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# GENETIC VARIABILITY AND ASSOCIATION OF CHARACTERS IN ETHIOPIAN HOT PEPPER (*CAPSICUM ANNUM* L.) LANDRACES

**Shimeles Aklilu[1*], Bekele Abebie[2], Dagne Wogari[3] and Adeferis T/Wolde[4]**

[1]Adama Science and Technology University,
Ethiopian Institute of Agricultural Research
[2]Arsi University, College of Agriculture
[3,4]CIMMYT- Ethiopia, Addis Ababa

**Abstract:** Forty nine hot pepper accessions collected from different agro-ecologies were compared in a 7x7 simple lattice design to estimate genetic variability and understand the association of characters. Plant characters and yield components were evaluated and analyzed accordingly. The values of genotypic correlation coefficients were higher in magnitude than phenotypic values in most instances in which fruit yield per plant showed high positive significant genotypic correlation value with pericarp thickness (r = 0.91) and number of fruits per plant (r = 0.61). On the other hand, significant negative associations were registered with days to flowering (r = -0.73) and 50% fruiting period (r = -0.75). The phenotypic correlation coefficient of most characters with yield was not significant except for flowering period, fruit length and number of fruits per plant. The path coefficient analysis indicated that pericarp thickness (mm) (5.5), fruit diameter (mm) (1.4), number of fruits per plant (0.8), number of branches (0.33) and flowering period (0.2) had the highest direct positive effect. However, fruit weight (-2.8), number of internodes (-1.66), leaf area index (-1.6) and plant height (-0.4) had a high negative direct effect on yield. The genetic component analysis indicated that phenotypic coefficient of variation (PCV) was higher in magnitude than genotypic coefficient of variation (GCV) for most characters except pericarp thickness and leaf area index. Higher magnitude of GCV was observed in leaf area index (67%) followed by pericarp thickness (34%), number of branches, internode length (23%) and plant height. Close estimates of GCV and PCV were recorded from fruit and internode length, pericarp thickness and fruiting period. Very high PCV and very low GCV estimates were obtained from fruit weight and number of fruits, fruit yield, plant height and canopy width. Broad sense heritability was high for fruiting date, fruit length, plant height, internode length and fruit diameter. However, genetic advance as percent of the mean (GAM) was high to moderate for length and number of internodes, number of branches, fruit diameter and weight, pericarp thickness and

*Corresponding author: e-mail: shimiakl@yahoo.com

leaf area index. Therefore, from this study, fruit diameter, pericarp thickness, leaf area index and internode length exhibited high to moderate genotypic and phenotypic coefficients of variation along with medium to high heritability and genetic advance and can be used as a selection criterion for pepper improvement program.

**Key words:** heritability, genetic advance, path analysis, accessions.

## Introduction

Different pepper types are grown in different parts of Ethiopia and they substantially contribute to the national economy of the country and to the balanced diet and are considered as commercial, industrial and important cash crops to the farmers. Due to a great deal of natural hybridization among different pepper cultivars, many local genotypes have evolved with various plant and fruit characters as well as disease and pest reactions. As a result, Ethiopia is considered as a source of pepper diversity (Marame et al., 2008), for availability of different commercially known hot pepper types in different agro-ecological parts of the country with specific local names (Shimeles et al., 2007). However, elongated brown fruit types with mildly to highly pungent cultivars are the most preferred and widely grown across the country. These landraces are heterogeneous materials that can serve as a reservoir of genetic variability for breeding. However, the yield of these landraces is very low and the report of CSA (2012) indicated that the national production of dry and green pepper was 209,872 t and 57,772 t with the average productivity of 2.52 and 9.98 t $ha^{-1}$ respectively which is much lower than in other African countries. Improving the crop through developing high-yielding varieties with desirable qualities could reverse the existing trend of low productivity of the crop.

It is well recognized that the knowledge and understanding of the genetic basis of economic traits are important to improve new crop varieties. However, in Ethiopia, the genetic improvement of hot pepper is lagging far behind the possible level that can be attained due to less availability of required genetic information. Moreover, no hybrid varieties have been developed through gene recombination except very few hybrid varieties developed and introduced by private seed companies of different countries. Efforts to improve the crop have been constrained mainly by lack of adequate information on the genetic control of characteristics of the yield and yield related traits of Ethiopian materials. Thus, about 49 hot pepper accessions have been collected from different regions of Ethiopia and compared for their yield potential and genetic diversity using major morphological traits. In the mean time, determination of heritability, genetic advance and understanding character association are useful to study genetic change of a population undergoing selection and to choose among alternative breeding programs (Falconer, 1989). Understanding the amount of genetic variation alone will not be of much use to the breeder unless supplemented with the information on heritability estimate, which gives a measure of the heritable portion of the total variation. Genotypic variation (GCV) and heritability estimates provide a better understanding of the amount of advance to be expected by phenotypic selection. Therefore, this study was undertaken with the objectives to understand the association of different characters and to estimate the heritability and genetic advance of 13 quantitative characters.

## Material and Methods

Forty-nine hot pepper accessions, whose local names, sources and places of collection are indicated in Table 1, were collected from different agro-ecologies and compared with a standard cultivar grown under irrigated conditions. The experiment was laid out in a 7 x 7 simple lattice design at the Melkassa Agricultural Research Center (MARC), central Ethiopia. Seedlings were raised from the collected seeds in nursery beds and transplanted in 2.8 x 3 m plots, 45 days after sowing. In each of the four-rowed plots, inter and intra-row spacings of 0.7 and 0.3 m respectively were maintained to raise 40 plants per plot. Diammunium Phosphate (DAP) as a source of $P_2O_5$ was applied at a rate of 200 kg $ha^{-1}$ during planting and the split application of nitrogen fertilizer in the form of UREA was applied at a rate of 100 kg $ha^{-1}$, half during transplanting and the rest was side-dressed 45 days after transplanting and the field was irrigated at 5- to 10-day intervals. To control insects (fruit worm and aphids) and blight diseases, the common insecticide celecron-720 EC (Profenofos-72%) and fungicides Ridomil Gold (Metalaxyle-M-4% and Mancozeb-64%) were applied twice (at flowering and fruiting period), respectively.

