Research Article

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Genotypic character relationship and phenotypic path coefficient analysis in chili pepper genotypes grown under tropical condition

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Abstract

BACKGROUND: Studies on genotypic and phenotypic correlations among characters of crop plants are useful in planning, evaluating and setting selection criteria for the desired characters in a breeding program. The present study aimed to estimate the phenotypic correlation coefficients among yield and yield attributed characters and to work out the direct and indirect effects of yield-related characters on yield per plant using path coefficient analysis. Twenty-six genotypes of chili pepper were laid out in a randomized complete block design with three replications.

RESULTS: Yield per plant showed positive and highly significant ($P \leq 0.01$) correlations with most of the characters studied at both the phenotypic and genotypic levels. By contrast, disease incidence and days to flowering showed a significant negative association with yield. Fruit weight and number of fruits exerted positive direct effect on yield and also had a positive and significant ($P \leq 0.01$) correlation with yield per plant. However, fruit length showed a low negative direct effect with a strong and positive indirect effect through fruit weight on yield and had a positive and significant association with yield.

CONCLUSION: Longer fruits, heavy fruits and a high number of fruits are variables that are related to higher yields of chili pepper under tropical conditions and hence could be used as a reliable indicator in indirect selection for yield.

Keywords: Cause-effect relationship; *Capsicum spp*; correlation; chili breeding

INTRODUCTION

Chili (*Capsicum annuum* and *Capsicum frutescence* L.) pepper is widely cultivated, mostly as a spice crop.[1] Optimum day temperatures for chili (*C. annuum* L.) pepper growth are in the range 20–30 °C.[2] However, because of environmental fluctuations, temperatures are often higher than optimal,[3] thus increasing the probability of the plant being exposed to extended periods of supra-optimum temperatures. Such a condition is one of the important factors limiting the production of chili. In general, high temperature may lead to significant losses in crop productivity in many species as a result of limited vegetative and reproductive growth and seed yield. Plant growth and development is the product of the interaction between the genotype (genetic potential) and the environment in which the plant grows. Cell membrane thermostability (CMT) is used for measuring electrolyte leakage from leaves of plants at different temperatures.[4] Several studies have indicated that CMT is effective in detecting genetic differences with respect to heat tolerance among several crops.[5] Although chili is an important spice crop, Malaysian domestic production still cannot meet demand as a result of the poor performance of local varieties under high temperatures.[6]

Studies on genotypic and phenotypic correlations among characters of crop plants are useful in planning, evaluating and setting selection criteria for the desired characters in a breeding program.[7] Genetic associations provide simple criteria for selection and lead to a directional model based on yield and its components in field experiments. To design appropriate breeding strategies that aim for an improvement in yield through selection, it would be desirable to conduct correlation and path coefficient analysis studies, which help to enable a better understanding of the relationship among yield and yield-related traits.[8,9] Correlation coefficient

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Corrections added on 18 July 2016, after first online publication: in "Materials and Methods" Section, "A total of 10 dependent and independent variables" has been changed to "A total of 10 dependent variables". In Table 1, "DF" has been changed to "df", and it refers to "degree of freedom", not to "days to flowering" as previously stated.

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analysis measures the mutual relationships between various characters and it also determines the component characters on which selection can rely upon with respect to an effect on improvement. In determining effective breeding procedures, correlation coefficient studies between characters are of great value.[7]

Assessing the direct and indirect effects of each component towards yield through path coefficient analysis would help in the identification of the reliable characters contributing to yield.[10] Path coefficient analysis is an efficient statistical technique that is especially designed to quantify the inter-relationships of different components on yield. This should assist in the selection and improvement of the yield of chili peppers through the manipulation of quantitative characters with correlations amongst themselves that influence yield. However, path coefficient analysis provides a detailed examination of the nature of association among the components of yield and hence will assist in developing a reliable criterion for selection and minimizing the risks of component compensation in yield improvement.[11]

The present study aimed to analyse more critically the inter-relationships and influential patterns among yield and components of yield in chili peppers using a path coefficient analysis tool. The results will shed light on the variables that need to be considered with respect to chili peppers when aiming for yield improvement in this location, as well as other similar locations.

