=stem diameter, FL=fruit length, FD= fruit diameter, FPT= fruit pericarp thickness, NFRPP=number of fruit per plant, FW= fruit weight, GPYPP=green pod yield per plant, TY= total green pod yield per hectare.

from the lowest to the highest value showing the number of occurrences (frequency) at each value or range of values. The frequency distributions were used to calculate the Shannon-Weaver diversity index (H') for each character (Hennink and Zewan, 1991). The index is defined as:

$$H' = - \sum_{i=1}^{s} (p_i ln P_i)$$

Where H'= diversity index
S= Total number of descriptors in the ith descriptor, Pi=fraction of individuals belonging to the ith descriptor state (number of observations/descriptor state in i^{th} descriptor divided by the total number of characterized plants)

The Shannon weaver index values (H') can range from 0 to ~ 4.6. A value near 0 indicated that every species in the sample is the same and a value near 4.6 indicated the numbers of individuals are evenly distributed between the hot pepper species A low H' indicates unbalance frequency class and lack of diversity for the traits. A higher H' value indicates presence of variability or diversity of genotypes for the trait (Hennink and Zewan, 1991).

RESULTS AND DISCUSSION

Analysis of variance

The analysis of variance for all morphological, yield and fruit characters indicated significant (P < 0.01) differences among the genotypes (Table 3). This indicates the existence of substantial amount of variability among the genotypes tested which confirms the possibility to select best genotypes and exploit them for variety development. The significant differences observed for measured quantitative traits in this study were in agreement with the findings of earlier authors (Berhanu et al., 2011b; Birhanu, 2017; Shimeles, 2018) who reported considerable genetic variability within the hot pepper population for yield, fruit and growth characters.

Range and mean performance of accessions

The studied landraces exhibited a wide range of mean

values for all traits, particularly for the economically most important traits, that is fruit yield per hectare which ranged from 3.8 to 14.3 tha^{-1}, whereas the mean was 9.3 tha^{-1} (Table 4).The mean, ranges in original units and as percent of the mean for the 17 quantitative traits of the 64 accessions are presented in Table 4. Since the various traits considered here were measured in different units, only variability in percent of the mean was used. The highest range of 296% was observed in fruit weight. Very high ranges were also observed for number of fruits per plant (194.55%), fruit length (172.98%), green pod yield per plant (171.53%), number of branches per plant (159.63%), fruit diameter (152.65%), fruit pericarp thickness (136.81%),number of flowers per plant (119.25%) and total green pod yield per hectare (114.66%). Ranges between 50 and 90% were observed for number of leaves per plant (79%), stem diameter (71%), days to germination (60%), canopy width (58%) and days to first flowering (57%). The remaining traits had low ranges which were between 45.68% for days to fruiting, 45.75% for days to flowering and 48.39% for plant height. This high range and mean value for each trait of interest suggests that great opportunity to improve the various desirable traits through selection as short term strategy and through hybridization as long term strategy. Hence, there is an opportunity to find genotypes having disease resistance and high yielding potential among the tested entries that perform better than the existing varieties to utilize for the future pepper improvement breeding.

Variance components

Estimates of phenotypic ($\sigma^2 p$), genotypic ($\sigma^2 g$) and environmental ($\sigma^2 e$) variances and phenotypic coefficients of variation (PCV) and genotypic coefficients of variation (GCV) along with the mean and the range of various characters investigated in the present study are depicted

Table 4. Mean, range and range in % mean of 17 quantitative traits.

Trait	Mean	Min	Max	Range	Range in % mean
DG(Days)	13.30	10.5	18.5	8	60.13
DIF(Days)	57.61	47	80	33	57.28
DFL(Days)	62.30	54.5	83	28.5	45.75
DFR(Days)	76.44	67.18	102.1	34.92	45.68
NFLPP	76.35	40.95	132	91.05	119.25
NLPP	243.69	160.4	353	192.6	79.03
NBPP	7.45	2.2	14.1	11.9	159.63
PHT(cm)	63.44	47.1	77.8	30.7	48.39
CW(cm)	34.12	25.4	45.1	19.7	57.74
SD(mm)	12.75	9.8	18.86	9.06	71.03
FL(cm)	7.45	1.81	14.7	12.89	172.98
FD(mm)	16.76	7.11	32.7	25.59	152.65
FPT(mm)	1.53	0.64	2.73	2.09	136.81
NFRPP	44.00	16.3	101.9	85.6	194.55
FW(g)	8.62	0.94	26.5	25.56	296.35
GPYPP(g)	219.56	87.4	464	376.6	171.53
TY(tha^{-1})	9.3	3.8	14.3	10.6	11.5