Field management

Seedlings were raised from the collected seeds, in nursery beds and transplanted in 2.8 x 3 m plots, 45 days after sowing, keeping 70 and 30 cm of inter- and intra-row spacing, respectively. Two fertilizer types, Diammonium Phosphate (DAP) and UREA were applied according to the recommendation given by MARC. The DAP was applied at a rate of 200 kg $ha^{-1}$ at planting and Urea at a rate of 100 kg $ha^{-1}$ was applied in two splits, by side-dressing half the recommended dose at transplanting and the remaining half was applied one and a half month after transplanting. Following the manufacturing company recommendations, Celecron and Ridomil Gold were applied twice in order to control insects and fungal diseases, respectively. Furrow irrigation was used to irrigate the plots at an interval of every 5–10 days.

Table 1. Local names, sources and areas of collections of forty-nine Ethiopian hot pepper landraces.

| Accession No. | Local name[§] | Area of collection | Source | Accession No. | Local name | Area of collection | Source |
|---|---|---|---|---|---|---|---|
| Acc-1 | Ed-Bure | Bure (Gojam) | Gojam market | Acc-26 | Awa-Gello2- | Gello-Argessa | Hawasa Research |
| Acc-2 | Mi-brshelko | Birshleko (Gojam) | Gojam market | Acc-27 | Halaba-Ansha | Halaba Ansha | Assossa Research |
| Acc-3 | Mi-alaba2 | kuleto(Halaba | Halaba market | Acc-28 | Halla-Gulleto | Hallaba Gulleto | Hawasa Research |
| Acc-4 | Am-Ybale | Bale 1(Adama) | Adama market | Acc-29 | Marko fana | Melkassa | Melkassa Research |
| Acc-5 | Sh-Marko3 | Mareko3(Meskan) | Meskan market | Acc-30 | ShB-1 | Butajira | Farmers field |
| Acc-6 | Mo-Marko2 | Mareko3(Meskan) | Meskan market | Acc-31 | RD-2 | Butajira | Farmers field |
| Acc-7 | Mo-Marko1 | Mareko1(Ensno) | Enseno market | Acc-32 | DR-3 | Enseno | Farmers field |
| Aac-8 | Na-Ybale | Bale2 (Adama) | Adama market | Acc-33 | Nsh-6 | Enseno | Farmers field |
| Acc-9 | Mi-Alaba1 | Halaba-(Adama) | Adama market | Acc-34 | Ab-5 | Enseno | Farmers field |
| Acc-10 | Ha-Bedessa | Bedessa (W/Hararghe) | W/Hararhe market | Acc-35 | Dk-4 | Bati-Futo | Farmers field |
| Acc-11 | Tad-Halaba | Ansia (Halaba)- | Halaba market | Acc-36 | Rad | Bati-Futo | Farmers field |
| Acc-12 | Tad-Agarfa) | Agarfa (Bale) | Bale market | Acc-37 | Knsa-8 | Enseno | Farmers field |
| Acc-13 | Wfo-Gojam | Finote-Selam (Gojam) | Gojam market | Acc-38 | Assossa-8 | Enseno | Farmers field |
| Acc-14 | Tad-Ybale Alemgena) | Alemgena (Bale) | Bale market | Acc-39 | Dari-10 | Enseno | Farmers seed lot |
| Acc-15 | Eta-Shirka | Shirka (Arsi) | Arsi market | Acc-40 | Turu-11 | Bati-Futo | Farmers seed lot |
| Acc-16 | Wfo-Tedele | Mechara(W/Hararghe) | Wolkite market | Acc-41 | Walga-2 | Abishege | Farmers seed lot |
| Acc-17 | Har-Milkay | Tedele (Wolkite) | W/Hararhe market | Acc-42 | Walga-4 | Abeshege | Farmers seed lot |
| Acc-18 | Tig-Hlaba | Halaba (Adama) | Adama market | Acc-43 | Asosa-6 | Benishangule | Assossa Research |
| Acc-19 | Absh-Fitejeju1 | Absheghe (Gurage) | Hawasa Research | Acc-44 | Assossa-12 | Benishangule | Assossa Research |
| Acc-20 | Absh-Fitejeju4 | Absheghe (Gurage) | Hawasa Research | Acc-45 | Assossa-2 | Benishangule | Assossa Research |
| Acc-21 | Marko-Kumo Almin8 | Gello-Argessa | Hawasa Research | Acc-46 | Assossa-9 | Benishangule | Assossa Research |
| Acc-22 | Marko-Didamidore9 | Marko (Gurage) | Hawasa Research | Acc-47 | Assossa-7 | Benishangule | Hawasa Research |
| Acc-23 | Meskan-1 | Meskan-Enseno | Hawasa Research | Acc-48 | Assossa-5 | Benishangule | Assossa Research |
| Acc-24 | Awa-Dalle1 | Awassa-Dalle2 | Hawasa Research | Acc-49 | Dilla-9 | Benishangule | Assossa Research |
| Acc-25 | Awa-Gello1 | Marko (Gurage) | Hawasa Research | | | | |

Mareko fana (Acc-29) is a standard check that was released in 1978 GC by the Ethiopian Institute of Agricultural Research and it is currently widely grown across the country.
[§]The local names of each accessions are given by local farmers and traders in different languages related to the locality where they were predominately grown and the names are mostly based on fruit color, size and market use, etc.