MATERIALS AND METHODS

The present study comprises an advanced stage of a long-term replicated trial conducted at University Putra Malaysia where 26 chili pepper genotypes obtained from Asian Vegetable Research and Development Centre (AVRDC), Taiwan from various source populations were evaluated. The genotypes are: AVPP9703, AVPP9806, AVPP9813, AVPP0004, AVPP0105, AVPP9815, AVPP0201, AVPP0116, AVPP0109, AVPP0305, AVPP0805, AVPP0506, AVPP0907, AVPP0306, AVPP0512, AVPP0514, C05573, AVPP0702, AVPP0103, AVPP0014, AVPP0904, AVPP0513, AVPP9812, AVPP0002, AVPP9905 and a local variety Kulai. The experiment was conducted under rain shelter at the Institute of Tropical of Agriculture, Faculty of Agriculture Universiti Putra Malaysia (UPM). The rain shelters were meant to protect the chili pepper plants against the impact of heavy rainfall and prevent frequent periods of leaf wetness. The seeds were first sown in seed trays containing peat moss with one or two seeds per cell and were later transplanted after four weeks to prepared polythene pots (17×30 cm) filled with cocoa dust with small holes to drain excess water. The experiment was laid in a randomized complete block design with three replications. Each rain shelter is 27×3 m and serves as a replication. Two pots were assigned for each genotype in each replication (52 pots per replication) and were oriented east to west (spaced 75×150 cm). Seedling emerged within 3–10 days after sowing and were transplanted 4 weeks after sowing. Fertigation system of cropping was adopted for both irrigation and fertilization. Drip system of irrigation was applied. Recommended agronomic practices were followed.

Data were collected from both morphological and physiological characters. A total of 10 dependent variables were recorded. Ten fruits were sampled for fruit length and weight records. The characters include; plant height, days to flowering, disease incidence, photosynthesis rate, chlorophyll content, fruit length, fruit weight, cell membrane thermostability and yield per plant. Plant height (cm) was taken from the surface of planting medium to the top of the plant. The number of days required to first flowering after transplanting measures days to flowering. Percentage of infected leaves by mosaic virus to total number of leaves in three random branches selected from each plant defines disease incidence. The length of fruit from pedicel to tip of the fruit was measured. Fruit weight was the weight of individual fruit. Total number of fruits harvested from each plant was counted as the number of fruits. Yield per plant was the total weight of fresh fruits harvested from each plant. Photosynthesis rate defines the net photosynthetic rate for the 26 genotypes from the leaves of 90 days old seedlings using an LI-6400XT portable photosynthesis system (Li-Cor, Lincoln, NE, USA). The photosynthesis rate measurement was based on carbon dioxide concentration. Chlorophyll content is the measurement of chlorophyll content in accordance with the procedure of Coombs *et al.*[12] The membrane stability was measured using the procedure described by Gajanayake *et al.*[4] to assess the variation among the genotypes for heat tolerance character and whether there is any strong association with yield. A sample for assay consists of a paired set comprising control (C) and treatment (T) sets of six leaf disks, each 1.3 cm^2. The T set of the test tubes was incubated for 20 min at 50 °C in a temperature controlled water bath, whereas the C set of test tubes was kept at room temperature (approximately 25 °C). Initial conductance reading of both sets (CEC 1 and TEC 1) was made using an electrical conductivity meter (Starter; Ohaus, Nänikon, Switzerland) after bringing test tubes to room temperature. Tubes were then sealed again with aluminium foil and autoclaved at 121 °C and 0.15 MPa for 20 min to completely kill the leaf tissue. Autoclaved tubes were cooled to room temperature; content was mixed thoroughly and final conductance (CEC 2 and TEC 2) readings were taken. The CMT was calculated using:

$$\text{CMT}\ (\%) = \frac{1 - (\text{TEC 1}/\text{TEC 2})}{1 - (\text{CEC 1}/\text{CEC 2})} \times 100$$

where TEC and CEC are a measure of conductance in treated and control test tubes, respectively, at initial (CEC 1 and TEC 1) and final (CEC 2 and TEC 2) conductance measurements.

The mean values of the dependent and independent variables were subjected to correlation coefficients using SAS, version 9.3 (SAS Institute Inc., Cary, NC, USA). Association of the various characters with yield per plant and among themselves was worked out at phenotypic and genotypic levels according to the method given by Kashiani and Saleh.[13] The phenotypic correlations were further partitioned into components of direct and indirect effects using path coefficient analysis as described by Wright.[14] The direct effects were obtained using SAS, version 9.3. The path coefficients were obtained by working out sets of simultaneous equations arranged in matrix notation which show the relationships between correlations and path coefficients,[11] as shown below.

Effects of morphological and physiological variables on the yield per plant

$$r_{110} = P_{110} + r_{12}\,P_{210} + r_{13}\,P_{310} + r_{14}\,P_{410} + r_{15}\,P_{510} + r_{16}\,P_{610} + r_{17}\,P_{710} + r_{18}\,P_{810} + r_{19}\,P_{910}$$

$$r_{210} = r_{21}\,P_{110} + P_{210} + r_{23}\,P_{310} + r_{24}\,P_{410} + r_{25}\,P_{510} + r_{26}\,P_{610} + r_{27}\,P_{710} + r_{28}\,P_{810} + r_{29}\,P_{910}$$