DG=days to germination; DIF= days to first flowering; DFL= days to flowering; DFR= days to fruiting; NFLPP= number of flowers per plant; NLPP= number of leaves per plant; NBPP=number of branches per plant; PHT=plant height; CW=canopy width; SD=stem diameter; FL=fruit length; FD= fruit diameter; FPT= fruit pericarp thickness; NFRPP=number of fruit per plant; FW= fruit weight; GPYPP=green pod yield per plant; TY= total green pod yield per hectare.

in Table 5. For all studied characters, the magnitude of environmental variance was lower than the corresponding genotypic variance. This indicates that the genotypic component of variation was the major contributor to the total variation in the studied characters. According to the categories of Johnson et al. (1955), both GCV and PCV were high for fruit weight (71.34, 72.39), fruit length (47.55, 47.89), number of fruits per plant (38.90, 39.75), number of branches per plant (37.88, 38.14), green pod yield plant (36.03, 36.07), fruit pericarp thickness (31.19, 31.54), fruit diameter (30.15, 30.54) and total green fruit yield per hectare (30.51, 32.04), respectively. The high values of PCV and GCV indicated the existence of substantial variability, ensuring better scope for their improvement through selection of these traits (Rosmaina et al., 2016). The moderate values of GCV and PCV were recorded for number of flowers per plant (19.76,21.24), number of leaves per plant (14.99,15), canopy width (14.85,14.96) and days to germination (13.44, 13.93); while low for stem diameter, plant height, days to first flowering, days to flowering, days to fruiting, respectively. This indicates low sensitivity of most of the traits to the effects of environmental factors, and expressions of these traits are dependent more on genetic factors rather than on environmental conditions. Higher magnitude of phenotypic coefficients of variation (PCV) than genetic coefficient of variation (GCV) indicated the role of environment for expression of the traits. Similar finding was reported by Berhanu et al. (2011a) indicating that days to flowering and days to maturity had low GCV and

PCV values, while fruit weight, number fruits per plant, number of primary branches per plant had high GCV and PCV. Razzaq et al. (2016) reported high values of GCV and PCV for weight of red fruit (110.02% and 112.02%) and number of fruits per plant (85.02% and 86.05%). Shimeles et al. (2016) also reported high estimates of GCV and PCV for fruit weight, number of branches per plant and number of fruits per plant. In addition, similar findings were reported by Sharma et al. (2010) and Rosmaina et al. (2016).

Heritability and genetic advance

The effectiveness of selection for any trait depends not only on the extent of genetic variability but also on the extent of transferring genes from one generation to the other (Rosmaina et al., 2016). According to Singh (2001) heritability values greater than 80% are considered as very high, 60-79% as moderately high, from 40-59% as medium and values less than 40% as low. Accordingly, the estimates of heritability of all traits in the current study were moderate to very high. In this study heritability (H^2) varied from 99.97 to 62.21% and the highest estimate of heritability was observed for number of leaves per plant (99.97%) followed by green fruit yield per plant (99.80%), fruit length (98.62%), fruit pericarp thickness (97.76%) and fruit diameter (97.44%) (Table 5). Whereas the estimates heritability was moderately high for green fruit yield per hectare (77.25%), days to first flowering

Table 5. Estimates of Range, Mean, Genotypic, Environmental and Phenotypic variances and Coefficient of variations, Heritability in broad sense, Genetic advance and Genetic advance as percentage of mean for 17 characters of 64 hot Pepper genotypes.