Data collection and method of analysis

Plant height, canopy width, internode length of five randomly selected plants in the two middle rows of each plot were measured and averaged using a measuring tape. Fruit length, width and pericarp thickness (mm) of 10 fruits were measured using a standardized electronic digital caliper. The average fruit weight (g) of 10 representative fruits from each plot was recorded using a sensitive balance. The leaf area index was measured with the use of leaf area meter (Model no. LI-3100C) using leaves obtained from 5 plants at the third harvest. Days to 50% flowering and fruiting period were recorded from each plot (from transplanting until 50% flowering and fruiting period).

Analysis of variance was carried out, using SAS/STAT software 9.2 program (SAS Institute Inc., Cary, NC, USA). Genotypic and phenotypic correlations were calculated from ANOVA table following Singh and Chaudhary (1985) procedure, and path coefficient analysis was performed following the procedures of Dewey and Lu (1959) for plant and fruit characters contributing to the fruit yield, with a view to partition the genotypic correlation into their direct and indirect contribution and to assess the relative importance of each causal factor affecting fruit yield. Analysis of variance was carried out for each variable and covariance analysis for each pair of variables. Genotypic and phenotypic correlations for all possible comparisons were calculated from these components using the following formula:

$$\sigma^2_p = \sigma^2_g + \sigma^2_e \quad (1)$$

$\sigma^2_p$ = phenotypic variance, $\sigma^2_g$ = genotypic variance, $\sigma^2_e$ = environmental variance (mse)

$\sigma^2_g$ = msv - mse/r

msv = mean square of the varieties, mse = mean square error, r = number of replications

$r_g = g_{covxy} / \sqrt{\sigma^2_x} . \sqrt{\sigma^2_y}$

$r_g$ = genotypic correlation, $g_{covxy}$ = genotypic covariance of x and y, $\sigma^2_x$ = variance of character x

$\sigma^2_y$ = variance of character y

Path coefficient analysis was determined by the formula $r_{ij} = P_{ij} + \sum r_{ik} P_{kj}$

where, rij = mutual association between the independent character (i) and dependent character (j) as measured by the genotypic correlation coefficient,

P ij = components of direct effects of the independent character (i) on the dependent character (j) as measured by the genotypic path coefficients, and $\sum r_{ik} p_{kj}$ = summation of components of indirect effects of the given independent character (i) on the given dependent character (j) via all other characters

$$\text{PCV (\%)} = \frac{\sqrt{Vp}}{X} \times 100, \quad (2)$$

$$\text{GCV (\%)} = \frac{\sqrt{Vg}}{X} \times 100, \quad (3)$$

where PCV is phenotypic coefficient of variance, VP is phenotypic variance, GCV

is genotypic coefficient of variance, and Vg is genotypic variance.
GCV and PCV, and genetic advance values were categorized as low (0–10%), moderate (10–20%), and high (>20%) broad sense heritability

$$(h^2bs) = \frac{Vg}{Vp} \times 100 \quad (4)$$

genetic advance (GA) = $h^2 * i * VP$
i = selection differential (2.06) at 5% selection intensity

$$\text{genetic advance as percent of the mean (GAM)} = \frac{GA}{X} \times 100 \quad (5)$$

where, Vp is the phenotypic variance and Vg is the genotypic variance.
Heritability percentage will be categorized as demonstrated by Robinson et al. (1994): 0–30% – low, 30–60% – moderate, 60% and above – high.
The genetic components, GCV and PCV were categorized as suggested by Johnson et al. (1955): 0–10% – low, 10–20% – moderate, 20% and above – high.

## Results and Discussion

The data on range, mean and genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), broad sense heritability ($Hb^2$), genetic advance (GA), genetic advance as percent of the mean (GAM) of the 13 characters have been presented in Table 2. The analysis of variance showed a wide range of means for fruit number (13±95), plant height (54±147) and yield per plant (29±185) providing an ample scope for selecting desirable types.

The phenotypic coefficient of variance (PCV) and the genotypic coefficient of variance (GCV)

The data revealed that the magnitude of PCV was higher than the magnitude of GCV for most of the characters except for leaf area index and pericarp thickness. The estimates of PCV were the highest for the number of branches followed by dry weight, number of fruits per plant and internode length and fruit yield per plant, pericarp thickness, flowering and fruiting period, leaf area index, plant height and fruit diameter. Medium phenotypic variation was observed in the number of internodes and fruit length. High GCV was obtained from leaf area index, pericarp thickness, number of branches and internode length. High phenotypic and genotypic coefficients of variations were obtained for leaf area index, pericarp thickness, plant height, number of branches and internode length. A high value of PCV and moderate value of GCV were recorded for fruit length, fruiting and flowering period, fruit yield and number of fruits per plant. Moderate PCV and low GCV were obtained only in number of internodes, whereas the values of both PCV and GCV were moderate only for fruit length. A high value of PCV and a low value of GCV were obtained from fruit weight and canopy width.

High values of PCV and GCV indicated the existence of substantial variability, ensuring ample scope for their improvement through selection. These results agreed with the findings of earlier researchers (Vani et al., 2007; Ukkund et al., 2007), for the number of fruits per plant (Sreelathakumary and Rajamony, 2004; Mishra et al., 2005), for fruit length (Ibrahim et al., 2001), for average fruit weight (Sreelathakumary and Rajamony, 2004), for plant height and days to 50% flowering (Ibrahim et al., 2001) (Table 2).