$$r_{310} = r_{31}\,P_{110} + r_{32}\,P_{210} + P_{310} + r_{34}\,P_{410} + r_{35}\,P_{510} + r_{36}\,P_{610} + r_{37}\,P_{710} + r_{38}\,P_{810} + r_{39}\,P_{910}$$

$$r_{410} = r_{41}\,P_{110} + r_{42}\,P_{210} + r_{43}\,P_{410} + P_{410} + r_{45}\,P_{510} + r_{46}\,P_{610} + r_{47}\,P_{710} + r_{48}\,P_{810} + r_{49}\,P_{910}$$

$$r_{510} = r_{51}\,P_{110} + r_{52}\,P_{210} + r_{53}\,P_{310} + r_{54}\,P_{410} + P_{510} + r_{56}\,P_{610} + r_{57}\,P_{710} + r_{58}\,P_{810} + r_{59}\,P_{910}$$

$$r_{610} = r_{61} P_{110} + r_{62} P_{210} + r_{63} P_{310} + r_{64} P_{410} + r_{65} P_{510} + P_{610} + r_{67} P_{710} + r_{68} P_{810} + r_{69} P_{910}$$
$$r_{710} = r_{71} P_{110} + r_{72} P_{210} + r_{73} P_{310} + r_{74} P_{410} + r_{75} P_{510} + r_{76} P_{610} + P_{710} + r_{78} P_{810} + r_{79} P_{910}$$
$$r_{810} = r_{81} P_{110} + r_{82} P_{210} + r_{83} P_{310} + r_{84} P_{410} + r_{85} P_{510} + r_{86} P_{610} + r_{87} P_{710} + r_{88} P_{810} + r_{89} P_{910}$$
$$r_{910} = r_{91} P_{110} + r_{92} P_{210} + r_{93} P_{310} + r_{94} P_{410} + r_{95} P_{510} + r_{96} P_{610} + r_{97} P_{710} + r_{98} P_{810} + r_{99} P_{910}$$

Character arrangement

1 = plant height
2 = days to flowering
3 = disease incidence
4 = photosynthesis rate
5 = chlorophyll content
6 = fruit length
7 = fruit weight
8 = number of fruits
9 = cell membrane thermostability
10 = yield per plant

The studied characters were further divided into two stage relations; first-order components and second-order components. The first-order components include plant height, days to flowering, disease incidence, photosynthesis rate and chlorophyll content. The second-order components are fruit length, fruit weight and number of fruits. The cause and effect relationships between the two components were worked out using simultaneous equations arranged in matrix notation as indicated below.

Effects of first-order components on the fruit length, fruit weight and number of fruits per plant

Fruit length

$$r_{16} = P_{16} + r_{12} P_{26} + r_{13} P_{36} + r_{14} P_{46} + r_{15} P_{56}$$
$$r_{26} = r_{21} P_{16} + P_{26} + r_{23} P_{36} + r_{24} P_{46} + r_{25} P_{56}$$
$$r_{36} = r_{31} P_{16} + r_{32} P_{36} + P_{36} + r_{34} P_{46} + r_{35} P_{56}$$
$$r_{46} = r_{41} P_{16} + r_{42} P_{26} + r_{43} P_{36} + P_{46} + r_{45} P_{56}$$
$$r_{56} = r_{51} P_{16} + r_{52} P_{26} + r_{53} P_{36} + r_{54} P_{46} + P_{56}$$

Fruit weight

$$r_{17} = P_{17} + r_{12} P_{27} + r_{13} P_{37} + r_{14} P_{47} + r_{15} P_{57}$$
$$r_{27} = r_{21} P_{17} + P_{27} + r_{23} P_{37} + r_{24} P_{47} + r_{27} P_{57}$$
$$r_{37} = r_{31} P_{17} + r_{32} P_{37} + P_{37} + r_{34} P_{47} + r_{35} P_{57}$$
$$r_{47} = r_{41} P_{17} + r_{42} P_{27} + r_{43} P_{37} + P_{47} + r_{45} P_{57}$$
$$r_{57} = r_{51} P_{17} + r_{52} P_{27} + r_{53} P_{37} + r_{54} P_{47} + P_{57}$$

Number of fruits

$$r_{18} = P_{18} + r_{12} P_{28} + r_{13} P_{38} + r_{14} P_{48} + r_{15} P_{58}$$
$$r_{28} = r_{21} P_{18} + P_{28} + r_{23} P_{38} + r_{24} P_{48} + r_{27} P_{58}$$
$$r_{38} = r_{31} P_{18} + r_{32} P_{28} + P_{38} + r_{34} P_{48} + r_{35} P_{58}$$
$$r_{48} = r_{41} P_{18} + r_{42} P_{28} + r_{43} P_{38} + P_{48} + r_{45} P_{58}$$
$$r_{58} = r_{51} P_{18} + r_{52} P_{28} + r_{53} P_{38} + r_{54} P_{48} + P_{58}$$