Characters	Ranges	Mean ± SEM	σ^2g	σ^2e	σ^2p	GCV (%)	PCV (%)	H^2 (%)	GA	GAM (%)
DG	10-18.5	13.3±0.49	3.20	0.24	3.43	13.44	13.93	93.15	3.56	26.77
DIF	47-80	57.61±2.41	19.43	5.80	25.23	7.65	8.72	76.99	7.98	13.85
DFL	54.5-83	62.30±1.57	14.76	2.48	17.23	6.17	6.66	85.63	7.33	11.77
DFR	67.18-102.1	76.44±1.63	21.54	2.65	24.20	6.07	6.44	89.03	9.03	11.82
NFLPP	40.95-132	76.35±5.94	227.64	35.30	262.94	19.76	21.24	86.58	28.96	37.93
NLPP	160.4-353	243.69±0.60	1335.26	0.36	1335.62	14.99	15.00	99.97	75.37	30.93
NBPP	2.2-14.1	7.45±0.33	7.97	0.11	8.08	37.88	38.14	98.64	5.79	77.61
PHT	47.1-77.8	63.44±3.24	21.54	10.51	32.05	7.32	8.92	67.21	7.85	12.37
CW	25.4-45.1	34.12±0.63	25.66	0.39	26.05	14.85	14.96	98.49	10.37	30.40
SD	9.8-18.86	12.75±0.72	1.55	0.52	2.07	9.78	11.29	74.99	2.23	17.46
FL	1.81-14.7	7.45±0.42	12.56	0.18	12.73	47.55	47.89	98.62	7.26	97.43
FD	7.11-32.7	16.76±0.82	25.54	0.67	26.21	30.15	30.54	97.44	10.29	61.40
FPT	0.64-2.73	1.53±0.07	0.23	0.01	0.23	31.19	31.54	97.76	0.97	63.61
NFRPP	16.3-101.9	44±3.59	292.91	12.90	305.81	38.90	39.75	95.78	34.55	78.54
FW	0.94-26.5	8.62±1.06	37.86	1.13	38.98	71.34	72.39	97.11	12.51	145.03
GPYPP	87.4-464	219.56±3.56	6258.23	12.65	6270.88	36.03	36.07	99.80	163.04	74.26
TY	37.5-143.3	92.26±11.94	483.83	142.52	626.35	23.84	27.13	77.25	39.88	43.23

DG=days to germination; DIF= days to first flowering; DFL= days to flowering; DFR= days to fruiting; NFLPP= number of flowers per plant; NLPP= number of leaves per plant; NBPP=number of branches per plant; PHT=plant height; CW=canopy width; SD=stem diameter; FL=fruit length; FD= fruit diameter; FPT= fruit pericarp thickness; NFRPP=number of fruit per plant; FW= fruit weight; GPYPP=green pod yield per plant; TY= total green pod yield per hectare; SEM = standard error of the mean; σ^2g = genotypic variance; σ^2e = error variance; σ^2p = phenotypic variance; PCV = phenotypic coefficient of variance; GCV = genotypic coefficient of variance; H^2 = broad sense heritability; GA = genetic advance; GAM = genetic advance as percent of mean.

(76.99%), stem diameter (74.99)and plant height (67.21%). The characters having very high heritability indicated relatively small contribution of the environmental factors to the phenotype and selection for such characters could be fairly easy due to high additive effect.

Heritability alone provides no indication of the amount of genetic improvement that would result from selection of individual genotypes. Hence knowledge about genetic advance coupled with heritability is very useful. A trait exhibiting high heritability may not necessarily give high genetic advance. According to Jonhson et al. (1955) high heritability accompanied by high genetic advance could help to arrive at more reliable conclusion. In the present investigation high to moderate heritability coupled with high to moderate genetic advance as percent of the mean were observed for all the traits. Similar findings were reported by earlier workers for some characters with moderate to high GCV, PCV, heritability and GAM estimates, for fruit yield per plant, fruit diameter, fruit length, average fruit weight and number of fruits per plant (Sharma et al., 2010; Sahu et al., 2016; Razzaq et al., 2016; Pujar et al., 2017).

Character association

Association of fruit yield with yield components was

detected (Table 6). Genotypic correlation coefficients were slightly higher than the corresponding phenotypic correlation coefficients. This indicated that there were strong inherent relations among the traits studied. Pod yield per plant had significant and positive genetic and phenotypic correlations with average fruit weight (0.72, 0.71), fruit length (0.69, 0.68), fruit diameter (0.61, 0.60) and fruit pericarp thickness (0.56, 0.55), respectively. However, non- significant positive correlation in case of stem diameter, and plant height at both genotypic and phenotypic levels were observed. Average green fruit weight had also significant positive correlation with fruit diameter (0.89, 0.87), fruit length (0.87, 0.86), and fruit pericarp thickness (0.77, 0.75) at both genetic and phenotypic levels, respectively. This suggested that, selection and improvement of genotypes based on those characters would result in a substantial increment on fruit yield of hot pepper. Similarly, Abrham et al. (2017) and Shimeles (2018) reported higher genotypic correlation coefficients than the phenotypic ones, implying the inherent associations between various characters in Ethiopian Capsicums.