Heritability and genetic advance

The heritability of the highest magnitude was noticed for the fruiting period (86%) and the heritability of the lowest magnitude was observed for fruit weight (20%). High broad sense heritability estimates were obtained for the fruiting period, fruit length, fruit diameter and internode length and moderate broad sense eritability estimates were obtained for flowering date, canopy width, number of internodes, leaf area index, plant height, pericarp thickness, fruit yield, and number of fruits and low broad sense itability estimates were obtained for the number of branches and fruit weight. Thus, these indicated that a larger proportion of phenotypic variance was attributed to genotypic variance and thus a reliable selection could be made for most of the traits on the basis of phenotypic expression. High estimates of broad sense heritability indicated that substantial improvement can be made using standard selection procedures. Similar findings were reported by earlier workers for some characters with moderate to high heritability estimates, for fruit yield per plant and number of fruits per plant (Sreelathakumary and Rajamony, 2004), for fruit length and diameter (Das and Choudhary, 1999), days to 50% flowering and fruit length (Bhardwaj et al., 2007), plant height (Ibrahim et al., 2001; Bhardwaj et al., 2007). High estimates of genetic advance (GA) were observed in case of yield per plant, fruiting period, fruit length and plant height. The expected genetic advance as percent of the mean was high for length of internode, leaf area index, and pericarp thickness. Moderate GAM was recorded for fruit weight and diameter, number of internodes and branches. High to moderate heritability along with high to moderate genetic advance were observed for pericarp thickness, leaf area index, internode length, number of internodes, and fruit diameter, which clearly showed that there is ample scope to improve this crop through selection of these traits. Unlike the current study, high heritability and high genetic advance have been obtained by many workers (Bhardwaj et al.,2007) for fruit yield per plant, for average fruit weight (Sreelathakumary and Rajamony, 2004), for the number of fruits per plant (Kataria et al.,1997). High to moderate heritability and low genetic advance were obtained for plant height, canopy width, fruit yield, number of fruits per plant, fruit length and days to 50% flowering and fruiting. These traits are governed by non-additive gene effects and can be improved through hybridization and use of hybrid vigor. This result is in agreement with findings of Ibrahim et al. (2001) for days to first harvest, fruit length, and plant height. The number of branches and fruit weight showed low heritability associated with moderate genetic advance indicating the role of non-additive genes for these traits suggesting that a chance of improvement through the standard selection procedure is very low, but could be achieved through heterosis breeding.

Table 2. Genetic components and heritability of yield and yield related traits in hot pepper landraces in Ethiopia.

| Characters | Mean | SE | C.V. | Range | H (bs)$^2$ | GA | GAM | GCV% | PCV% | PCV and GCV differences |
|---|---|---|---|---|---|---|---|---|---|---|
| FYPP | 96.7 | 17.5 | 25 | 29±185 | 37 | 4.3 | 4 | 19 | 35 | 16 |
| FLW | 53.56 | 8.6 | 16 | 35±75 | 57 | 3.99 | 7 | 12 | 22 | 10 |
| FRUT | 85.67 | 8.5 | 10 | 55±140 | 86 | 7.64 | 9 | 19 | 22 | 3 |
| FL | 95.5 | 1.6 | 17 | 53±128 | 74 | 6.08 | 6 | 12 | 17 | 5 |
| FD | 17.21 | 2.5 | 18 | 9±26 | 61 | 2.38 | 14 | 10 | 21 | 11 |
| PH | 78.1 | 9.5 | 12 | 54±147 | 51 | 4.5 | 5 | 21 | 43 | 22 |
| CW | 56.4 | 8.7 | 15 | 36±91 | 33 | 2.3 | 4 | 8 | 24 | 16 |
| NB | 10.4 | 2.5 | 24 | 4±26 | 27 | 1.68 | 16 | 23 | 85 | 62 |
| NI | 13.6 | 1.9 | 14 | 7±21 | 46 | 1.43 | 11 | 7 | 16 | 9 |
| IL | 14.9 | 3.9 | 25 | 6±32 | 67 | 3.18 | 21 | 23 | 34 | 11 |
| PKT | 2.77 | 0.67 | 24 | 1.1±5 | 35 | 0.64 | 23 | 34 | 28 | -6 |
| FWT | 2.55 | 0.82 | 32 | 0.8±7 | 20 | 0.42 | 16 | 6 | 38 | 32 |
| NFP | 39.04 | 12 | 30 | 12.8±95 | 38 | 3.09 | 8 | 10 | 38 | 28 |
| LAI | 0.71 | 0.16 | 27 | 0.3±1.1 | 37 | 0.34 | 48 | 67 | 27 | -40 |

FYPP = fruit yield per plant, FLW = days to flowering, FRUT = days to 50% fruiting, FL = fruit length (mm), PD = fruit diameter (mm), PH = plant height, CW = canopy width, NB = number of branches, NI = number of internodes, IL = internode length, PKT = pericarp thickness, FWT = fruit weight, NFP = number of fruits per plant, LAI = leaf area index

## Correlation

The phenotypic and genotypic correlation coefficients for different pairs of characters and yield are presented in Table 3. The phenotypic and genotypic correlation coefficients were not close to each other in most instances, due to high environmental variance. However, a number of interesting relationships were observed at genotypic level, and in most cases, the genotypic correlation was higher in magnitude than the phenotypic one, which showed the inherent associations between various characters.

Genotypic correlation: Fruit yield per plant showed significant positive associations only with pericarp thickness (r = 0.91) and number of fruits per plant (r = 0.61), which indicates that these characters are the major components for pepper fruit yield. On the other hand, fruit yield per plant showed significant negative associations with days to flowering (r = -0.73) and 50% fruiting period (r = -0.75).