Character arrangements

1 = plant height
2 = days to flowering
3 = disease incidence
4 = photosynthesis rate
5 = chlorophyll content
6 = fruit length
7 = fruit weight
8 = number of fruits

Effects of second-order components on yield per plant

$$r_{610} = P_{610} + r_{67} P_{710} + r_{68} P_{810}$$
$$r_{710} = r_{76} P_{610} + P_{710} + r_{78} P_{810}$$
$$r_{810} = r_{86} P_{610} + P_{810} + r_{87} P_{710}$$

Character arrangement

6 = fruit length
7 = fruit weight
8 = number of fruits
10 = yield per plant

In the above equations, *r* values are the phenotypic correlations between variables, *P* values are the direct effects (coefficients) of one variable upon another and $r_{ij}P_{ij}$ values are the indirect effects. Cell membrane stability was not included in the first- and second-order analysis as it is considered a secondary parameter and does not seem to influence the yield.

RESULTS

Analysis of variance

All the morpho-physiological characters studied in this experiment showed significant ($P \leq 0.01$) difference among the genotypes except days to flowering, disease incidence and chlorophyll content (Table 1).

Phenotypic and genotypic correlation

A complex association exists among different plant characters and character themselves do not exist in isolation. Yield per plant showed strong and highly significant correlations with most of the characters studied (Table 2) both at the phenotypic and genotypic levels. The correlation coefficients between the characters ranges from 0.230 to 0.564 at the phenotypic level and from 0.161 to 0.722 at the genotypic level, indicating higher magnitudes at genotypic coefficients relative to corresponding estimates of phenotypic coefficients. This demonstrates the high heritability of the traits under study. Yield per plant showed strong, positive and highly significant phenotypic and genotypic associations with fruit length, fruit weight and number of fruits. On the other hand, days to flowering and disease incidence showed a negative association with yield per plant. Moreover, significant correlations among the characters studied were also observed (Table 2).

Direct and indirect effects of morpho-physiological characters on yield per plant

The phenotypic direct and indirect effects of yield-related characters on yield per plant are shown in Fig. 1 and Table 3. Plant height,

Table 1. Analysis of variance (Mean Squares) for 10 characters for the 26 *Capsicum* spp.

Traits	Genotype (df = 25)	Error (df = 50)
Yield	140576**	58345
Plant height	331**	86
Days to flowering	20^NS	13
Disease incidence	177^NS	372
Photosynthesis rate	35**	0
Chlorophyll content	2.09^NS	1.8
Fruit length	15**	2
Fruit weight	62**	4
Number of fruits	5058**	1496
Cell membrane stability	1282**	128

** ($P \leq 0.01$). NS, not significant ($P > 0.05$). df, degree of freedom.

Table 2. Estimates of correlation coefficients at phenotypic and genotypic (indicated in bold) levels among 10 traits in chili pepper genotypes

	PLHH	DF	DI	CPL	PHOTO	FL	FW	NF	YIELD	CMT
PLHH		**0.699^{**}**	**-0.490^{**}**	**NA**	**0.01^{**}**	**-0.028^{**}**	**-0.213^{**}**	**0.223^{NS}**	**0.190^{**}**	**0.388^{NS}**
DF	0.113^{**}		**1^{**}**	**NA**	**1^{**}**	**NA**	**-1^{**}**	**-0.231^{*}**	**-0.673^{**}**	**0.036^{NS}**
DI	-0.024^{NS}	0.150^{NS}		**NA**	**0.229^{**}**	**-0.407^{**}**	**-0.188^{**}**	**-0.223^{**}**	**-0.209^{**}**	**-0.449^{**}**
CPL	-0.248^{NS}	-0.205^{*}	0.117^{NS}		**NA**	**1^{**}**	**NA**	**-0.020^{**}**	**NA**	**NA**
PHOTO	0.126^{NS}	0.036^{NS}	0.057^{NS}	0.071^{NS}		**0.095^{**}**	**0.123^{**}**	**NA**	**NA**	**-0.246^{**}**
FL	-0.132^{**}	-0.365^{NS}	-0.097^{NS}	-0.081^{NS}	-0.084^{NS}		**0.671^{NS}**	**-0.365^{**}**	**0.722^{**}**	**0.262^{**}**
FW	-0.086^{**}	-0.230^{NS}	0.023^{NS}	-0.110^{NS}	-0.049^{NS}	0.774^{**}		**-0.587^{**}**	**0.306^{**}**	**0.207^{**}**
NF	0.153^{**}	-0.188^{NS}	-0.139^{NS}	-0.011^{NS}	0.112^{NS}	-0.057^{NS}	-0.300^{**}		**0.161^{**}**	**0.073^{NS}**
YIELD	0.181^{NS}	-0.356^{**}	-0.136^{NS}	-0.060^{NS}	-0.031^{NS}	0.434^{**}	0.442^{**}	0.564^{**}		**0.350^{**}**
CMT	0.165^{NS}	0.157^{NS}	-0.124^{NS}	-0.114^{NS}	-0.364^{**}	0.103^{NS}	0.075^{NS}	-0.100^{NS}	0.049^{NS}	

$^{*}P \leq 0.05$.
$^{**}P \leq 0.01$. NS, not significant. PLHH, plant height at harvest; DF, days to flowering; DI, disease incidence; CPL, chlorophyll content; PHOTO, photosynthesis rate; FL, fruit length; FW, fruit weight; NF, number of fruits; CMT, cell membrane thermostability.