The result further illustrated that plant height was non-significantly correlated with most of the traits at phenotypic level except stem diameter (0.59) and canopy width (0.29); however, at both genotypic and phenotypic levels it was positively and significantly correlated with

Table 6. Estimation of genotypic (rg) (above diagonal) and phenotypic (rp) (below diagonal) correlation coefficients for 14 traits in 64 hot pepper genotypes.

Traits	DFL	DFR	NFLPP	NLPP	NBPP	PHT	CW	SD	FL	FD	FPT	NFRPP	FW	GPYPP
DFL		0.79**	-0.19ns	-0.01ns	0.29*	0.61**	0.30*	0.71**	-0.27*	-0.28*	-0.21ns	0.33**	-0.25*	-0.14ns
DFR	0.75**		-0.02ns	0.02ns	0.46**	0.53**	0.36**	0.67**	-0.46**	-0.46**	-0.31*	0.42**	-0.48**	-0.37**
NFLPP	-0.14ns	-0.04ns		0.56**	0.41**	-0.03ns	0.23*	-0.06ns	-0.33**	-0.30*	-0.13ns	0.25*	-0.36**	-0.12ns
NLPP	0.00ns	0.02ns	0.53**		0.31*	0.02ns	0.33**	0.12ns	-0.19ns	-0.09ns	0.01ns	0.23ns	-0.12ns	0.11ns
NBPP	0.28**	0.43**	0.39**	0.31**		0.17ns	0.56**	0.41**	-0.67**	-0.63**	-0.51**	0.67**	-0.69**	-0.31*
PHT	0.47**	0.39**	-0.01ns	0.01ns	0.16ns		0.32*	0.74**	-0.11ns	-0.11ns	-0.04ns	0.17ns	-0.10ns	0.05ns
CW	0.28**	0.33**	0.22*	0.33**	0.56**	0.29**		0.49**	-0.44**	-0.54**	-0.42**	0.56**	-0.50**	-0.16ns
SD	0.60**	0.57**	-0.06ns	0.10ns	0.36**	0.59**	0.44**		-0.28*	-0.28*	-0.21ns	0.47**	-0.25*	0.01ns
FL	-0.26**	-0.44**	-0.31**	-0.19*	-0.66**	-0.09ns	-0.43**	-0.25**		0.68**	0.63**	-0.61**	0.87**	0.69**
FD	-0.27**	-0.43**	-0.28**	-0.09ns	-0.62**	-0.09ns	-0.53**	-0.25**	0.67**		0.82**	-0.71**	0.89**	0.61**
FPT	-0.19*	-0.28**	-0.13ns	0.01ns	-0.50**	-0.06ns	-0.41**	-0.20*	0.61**	0.80**		-0.58**	0.77**	0.56**
NFRPP	0.30**	0.39**	0.24**	0.23**	0.66**	0.16ns	0.55**	0.42**	-0.60**	-0.69**	-0.57**		-0.70**	-0.40**
FW	-0.25**	-0.46**	-0.34**	-0.12ns	-0.68**	-0.08ns	-0.49**	-0.22*	0.86**	0.87**	0.75**	-0.68**		0.72**
GPYPP	-0.13ns	-0.35**	-0.11ns	0.11ns	-0.31**	0.04ns	-0.16ns	0.01ns	0.68**	0.60**	0.55**	-0.39**	0.71**	

ns= non Significance *and **=significant at 5% and 1% probability levels; respectively. DFL= days to flowering; DFR= days to fruiting; NFLPP= number of flowers per plant; NLPP= number of leaves per plant; NBPP=number of branches per plant; PHT=plant height; CW=canopy width; SD=stem diameter; FL=fruit length; FD= fruit diameter; FPT= fruit pericarp thickness; NFRPP=number of fruit per plant; FW= fruit weight; GPYPP=green pod yield per plant.

days to flowering and days to fruiting.

The study confirmed significant association between branch number and canopy width was significant at both genotypic and phenotypic (0.56, 0.56) levels. Furthermore, branch number had positively significant association with number of leaves per plant, number of flowers per plant, days to fruiting and flowering at both genotypic and phenotypic, levels respectively. Fruit length depicted positive significant correlation at both genotypic and phenotypic levels with fruit width, fruit pericarp thickness and fruit weight. These results are in agreement with those reported by Sharma et al. (2010) and Abrham et al. (2017) who advocated that importance should be given to number of fruits per plant, fruit weight, number of primary branches, fruit length, fruit diameter and plant height during selection process because these characters contribute directly towards the yield.