Table 3. Genotypic and phenotypic correlation coefficients of yield and yield components in Ethiopian hot pepper landraces.

| | Corrn | FLW | FRUT | FL | FD | PH | CW | NB | NI | IL | PKT | FWT | NAP | LAI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FLW | G | 1 | 0.75** | 0.52** | 0.55** | 0.56** | 0.05 | -0.1 | 0.35 | 0.36* | -0.88** | -0.21 | -0.63** | -1.80 |
| | P | | 0.52** | 0.21 | -0.05 | 0.41 | 0.05 | -0.05 | 0.09 | 0.16 | -0.06 | -0.04 | -0.11 | 0.14 |
| FRUT | G | | 1 | 0.055** | 0.39* | 0.74** | 0.65** | -0.11 | 0.69** | 0.59* | -0.36 | -0.66** | 0.76** | -0.78** |
| | P | | | 0.34 | 0.11 | 0.51** | 0.26 | -0.05 | 0.26 | 0.37* | -0.03 | 0.11 | -0.23 | 0.27 |
| FL | G | | | 1 | 0.17 | 0.87** | -0.03 | -0.09 | 0.69** | 0.89** | 0.55** | 0.21 | -0.03 | 0.91** |
| | P | | | | 0.05 | 0.47 | 0.01 | 0.04 | 0.46 | 0.31 | 1.41 | 0.31 | 0.03 | 0.44 |
| FD | G | | | | 1 | 0.54** | -0.28 | -0.84** | 0.41* | 0.53** | 0.25 | -0.12 | -0.62** | 0.61** |
| | P | | | | | 0.08 | -0.03 | -0.84** | 0.08 | 0.05 | 0.30 | 0.12 | -0.17 | 0.04 |
| PH | G | | | | | 1 | 0.11 | -0.04 | 0.52** | -0.36 | -0.09 | 0.35 | -0.89** | -0.96** |
| | P | | | | | | 0.38* | -0.25 | 0.52** | 0.04 | 0.11 | 0.03 | -0.24 | 0.30 |
| CW | G | | | | | | 1 | -0.06 | 0.92** | 0.96** | 0.74** | 0.91** | -0.39* | -0.09 |
| | P | | | | | | | 0.19 | 0.45* | 0.21 | 0.09 | 0.02 | -0.05 | 0.01 |
| NB | G | | | | | | | 1 | 0.32** | -0.07 | 0.05 | 0.32 | 0.38** | -0.56** |
| | P | | | | | | | | 0.07 | 0.01 | -0.08 | 0.13 | -0.04 | 0.20 |
| NI | G | | | | | | | | 1 | 0.96** | 0.98** | 0.68** | -0.74** | 0.61** |
| | P | | | | | | | | | 0.33 | 0.04 | -0.03 | 0.06 | -0.15 |
| IL | G | | | | | | | | | 1 | -0.20 | 0.01 | -0.14 | 0.11 |
| | P | | | | | | | | | | 0.01 | 0.01 | -0.02 | 0.02 |
| PKT | G | | | | | | | | | | 1 | 0.51** | -1.00 | 0.60** |
| | P | | | | | | | | | | | 0.11 | -0.14 | 0.08 |
| FWT | G | | | | | | | | | | | 1 | -0.55** | 0.82** |
| | P | | | | | | | | | | | | -0.04 | 0.29 |
| NFP | G | | | | | | | | | | | | 1 | -1.01 |
| | P | | | | | | | | | | | | | -0.17 |
| LAI | G | | | | | | | | | | | | | |

*significant at 5% = 0.362, and **significant at 1= 0.46.

n = genotypic and phenotypic correlation coefficients, FLW = days to 50% flowering, FRUT = days to 50% fruiting, FL = fruit length (mm), FD = fruit diameter (mm), PH = plant height, CW = canopy width, NB = number of branches, NI = number of internodes, ILs = internode length, PKT = pericarp thickness, FWT = fruit weight, NFP = number of fruits per plant, LAI = leaf area index.

This clearly indicated that early flowering and fruiting cultivars produced high yields due to high rates of early flower initiation and fruit development unlike late flowering of vigorous tall plants which need a long growing period for fruiting which later produced the lowest yield. Another interesting genotypic correlation was obtained between 50% flowering and fruiting period and with other plant growth characters. Except with fruit length and fruit diameter, a highly negative association was obtained for most fruit characters like fruit weight, pericarp thickness and number of fruits per plant. Canopy width showed a significant positive association with plant and fruit characters except with the number of fruits per plant. Whereas the number of branches had significant positive associations with canopy width and number of fruits per plant, it had a negative association only with fruit diameter and leaf area index. As the number of branches increased with those short statured accessions, the number of fruits per plant also increased, which was directly associated with an increase in yield per plant. However, plant height had a significant negative association with fruit number per plant, but a good positive association was obtained only with number of internodes, fruit length, and diameter as opposed to other reports (Patel et al., 2009). However, fruit length and diameter had a significant positive association with plant height, number and length of internodes, pericarp thickness and leaf area index. This showed that accessions with vigorous tall plants produced low number of fruits with better fruit size. However, fruit diameter was negatively affected by number of fruits and number of branches. Whereas the number of fruits per plant had a significant positive association only with number of branches, a perfect negative correlation was observed with pericarp thickness. This clearly indicated that when the number of fruits per plant increased, fruit diameter and pericarp thickness highly reduced due to high competition of fruits.

Fruit weight had a significant positive association with the most important yield components like leaf area index, canopy width, pericarp thickness and number of internodes, whereas a significantly high negative association was noted with the number of fruits per plant. Similarly, pericarp thickness had a positive association with canopy width, number of internodes, leaf area index and fruit weight, but it showed a negative association with the number of fruits. Therefore, early flowering cultivars with a wider canopy size and high leaf area index could give long and wider fruits with thick pericarp and good weight due to favorable conditions for better fruit development.