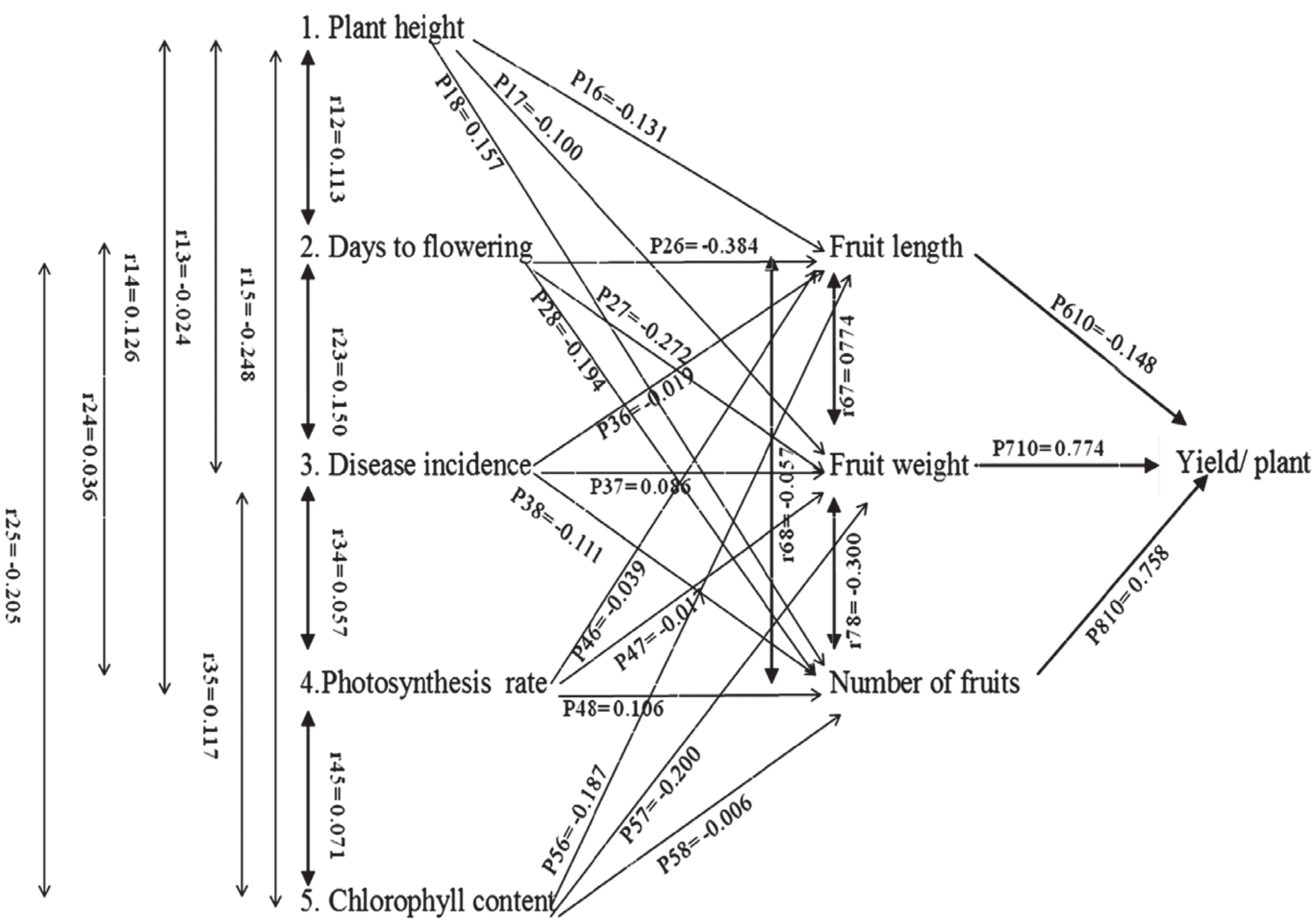

Figure 1. Path diagram and coefficients of factors on the influence of first-order on second-order components and the latter on yield of chili pepper. P_{ij} values are the direct effects. r_{ij} values are the correlation coefficients.

chlorophyll content, fruit weight, number of fruits and cell membrane thermostability indicated positive direct effects on yield per plant. Among these, fruit weight and number fruit showed positive and significant favourable direct effects on yield per plant. Number of days to flowering was significantly and negatively correlated with yield per plant and this was largely a result of its negative direct effect on yield. On the other hand, fruit length showed a negative direct effect on yield per plant; however, its correlation with yield is high and significant. The highest indirect effect on yield per plant was exerted by fruit length through fruit weight (Table 3).