The study revealed that days to 50% flowering had positive and highly significant association with days to 50% fruiting, Plant height, stem diameter, canopy diameter, number of branches per plant and number of fruits per plant both at genotypic and phenotypic levels (Table 6). The positive correlations between different traits show the possibility of improving hot pepper based on these multiple traits.

Days to fruiting had significant and positive correlation at both genotypic and phenotypic level with number of primary branches per plant, number of fruits per plant, canopy width, stem diameter and plant height. In contrast, days to fruiting exhibited significant negative correlation both at genotypic and phenotypic level with fruit length, fruit diameter, fruit pericarp thickness, average fruit weight and fruit yield per plant. This reveals that early flowered genotypes produced long and large pods with thick pericarp and high fruit yield per plant. Similarly, Sharma et al. (2010) reported a high positive significant correlation of days to 50% flowering and days to fruiting suggesting that early flowering traits would be an appropriate selection criterion to get early fruit yield.

The current result exhibited that green pod yield had significant positive genotypic and phenotypic correlations with fruit length, fruit diameter, fruit pericarp thickness and fruit weight. Hence, these traits were found to be yield contributing characters towards increased fruit yield and weight. This also might indicate complementary gene actions for the traits which could be selected simultaneously.

Table 7. Estimates of direct (bold and diagonal) and indirect effect (off diagonal) of different characters on green pod yield per plant at genotypic level in 64 hot Pepper genotypes.

Traits	DFL	DFR	NFLPP	NLPP	NBPP	PHT	CW	SD	FL	FD	FPT	NFRPP	FW	rg
DFL(Days)	**0.08**	-0.24	-0.01	0.00	0.08	-0.02	0.02	0.23	-0.13	-0.03	-0.01	-0.03	-0.09	-0.14ns
DFR(days)	0.07	**-0.30**	0.00	0.00	0.12	-0.02	0.03	0.21	-0.22	-0.04	-0.01	-0.03	-0.17	-0.37**
NFLPP	-0.02	0.01	**0.07**	0.05	0.11	0.00	0.02	-0.02	-0.15	-0.03	0.00	-0.02	-0.13	-0.12ns
NLPP	0.00	-0.01	0.04	**0.09**	0.08	0.00	0.02	0.04	-0.09	-0.01	0.00	-0.02	-0.04	0.11ns
NBPP	0.02	-0.14	0.03	0.03	**0.27**	-0.01	0.04	0.13	-0.31	-0.06	-0.02	-0.05	-0.25	-0.31*
PHT(cm)	0.05	-0.16	0.00	0.00	0.05	**-0.04**	0.02	0.23	-0.05	-0.01	0.00	-0.01	-0.03	0.05ns
CW(cm)	0.02	-0.11	0.02	0.03	0.15	-0.01	**0.07**	0.16	-0.20	-0.05	-0.02	-0.04	-0.18	-0.16ns
SD(mm)	0.06	-0.20	0.00	0.01	0.11	-0.03	0.03	**0.32**	-0.13	-0.03	-0.01	-0.04	-0.09	0.01ns
FL(cm)	-0.02	0.14	-0.02	-0.02	-0.18	0.00	-0.03	-0.09	**0.46**	0.07	0.02	0.05	0.31	0.69**
FD(cm)	-0.02	0.14	-0.02	-0.01	-0.17	0.00	-0.04	-0.09	0.32	**0.10**	0.03	0.05	0.32	0.61**
FPT(mm)	-0.02	0.09	-0.01	0.00	-0.14	0.00	-0.03	-0.07	0.29	0.08	**0.04**	0.04	0.27	0.56**
NFRPP	0.03	-0.13	0.02	0.02	0.18	-0.01	0.04	0.15	-0.28	-0.07	-0.02	**-0.08**	-0.25	-0.40**
FW(g)	-0.02	0.14	-0.03	-0.01	-0.19	0.00	-0.04	-0.08	0.40	0.09	0.03	0.05	**0.36**	0.72**

*and ** = significant at 5% and 1% probability levels; respectively. DFL= days to flowering; DFR= days to fruiting; NFLPP= number of flowers per plant; NLPP= number of leaves per plant; NBPP=number of branches per plant; PHT=plant height; CW=canopy width; SD=stem diameter; FL=fruit length; FD= fruit diameter; FPT= fruit pericarp thickness; NFRPP=number of fruit per plant; FW= fruit weight; GPYPP=green pod yield per plant; rg = genotypic coefficient of correlation.