Similar results were reported by Birhanu et al. (2011), regarding AVRDC materials that gave a high positive genotypic correlation of fruit yield with the number of fruits per plant and pericarp thickness. However, in their study, unlike in the current study, plant height and canopy diameter showed a positive correlation with fruit yield. Except for plant height and fruit length, the results of the current study are in agreement with the report of Bharadwaj et al. (2007), who advocated to give emphasis to the number of fruits per plant, number of branches, fruit length, fruit diameter and plant height during the selection process because these characters significantly affected pepper yield. From this study, the significant association of fruit yield with pericarp thickness and number of fruits per plant suggests that an increase in any one of these traits may results in an increase in fruit yield. Moreover, number of internodes and length of internodes, number of branches and canopy width gave positive association with most other yield components and can be regarded as very important traits to consider for selection.

Phenotypic correlations: The phenotypic correlation coefficients of most characters with yield were not significant except for flowering period, fruit length and number of fruits per plant though fruit yield per plant had a high significant positive association with the number of fruits per plant and flowering period.

Flowering periods had a low negative association with most of the parameters at phenotypic level. However, the fruiting period had a high positive association with plant height and internode length. Similarly, fruit diameter did not show any significant association with most characters except with the flowering period. On the other hand, fruit length had a significant positive association with the number of internodes, plant height and leaf area index and also showed a positive association with fruit weight and internode length, but it did not show a negative association with any of the characters, which indicated that the association of fruit length with these characters was environmental. Pericarp thickness gave higher phenotypic than genotypic value with fruit weight, fruit diameter and fruit length, which indicated that the association of these characters was influenced greatly by the environment. The number of internodes had a very high positive association with fruit length, plant height, canopy width, which indicated that this parameter could be potential character for fruit yield improvement in pepper though it was greatly affected by environmental factors.

Path coefficient analysis

Out of 13 characters which were treated as causal factors, the highest positive direct effect was obtained from pericarp thickness (5.5), followed by fruit diameter (1.4), number of fruits per plant (0.8), number of branches (0.33) and flowering period (0.2). Fruit weight (-2.8), number of internodes (-1.66), leaf area index (-1.6) and plant height (-0.4) had a high negative direct effect on yield (Table 4). The residual effect was 0.27.

Fruit yield vs flowering and fruiting period: The direct effect of the flowering period on fruit yield was low and positive and its indirect effect on leaf area index, fruit diameter, number of internodes, and fruit weight was high and positive. However, the influences of the flowering period on pericarp thickness and fruit number per plant were high and negative. The net effect in the system of the opposing influence was that seven positive effects counter-balanced with six negative effects made the overall correlation between flowering period and yield high and negative. The direct effect of the fruiting period on yield was also negative and medium (-0.3). However, the indirect effect on leaf area index, fruit diameter and fruit weight was high and positive, but the influences of the flowering period on pericarp thickness, fruit number and number of internodes were high and negative. These effects counter-balanced with 6 positive effects made the overall correlation between fruiting period and yield high and negative. The results indicated that in the selection program, considering early flowering cultivars was very important for high pepper fruit yield.

Fruit yield vs fruit length and diameter: The direct effect of fruit length on yield was very low and positive (0.06) and the indirect effects on fruit diameter and pericarp thickness were positive, but the indirect effects on leaf area index, number of internodes and fruit weight were negative though a high value was recorded through the first two characters. The results indicated that considering only fruit length in the selection program was not rewarding for pepper yield due to its very low positive direct effect and high negative indirect effect through most components. The direct influence of fruit diameter was very high and positive (1.4) and a positive indirect influence on pericarp thickness, fruit weight and number of internodes and a negative indirect influence on number of fruits per plant and leaf area index were obtained. This caused the net effect of the overall correlation between fruit diameter and fruit yield to be negative. However, this low negative association with fruit yield, which was not so important for fruit yield, was revealed by path analysis as a major contributor to fruit yield next to pericarp thickness.

Fruit yield vs number of fruits: The correlation between yield and this component was high and positive (r = 0.62) and the direct effect on yield was also high (0.8) and positive. However, such high positive correlation value with yield was due to its high direct positive effect of number of fruits on yield and its indirect positive effect on leaf area index, fruit weight, number of internodes and branches and flowering period. However, a high negative effect was recorded through pericarp thickness and fruit diameter. As there was a close positive association between the direct effect and the genotypic correlation coefficient, considering the number of fruits per plant in the selection program is rewarding for pepper cultivars to improve yield.

Fruit yield vs fruit weight: Fruit weight had the highest direct negative effect on fruit yield (-2.8) and also produced a high indirect negative effect on the number of internodes and leaf area index. However, the indirect effects on pericarp thickness, number of fruits and fruiting period were high and positive. The direct selection for this trait was not found important for yield improvement as its positive effect was indirect through other major yield components.