Two-stage relations

First-order components (plant height, days to flowering, disease incidence, photosynthesis rate and chlorophyll content) on fruit weight

Table 3. Phenotypic path analysis of the direct (diagonal) and indirect effects of nine traits on yield per plant in the chili pepper genotypes

	PLHH	DF	DI	PHOTO	CPL	FL	FW	NF	CMT
PLHH	0.140	0.016	−0.003	0.018	−0.035	−0.018	−0.012	0.021	0.023
DF	−0.010	−0.092	−0.014	−0.003	0.019	0.033	0.021	0.017	−0.014
DI	0.001	−0.006	−0.042	−0.002	−0.005	0.004	−0.001	0.006	0.005
PHOTO	−0.012	−0.003	−0.005	−0.092	−0.007	0.008	0.004	−0.010	0.033
CPL	−0.013	−0.011	0.006	0.004	0.053	−0.004	−0.006	−0.001	−0.006
FL	0.020	0.054	0.014	0.012	0.012	−0.148	−0.115	0.008	−0.015
FW	−0.066	−0.178	0.018	−0.038	−0.085	0.599	0.774	−0.232	0.058
NF	0.116	−0.142	−0.105	0.085	−0.008	−0.043	−0.227	0.758	−0.075
CMT	0.007	0.006	−0.005	−0.015	−0.005	0.004	0.003	−0.004	0.040
Correlation with yield	0.181^{NS}	-0.356^{**}	-0.136^{NS}	-0.031^{NS}	-0.060^{NS}	0.434^{**}	0.442^{**}	0.564^{**}	0.049^{NS}

$^{*}P \leq 0.05$.
$^{**}P \leq 0.01$. NS, not significant. PLHH, plant height at harvest; DF, days to flowering; DI, disease incidence; PHOTO, photosynthesis rate; CPL, chlorophyll content; FL, fruit length; FW, fruit weight; NF, number of fruits; CMT, cell membrane thermostability.

The path of influence of these characters on fruit weight is presented in Table 4. Plant height, days to flowering, photosynthesis rate and chlorophyll content had a negative relationship with fruit weight and this was predominantly a result of the negative direct effects of these characters on fruit weight. Among these, only days to flowering showed a significant negative relationship. On the other hand, disease incidence showed a positive relationship with fruit weight.

First-order components (plant height, days to flowering, disease incidence, photosynthesis rate and chlorophyll content) on fruit length

The inter-relationships of plant height, days to flowering, photosynthesis rate and chlorophyll content with fruit length are presented in Table 4. Days to flowering had a significant negative relationship with fruit length and this was largely a result of its negative direct effect on fruit length (Table 5).

First-order components (plant height, days to flowering, disease incidence, photosynthesis rate and chlorophyll content) on number of fruits

The path analysis of the first-order components on number of fruits is presented in Table 6. The positive and negative relationships between the components and the number of fruits were not found to be statistically significant (Table 6).

Second-order (fruit length, fruit weight and number of fruits) on yield per plant

The effects of second-order components on yield per plant are shown in Fig. 1 and Table 7. The negative direct effect of fruit length on yield was low and this might be attributed to the high positive indirect effect of fruit length on yield through fruit weight. However, a highly positive correlation between fruit length and yield was observed (Table 7). Fruit weight and number of fruits were significantly and positively highly correlated with yield per plant (Table 7) and this was mainly a result of the high direct effects of fruit weight and number on yield per plant.

Table 4. Relationship between first-order components with fruit weight (FW)

Plant height		
	Direct effects on FW	**−0.100**
	Indirect effects through DF	−0.031
	Indirect effects through DI	−0.002
	Indirect effects through PHOTO	−0.002
	Indirect effects through CPL	0.049
	Correlation with FW	-0.086^{NS}
Days to flowering		
	Direct effects on FW	**−0.272**
	Indirect effects through PLHH	−0.011
	Indirect effects through DI	0.013
	Indirect effects through PHOTO	−0.001
	Indirect Effects through CPL	0.041
	Correlation with FW	−0.230*
Disease incidence		
	Direct effects on FW	**0.086**
	Indirect effects through PLHH	0.002
	Indirect effects through DF	−0.041
	Indirect effects through PHOTO	−0.001
	Indirect effects through CPL	−0.023
	Correlation with FW	0.023^{NS}
Photosynthesis rate		
	Direct effects on FW	**−0.017**
	Indirect effects through PLHH	−0.013
	Indirect effects through DF	−0.001
	Indirect effects through DI	0.005
	Indirect effects through CPL	−0.014
	Correlation with FW	-0.049^{NS}
Chlorophyll content		
	Direct effects on FW	**−0.200**
	Indirect effects through PLHH	0.025
	Indirect effects through DF	0.056
	Indirect effects through DI	0.010
	Indirect effects through PHOTO	−0.001
	Correlation with FW	-0.110^{NS}

PLHH, plant height at harvest; DF, days to flowering; DI, disease incidence; PHOTO, photosynthesis rate; CPL, chlorophyll content; FW, fruit weight.