Therefore, fruit length, fruit diameter andfruit weight were the most important traits for improving the genotypes for higher fruit yield and may be applied for selection in hot pepper improvement. The results agreed well with Shimeles (2018) who found high positive genotypic correlation of fruit yield with the pericarp thickness. In addition, Razzaq et al. (2016) reported a significant positive correlation between fruit width and fruit length with fruit yield per plant and plant height with fruit length which was in agreement with the current finding. They further suggested that, the presence of such effects of genes lead to the improvement of yield as the improvement made in these characters. Lavinia et al. (2013) confirmed the existence of strong correlation between fruit weight to fruit length and diameter and also weight of fruits per plant. They further concluded that selection made towards increasing the length and diameter of pods can be used as indirect selection criteria to develop varieties with highest fruit weight.

Path coefficient analysis

Significant genetic correlation coefficient between two traits does not always indicate the presence of linkage between them (Sigh, 2001). Path analysis is the partitioning of the correlations into direct and indirect effects. Fruit yield being the complex outcome of various traits was considered to be the resultant variable and the rest of the variables viz; days to flowering, days to fruiting, number of flowers per plant, number of leaves per plant, number of branches per plant, plant height, canopy width, stem diameter, fruit length, fruit diameter,

fruit pericarp thickness, number of fruits per plant, fruit weight, green pod yield per plant, were the causal variables. It was observed that each of these traits did influence fruit yield directly or indirectly. The path analysis was done at genetic level and the results are given in Table 7. Fruit length exhibited the highest positive direct effect (0.46) on fruit yield per plant; and had also indirect positive effects on average fruit weight, fruit diameter, and fruit pericarp thickness. The second maximum positive direct effect was exerted by Average fruit weight (0.36) and had positive and significant correlation with fruit yield per plant. This suggests that the correlation has revealed the true relation and direct selection through this trait could be effective. Stem diameter, number of branches per plant, fruit diameter, number of leaves per plant ,number of flowers per plant, canopy width and fruit pericarp thickness had also positive direct effect on green fruit yield per plant. Similar result was reported by Abrham et al. (2017) who found fruit length and diameter could be the most important yield component characters which might be used as selection criteria for yield improvement.

Thus, on the basis of current result, green fruit length, fruit pericarp thickness, average fruit weight, and number of primary branches per plant could be the most important yield components which might be considered as selection criteria for yield improvement. Similar results had been reported by Kumari (2017). Similarly, Shimeles (2018) reported that direct influence of pericarp thickness on fruit yield was very high and positive and its indirect influence through fruit diameter was also positive. However, pericarp thickness showed high negative indirect effect on number of fruits per plant.

Table 8. Frequency distribution, proportion and Shannon-waver diversity index (H') of qualitative traits of 64 hot pepper Landraces.

Characters	Description and codes	Frequency distribution		(H')
		No. of accessions	Percent (%)	
Plant growth habit	Prostrate(3)	13	20.31	0.95
	Intermidate(5)	20	31.25	
	Erect(7)	31	48.44	
Leaf color	Yellow (1)	5	7.8	0.92
	Light green(2)	20	31.25	
	Green (3)	15	23.44	
	Dark green(4)	24	37.51	
Branching habit	compact(3)	6	9.34	0.85
	sparse(5)	28	43.75	
	Dense(7)	30	46.88	
Tillering	Sparse(3)	28	43.75	**0.98**
	Intermediate(5)	17	26.56	
	Dense(7)	19	29.69	
Leaf density	Sparse(3)	2	3.12	0.67
	Intermediate (5)	19	29.69	
	Dense(7)	43	67.19	
Fruit set	Low(3)	13	20.31	0.92
	Intermediate(5)	17	26.56	
	High(7)	34	53.13	
Fruit colour at mature stage	Light red(7)	18	28.13	0.83
	Red(8)	19	29.69	
	Dark Red(9)	26	40.62	
	brown(11)	1	1.56	
Fruit shape	Elongate(1)	50	78.13	**0.45**
	Almost round(2)	1	1.56	
	Triangular(3)	10	15.62	
	Campanulate(4)	1	1.56	
	Blocky(5)	2	3.12	
Fruit shape at pedicel attachment	Acute(1)	9	14.06	0.89
	Truncate(3)	18	28.12	
	Cordate(4)	7	10.93	
	Lobate(5)	30	46.88	
Fruit shape at blossom end	Pointed(1)	37	57.81	0.73
	Blunt(2)	19	29.69	
	Sunken(3)	6	9.38	
	Sunken and pointed(4)	2	3.12	
Overall mean of H'				**0.82**