Table 4. The direct and indirect effects of path coefficient analysis of thirteen characters in hot pepper landraces in Ethiopia.

| Characters | FLW | FRUT | FL | FD | PH | CW | NB | NI | IL | PKT | FWT | NFP | LAI | GC YPP |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FLW | **0.17** | -0.23 | 0.03 | 0.77 | -0.20 | 0.00 | -0.03 | 0.70 | -0.07 | -4.73 | 0.55 | -0.50 | 2.81 | -0.73 |
| FRUT | 0.13 | **-0.30** | 0.03 | 1.00 | -0.26 | 0.05 | -0.03 | -1.18 | -0.12 | -1.50 | 0.87 | -0.64 | 1.23 | -0.73 |
| FL | 0.09 | -0.17 | **0.06** | 0.24 | -0.31 | 0.00 | -0.02 | -0.18 | -0.18 | 2.90 | -0.56 | -0.03 | -1.43 | -0.58 |
| FD | 0.09 | -0.12 | 0.01 | **1.40** | -0.11 | -0.02 | -0.21 | -0.68 | -0.11 | 0.55 | 0.37 | -0.50 | -1.43 | -0.28 |
| PH | 0.10 | -0.22 | 0.05 | 0.75 | **-0.40** | 0.40 | -0.06 | -0.66 | 0.08 | -0.48 | -0.80 | -0.90 | 1.48 | -0.64 |
| CW | 0.01 | -0.19 | 0.00 | -0.39 | -0.03 | **0.07** | 0.24 | -1.56 | -0.19 | 4.00 | -2.55 | -0.31 | 0.15 | -0.76 |
| NB | -0.02 | 0.03 | -0.01 | -1.08 | 0.09 | 0.07 | **0.30** | -0.55 | 0.01 | 0.28 | -0.81 | 0.55 | 0.88 | -0.25 |
| NI | 0.06 | -0.21 | 0.04 | 0.55 | -0.22 | 0.07 | 0.08 | **-1.66** | -0.19 | 3.30 | -0.92 | -0.75 | -.95 | -0.80 |
| IL | 0.06 | -0.18 | 0.05 | 0.72 | 0.07 | 0.07 | -0.02 | -1.70 | **-0.21** | 0.02 | 0.33 | 0.07 | 0.09 | -0.63 |
| PKT | -0.15 | 0.11 | 0.05 | 0.76 | 0.03 | 0.05 | 0.01 | -1.63 | 0.01 | **5.48** | -1.10 | -1.75 | -0.95 | 0.91 |
| FWT | -0.03 | 0.20 | 0.01 | -0.12 | -0.13 | 0.10 | 0.10 | -1.16 | 0.03 | 2.20 | **-2.8** | 2.60 | -1.29 | -0.29 |
| NFP | -0.12 | 0.23 | 0.01 | -0.87 | 0.32 | -0.03 | 0.10 | 1.26 | -0.04 | -4.30 | 1.53 | **0.80** | 1.73 | 0.61 |
| LAI | -0.25 | 0.24 | 0.10 | 1.28 | 0.30 | -0.01 | -0.14 | -1.00 | 0.03 | 3.40 | -2.20 | -0.81 | **-1.50** | -0.56 |

FLW = days to 50% flowering, FRUT = days to 50% fruiting, FL = fruit length (mm), FD = fruit diameter (mm), PH = plant height, CW= canopy width, NB = number of branches, NI = number of internodes, IL = internode length, PKT = pericarp thickness, FWT = fruit weight, NFP = number of fruits per plant, LAI = leaf area index, GC YPP = genotypic correlation of yield per plant.

Fruit yield vs pericarp thickness: The direct influence was very high and positive (5.5) and its indirect influence on fruit diameter was also positive, but showed a high negative indirect influence on the number of fruits per plant, number of internodes, leaf area index and fruit weight. This was counter-balanced by its high direct positive effect, which caused the net effect of the overall correlation with yield to be positive and highly significant. The very high positive association and direct positive effect made it the most important trait for fruit yield improvement.

Fruit yield vs canopy width and number of branches: Canopy width had a low positive direct influence (0.07) and also exerted a moderately high positive indirect effect on leaf area index, number of fruits and pericarp thickness. However, a high indirect negative influence was noted through fruit weight and diameter, number of internodes and plant height. However, the number of branches had a good positive direct influence (0.3) and high indirect positive effect on number of fruits, fruit weight, and number of internodes and canopy width. A very high indirect negative influence was noticed on fruit diameter and leaf area index and this caused the total correlation value of canopy width with fruit yield to be negative and low (r = -0.3). Thus, considering these traits in the selection program is very useful for pepper yield improvement as their positive effects on fruit characters were high and positive.

Fruit yield vs plant height: Plant height had a high direct negative effect on fruit yield (-0.4), but its high indirect positive effect was noticed on leaf area index, fruit diameter, canopy width and internode length. However, the most important yield components were found to contribute negatively to fruit yield indirectly through plant height and its correlation coefficients were also negative with fruit yield and most other components. Thus, considering only this trait in the selection program is not very useful for pepper yield improvement.

Fruit yield vs number of internodes and internode length: These components were among the direct negative contributors to fruit yield (-1.7 and -0.2), respectively. The number of internodes had a high indirect positive effect only on fruit diameter and pericarp thickness. However, a high negative indirect effect was noted on leaf area index, fruit number and weight, plant height and fruiting period. Internode length had a high indirect positive effect only on fruit diameter and fruit weight, but a high negative indirect effect was obtained only through the number of internodes and fruiting period, which made the balance of correlation coefficient and yield negative. This clearly indicated that through their indirect influences on major fruit characters, they can be considered as the most important yield components in pepper yield improvement.

Fruit yield vs leaf area index: Leaf area index had a high direct negative effect on fruit yield (-1.6) and the indirect effect on yield, fruit diameter, pericarp thickness and plant height was positive. On the other hand, the effects on number of internodes, number of fruits and fruit weight were low and negative. The direct negative effect of leaf area index on yield was high, which indicates that this trait influences fruit yield indirectly though other yield components like fruit diameter and pericarp thickness in pepper cultivars. In general, from path analysis, the number of fruits per plant, and fruit diameter with pericarp thickness, number of branches exhibited the highest direct positive effect in which one can improve the dry fruit yield through direct selection of either of these characters during yield improvement program. These findings were in agreement with Dipendra and Gautam (2003) and Yadwad (2005) that more fruits per plant were highly reliable components regarding yield improvement in many crops.