DISCUSSION

A complex association exists among different plant characters (variables) and character themselves do not exist in isolation.[10] Yield is expressed as a complex character in *C. annuum* L. as in other crops, because its influenced by a number of yield contributing components [15] Yield is influenced considerably by the interaction of several factors that are directly or indirectly related to

Table 5. First-order components on fruit length

Plant height		
	Direct effects on FL	**−0.131**
	Indirect effects through DF	−0.043
	Indirect effects through DI	0.001
	Indirect effects through PHOTO	−0.005
	Indirect effects through CPL	0.046
	Correlation with FL	−0.132NS
Days to flowering		
	Direct effects on FL	**−0.384**
	Indirect effects through PLHH	−0.015
	Indirect effects through DI	−0.003
	Indirect effects through PHOTO	−0.001
	Indirect effects through CPL	0.038
	Correlation with FL	−0.365**
Disease incidence		
	Direct effects on FL	**−0.019**
	Indirect effects through PLHH	0.003
	Indirect effects through DF	−0.058
	Indirect effects through PHOTO	−0.002
	Indirect effects through CPL	−0.022
	Correlation with FL	−0.097NS
Photosynthesis rate		
	Direct effects on FL	**−0.039**
	Indirect effects through PLHH	−0.016
	Indirect effects through DF	−0.014
	Indirect effects through DI	−0.001
	Indirect effects through CPL	−0.013
	Correlation with FL	−0.084NS
Chlorophyll content		
	Direct effects on FL	**−0.187**
	Indirect effects through PLHH	0.032
	Indirect effects through DF	0.079
	Indirect effects through DI	−0.002
	Indirect effects through PLHH	−0.003
	Correlation with FL	−0.081NS

PLHH, plant height at harvest; DF, days to flowering; DI, disease incidence; PHOTO, photosynthesis rate; CPL, chlorophyll content; FL, fruit length.

Table 6. First-order components on number of fruit

Plant height		
	Direct effects on NF	**0.157**
	Indirect effects through DF	−0.022
	Indirect effects through DI	0.003
	Indirect effects through PHOTO	0.013
	Indirect effects through CPL	0.001
	Correlation with NF	0.152NS
Days to flowering		
	Direct effects on NF	**−0.194**
	Indirect effects through PLHH	0.018
	Indirect effects through DI	−0.017
	Indirect effects through PHOTO	0.004
	Indirect effects through CPL	0.001
	Correlation with NF	−0.188NS
Disease incidence		
	Direct effects on NF	**−0.111**
	Indirect effects through PLHH	−0.004
	Indirect effects through DF	−0.029
	Indirect effects through PHOTO	0.006
	Indirect effects through CPL	−0.001
	Correlation with NF	−0.139NS
Photosynthesis rate		
	Direct effects on NF	**0.106**
	Indirect effects through PLHH	0.020
	Indirect effects through DF	−0.007
	Indirect effects through DI	−0.006
	Indirect effects through CPL	−0.001
	Correlation with NF	0.112NS
Chlorophyll content		
	Direct effects on NF	**−0.006**
	Indirect effects through PLHH	−0.039
	Indirect effects through DF	0.040
	Indirect effects through DI	−0.013
	Indirect effects through PHOTO	0.008
	Correlation with NF	−0.011NS

PLHH, plant height at harvest; NF, number of fruits; DF, days to flowering; DI, disease incidence; PHOTO, photosynthesis rate; CPL, chlorophyll content.