Days to fruiting had a high direct negative effect on fruit yield per plant (-0.3), but indirect positive effect on average fruit weight, fruit length, fruit diameter, fruit pericarp thickness and number of flowers per plant. This suggested that early fruiting traits would be an appropriate selection criterion to get early fruit yield. Number of fruits per plant had direct negative effect on fruit yield per plant (-0.08), but it showed indirect high positive effect on average fruit weight, fruit pericarp thickness, fruit diameter and fruit length. Similar finding was reported by

Berhanu et al. (2011b) who observed direct positive effects of fruit weight, canopy width, fruit pericarp thickness and number of branches per plant on fruit yield per plant. The set of characters identified as selection indices for fruit yield per plant based on the genetic variability parameters for the characters, their correlations and path coefficient analysis are: fruit length, average fruit weight, stem diameter, number of branches per plant fruit diameter, number of leaves per plant, number of flowers per plant and canopy width.

Frequency distribution and Shannon-Weaver diversity Index (H') analysis of qualitative characters

Frequency distribution patterns, percent of proportion and Shannon-Weaver diversity index were estimated for 64 hot pepper genotypes from 10 qualitative characters and results are presented in (Table 8). Generally, 48.44% of them showed an erect growth habit, 31.25 and 20.31% showed intermediate and prostrate growth habits, respectively. The proportions of genotypes for dense, sparse and compact branching habits were 46.88, 43.75 and 9.34%, respectively. Based on their fruit colour, the genotypes were categorized into dark red (40.62%), Red (29.69%), light red (28%) and brown (1.5%). The predominant leaf colour was dark green (37.51%), light green (31.25%), green (23.44%) and yellow (7.8%). For the fruit shape, 78.13% of the genotypes were elongated, 15.62% triangular and 3.12% were blocky types. In addition, 57.81% of the genotypes have fruits with pointed blossom-end and those showed Blunted and sunken fruit types were 29.69 and 9.38%%, respectively.

The value of Shannon-Weaver diversity index for all characters varied from 0.45 for fruit shape to 0.98 for tillering with an overall mean of 0.82 and also for all of the traits assessed such as plant growth habit (0.95), leaf color (0.92), fruit set (0.92), fruit shape at pedicel attachment (0.89), branching habit (0.85), fruit color at mature stage (0.83) and fruit shape at blossom end (0.73). The overall mean of H' value of 0.82 confirmed the existence of diversity among the accessions.

Furthermore, the diversity indices of all of the quality traits suggested the presence of adequate variability for these traits among genotypes. High Shanon-Waver diversity index with an overall mean of 82% was obtained. The predominant traits that showed wider variations among the genotypes were sparse tillering (98%), followed by erect growth habit (95%) and dark green leaf color (92%). The lowest diversity value of less than the overall mean was recorded for fruit shape (45%) indicating that most of the genotypes used for this study had elongated fruit length. Nsabiyera et al. (2013) reported that the frequency distribution and Shanon weaver-diversity index and observed highly divergent qualitative traits of hot pepper collections. Similar agreement with Shimeles (2018) who found greater level of diversity which ranged from 0.65 to 0.98 among hot

pepper quality traits from Bale, Halaba, Assossa, Abshge and Marko parts of the country.

Conclusion

The study showed significant amount of variation among genotypes in most of the studied traits of hot pepper. High heritability and genetic advance were observed in fruit yield per plant, fruit diameter, fruit length, average fruit weight and number of fruits per plant. Yield had significant positive associations with fruit weight, fruit length, fruit diameter and fruit pericarp thickness. From path analysis, fruit length, average fruit weight, stem diameter, number of branches per plant, fruit diameter and fruit pericarp thickness exhibited the highest direct positive effects on fruit yield Overall, the results of this study indicated fruit length and diameter, average fruit weight, number of branches per plant and fruit pericarp thickness can be used as indirect selection criteria in improving hot pepper for green pod production.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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