## Conclusion

Forty-nine hot pepper accessions collected from different agro-ecologies were compared at Melkassa in a 7x7 simple lattice design to estimate genetic variability and understand the association of characters with fruit yield. Plant characters and yield components were evaluated from five randomly selected plants of each accession and analyzed accordingly. The genotypic and phenotypic correlation coefficients were not close in most comparisons. However, in most instances, the genotypic correlation coefficient values were higher in magnitude which showed the inherent association of these characters. An important positive association existed between fruit yield and number of fruits per plant and pericarp thickness at genotypic and phenotypic levels. However, an interesting highly significant negative correlation was obtained with flowering and fruiting period which indicated that selection should focus on early flowering materials. From the overall path analysis among fruit characters, fruit diameter, pericarp thickness, fruit number per plant and number of branches and flowering period can be used as a selection criterion to develop high yielding pepper cultivars as their direct and indirect effects on most other components are high and positive. Moreover, from genetic component analysis, number of fruits per plant, leaf area index, fruiting periods, internode length, pericarp thickness, plant height, fruit diameter exhibited high to moderate genotypic and phenotypic coefficients of variation along with medium to high heritability and medium to high genetic advance. Phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) for most characters studied except for pericarp thickness and leaf area index indicating that the influence of the environment was high on the manifestation of most of these characters. However, the difference between PCV and GCV was low for some of the characters like fruiting date, fruit length, pericarp thickness, and internode length and number, which indicated that there was a predominance of genetic factors controlling variability in these traits. Higher magnitudes of GCV coupled with high to moderate estimates of heritability were observed in leaf area index (67%) followed by pericarp thickness (34%), length of internode (23%), fruit diameter and plant height. Similarly, high to moderate genetic advance over mean coupled with high to medium heritability values was observed for internode number and length, leaf area index, pericarp thickness and fruit diameter. This clearly indicated that additive gene action governing these traits and improvement of any of these traits could be made through standard selection methods.

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# GENETIČKA VARIJABILNOST I POVEZANOST OSOBINA POPULACIJA ETIOPSKE LJUTE PAPRIKE (*CAPSICUM ANNUUM* L.)

**Shimeles Aklilu[1*], Bekele Abebie[2], Dagne Wogari[3] i Adeferis T/Wolde[4]**

[1]Naučni i tehnološki univerzitet u Adami,
Etiopski institut za istraživanja u poljoprivredi
[2]Univerzitet u Arsiju, Poljoprivredni koledž
[3,4]CIMMYT– Etiopija, Adis Abeba

## R e z i m e

Četrdeset devet genotipova ljute paprike, sakupljenih iz različitih agroekoloških sredina, analizirano je preko nepotpunog blok sistema (lattice designs, 7x7), kako bi se procenila genetička varijabilnost i razumela veza između njihovh osobina. U skladu sa tim, procenjivane su i analizirane osobine biljke i komponente prinosa. Vrednosti genetičkih korelacionih koeficijenata su bile više nego fenotipske, u većini slučajeva u kojima je prinos ploda po biljci imao značajno visoku pozitivnu genetičku korelacionu vrednost sa debljinom perikarpa (r = 0,91) i brojem plodova po biljci (r = 0,61). S druge strane, značajne negativne veze su zabeležene u slučaju broja dana do cvetanja (r = -0,73) i 50% perioda plodonošenja (r = -0,75). Fenotipski korelacioni koeficijent većine osobina, upoređenih sa prinosom, nije bio značajan, osim za period cvetanja, dužinu ploda i broj plodova po biljci. Analizom path koeficijenta korelacije pokazano je da su debljina perikarpa (mm) (5,5), prečnik ploda (mm) (1,4), broj plodova po biljci (0,8), broj grana (0,33) i period cvetanja (0,2) imali najviši direktan pozitivan uticaj, dok su s druge strane, masa

*Autor za kontakt: e-mail: shimiakl@yahoo.com

ploda (-2,8), broj internodija (-1,66), indeks lisne površine (-1,6) i visina biljke (-0,4) imali visok negativan uticaj na prinos. Analiza genetičkih komponenti je ukazala da je fenotipski koeficijent varijacije (PCV) bio izraženiji nego genetički (GCV) za većinu osobina, osim za debljinu perikarpa i indeks lisne površine. Izraženiji GCV zabeležen je kod indeksa lisne površine (67%), debljine perikarpa (34%), broja grana, dužine internodija (23%) i visine biljke. Bliske vrednosti GCV-a i PCV-a zabeležene su kod dužine ploda i internodija, debljine perikarpa i perioda plodonošenja. Veoma visoke vrednosti PCV-a (niske vrednosti GCV-a) registrovane su kod mase i broja plodova, prinosa ploda, visine biljke i širine krošnje. Heritabilnost u širem smislu je bila visoka za datum plodonošenja, dužinu ploda, visinu biljke, dužinu internodije i prečnik ploda. S druge strane, genetička dobit izražena u procentima od proseka (GAM) je bila visoka do umerena za dužinu i broj internodija, broj grana, prečnik i masu ploda, debljinu perikarpa i indeks lisne površine. Prema tome, tokom ovih istraživanja parametri prečnik ploda, debljina perikarpa, indeks lisne površine i dužina internodija su pokazali visoke do umerene genetičke i fenotipske koeficijente varijacije, zajedno sa srednjom do visokom heritabilnošću i genetičkom dobiti i mogu se upotrebiti kao kriterijumi za program unapređenja selekcije paprike.

**Ključne reči:** heritabilnost, genetička dobit, path analiza, genotipovi.

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