it.[16] A significant strong positive correlation exists between all the studied characters with yield except disease incidence and days to flowering, which showed a negative correlation at the genetic level, indicating the usefulness of these characters for improving yield per plant in chili peppers. The genetic coefficients were higher in magnitude relative to corresponding estimates of phenotypic coefficients and this might be a result of the masking effect of the environment causing differential phenotypic and genotypic expression of these characters. This indicates that selection for yield improvement among the chili genotypes could be effective because any variation is mainly a result of the genetic effect, with little influence originating from the environment. This was supported by the results of a previous study by Ajjapplavara *et al*.[10] The significant association of plant height with yield could be justified by the increases in number of fruits as a result of a greater number of branches per plant leading to high total yield per plant. This work is in agreement with the findings of Ajjapplavara *et al*.[10] and Jabeen *et al*.[16] who observed a significant correlation of various yield attributing characters with yield per plant. Fruit length and weight show a strong and positive association, which suggested that an increase in fruit length could lead to a significant increase in weight of fruit, thereby increasing total fruit yield per plant. Significant positive correlations were reported previously.[17,18] Similarly, the negative relationship of disease incidence with yield might explain the reduction in yield as a result of disease infection. This clearly indicates that, as the disease incidence increases, it delays the days to flowering and consequently reduces the yield per plant.[10,19] Various factors have been advocated in contributing to negative relationships among plants components, including competition for ambient resources, such as nutrient, moisture and light, as well as genetic factors, such as linkage and pleiotropy.[11]

Despite the present study revealing a significant inter-relationship among various yield components, the component characters define the limit of yield not only by their direct effects, but also by their indirect effects as a result of inter-relationships between them. Therefore, path coefficient analysis investigates the direct and indirect relationships among the component characters through the partitioning of correlation

Table 7. Second-order component on yield per plant

Fruit length		
	Direct effects on yield	**−0.113**
	Indirect effects on FW	0.592
	Indirect effects on NF	−0.045
	Correlation with yield	0.434**
Fruit weight		
	Direct effects on yield	**0.765**
	Indirect effects on FL	−0.088
	Indirect effects on NF	−0.236
	Correlation with yield	0.442**
Number of fruits		
	Direct effects on yield	**0.787**
	Indirect effects on FL	0.006
	Indirect effects on FW	−0.230
	Correlation with yield	0.564**

FL, fruit length; FW, fruit weight; NF, number of fruits.

coefficients.[18] Path analysis revealed that the maximum direct effect on fruit yield/plant was exerted by average fruit weight followed by number of fruits/plant, whereas the maximum indirect effect on fruit yield/plant was exerted by fruit length through fruit weight. These characters can be used to develop an optimally reliable selection index for realizing improvements in fruit yield in chili. Similar results have been reported by Jabeen *et al.*[16] and Sabina and Singh.[20] Heavy fruits per plant had the maximum positive direct effect on yield followed by number of fruits per plant, whereas longer fruits had minimum negative direct effect, which was counter balanced by its positive direct effect via fruit weight. The conclusion agreed with the study by Islam *et al.*[5]

Component compensation was noted in the relationships among fruit length, fruit weight and yield per plant of the chili pepper. Thus, the negative direct effect of fruit length on yield was a result of the sacrificial and unfavourable indirect influence through fruit weight. However, when a character had a positive relationship and a high positive indirect effect but a negative direct effect, such as in fruit length, emphasis should be given to the indirect effects and thus indirect causal factors are to be considered simultaneously for selection. Similar observations were reported by Sabina and Singh[20] and Tulu.[7] The results suggest that, if fruit length was to be held constant, increased fruit weight would increase yield per plant of chili.

The present study suggests that late flowering has a detrimental effect on yield per plant of chili pepper in the environment of investigation. In areas where chilies are grown under rain shelter, earlier flowering confers an advantage of forming more fruits and consequently higher yields. This is in contrast the findings of Islam *et al.*[5] who reported that early genotypes are less yielder. Early fruit set may cause plants to use assimilates for reproductive growth at the expense of vegetative growth, thereby reducing yield. Similar results were reported previously.[21,22] Fruit length revealed a non-significant genetic association with fruit weight, whereas it was positive and significant with fruit yield per plant. This indicates that chili pepper fruits first increase in length and gain in diameter and flesh thickness is achieved subsequently.[5]

Genetic improvement for a greater number of fruits should be accompanied by optimum management practices that minimize adverse relationships among components of yield to realize the benefits of genetic manipulations.[22] Crossing, selfing and selection among segregates may break unfavourable linkages, resulting in offspring combining genes for higher number of fruits and a fruits with higher weight.[23] The significant positive relationships among the number of fruits and fruit weight suggest that these characters are influenced by similar physiological and genetic patterns and that simultaneous selection for them can be achieved in a breeding programme. The investigation revealed considerable amount of variation for the characters studied.[24] Such wide variations indicated the scope for improving the genotypes for these characters with respect to heat tolerance (CMT) and morpho-physiological characters.

CONCLUSIONS

The results of the present study indicate that fruit length, fruit weight and number of fruits should be considered during the selection process in chili pepper crops because these characters contribute directly towards high yields per plant. Breeders in these areas should therefore develop early maturing genotypes with fruit length and weight of chili pepper that can produce a high number of fruits for improving the fruit yield per plant under rain shelters. However, programmes should also aim to develop genotypes producing appropriate amounts of fruits for the production of an optimum yield. Research is needed to investigate husbandry practices that minimize component compensation effects for realizing higher yields of chili pepper.

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