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PATH ANALYSIS OF THE RELATIONSHIPS BETWEEN FRUIT YIELD AND SOME YIELD COMPONENTS IN PAPAYA (*Carica papaya* L.)

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ABSTRACT
Path analysis was performed on plant and fruit characters of twenty four papaya genotypes grown in a two year field experiment to determine for fruit yield, the direct and indirect effects of the various yield contributing traits. Fruit yield per plant was positively and significantly correlated with plant girth (0.44, 0.43), number of fruits per plant (0.89, 0.89) and average fruit weight (0.59,0.57) at both genotypic and phenotypic levels, respectively. Path analysis showed that canopy spread (N-S), had the highest positive and significant direct effect (1.83) on fruit yield followed by days to first flowering (1.40), number of fruits per plant (0.94), plant height (0.50) and average fruit weight (0.46). The significant positive correlation coefficients of number of fruits per plant and average fruit weight with fruit yield were resulted mainly from high and positive direct effects of these traits with fruit yield suggesting direct selection would be rewarding whereas for the character days to first flowering for which correlation coefficient was negative (0.02,0.02) but the direct effect was positive and significant, a restricted simultaneous selection model is to be followed. For the character like plant girth, the indirect causal factors are to be considered simultaneously for selection.

INTRODUCTION

Papaya (*Carica papaya* L.), family Caricaceae, also known as papaw or paw paw in Australia, mamao in Brazil and tree melon in China, is native to Southern Mexico and Central America, but has long been known and cultivated in the home gardens of people in tropical and sub-tropical areas world-wide for its large, sweet, melon-like fruits. Ripe papaya is used to make fruit salads, refreshing drinks, jam, jelly, and candies. Green fruits are cooked as vegetable and are also used in the preparation of tutti-frutti. It is rich in a number of nutrients and antioxidants and has a high medicinal value. Papain is tapped from green fruits which has industrial use. India, Brazil, Indonesia, Mexico and Nigeria are the leading papaya growing countries. In India, papaya was introduced in early part of 16th century from Philippines through Malaysia and slowly spread to different parts of the country. India is the largest producer of papaya in the world covering an area of 0.122 mh with an annual production of 4.68Mt (accounting for 42% of the world production) with the productivity of 39.6 t/h (Horticulture Statistics Division, 2016-17). Out of six genera (*Carica, Jacaratia, Jarilla, Horovitzia, Cylicomorpha and Vasconcellea*) of the family Caricaceae reported, *Carica papaya* is the only species within the genus *Carica* (Badillo, 2000), which is cultivated in India. Lack of variety having precocity, high yield potentiality, good adaptability under subtropical condition along with low level of resistance to virus and other diseases are the main hindrance for its expansion of cultivation (Oliveira *et al.*,2015; Silva *et al.*, 2016). The search for new genotypes is facilitated when the relationships among characters used in selection are known, especially when the variable of interest is polygenic.

Plant breeding may alleviate the deficiency in papaya production by developing varieties yielding higher under the different ecological conditions prevailing in the country. For that purpose, superior varieties must be developed by selection among and within populations that have very rich variations in important agronomic traits. The success of selection depends on the choice of selection criteria for improving fruit yield. Yield components do not only directly affect the yield, but also indirectly by affecting other yield components in negative or positive ways. As a trait can affect another trait positively, it can affect some other or all traits negatively (Walton,1980). For that reason, it is clear that correlation coefficient, which measures the simple linear relationship between two traits, does not alone predict the success of selection. Correlation studies along with path analysis provide a better understanding of the association of different characters with yield. Path analysis is a standardized partial regression coefficient measuring the direct influence of one variable upon the other and permits separation of correlation coefficient into components of direct and indirect effects (Bhatt, 1973). Path analysis has been used to define the best criteria for selection in biological and agronomic studies (Mishra and Drolsom, 1975; Williams *et al.,* 1990). Correlation and path coefficient could be necessary tools at the disposal of the breeder (Salahuddin *et al.*, 2010) in papaya improvement programme

for enhancing the production and productivity. Although reports on correlation among different characters and information on direct and indirect effect of different characters on papaya are scanty, similar types of works were carried out in papaya by Dash *et al*. (2000), Magdalita *et al*. (1984), Jana *et al*. (2006) and Jambhale *et al*. (2014). The present investigation was, therefore, undertaken with an objective to determine the nature of association of different characters through correlation and path coefficient analysis with the expectation that the result might be of practical use to the plant breeders to achieve the desired level of yield improvement in this crop.

MATERIALS AND METHODS

The field experiments were carried out at Horticulture Research Station, Mondouri, Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal(23.5ºN latitude and 89ºE; and 9.75 masl). Topographic situation of the experimental site comes under Gangetic new alluvial plains of West Bengal. The soil is sandy loam in texture with pH = 6.5. Twenty four diverse papaya genotypes including released varieties, breeding lines, indigenous cultivars and two different species other than *Carica papaya* collected from different parts of the country and abroad constituted the plant materials for the present study. The list of genotypes along with source included has been furnished in Table 1.

Seedling of papaya genotypes were raised in 2m x 1m seed bed, prepared by thorough pulverizing the soil. The 45 days old seedlings were transplanted in the main field at 2x2 m distance and the crop was maintained for two years. The population included male, female, gynodioecious plants as per the sex form of the respective genotype. The experiments were arranged in a randomized complete block design with three replications keeping plant spacing in the plot 2.0 x 2.0 m. Proper agronomic practices and plant protection measures were taken during the experiment. Observations were recorded on five random productive plants per treatment (possessing female and gynodioecious sex form excluding male form) regarding vegetative characters till flowering. Data on various quantitative characters *viz*. plant height (cm), plant girth (cm), leaves at first flowering, height at first flowering (cm), girth at first flowering (cm), nodes at first flowering, petiole length (cm), leaf blade length (cm), leaf blade width (cm), canopy spread (E-W and N-S) (cm), days to first flowering, days to first fruiting, first fruit height (cm), days to first harvest, fruits per plant (first year and second year), average fruit weight (g) (first year and second year) and yield per plant (kg) (first year and second year), were recorded.

Data collected during two growing seasons on these quantitative characters were pooled and correlation (phenotypic and genotypic) was performed as suggested by Al. Jibouri *et al*. (1958). The relative importance of direct and indirect effects of measured traits on fruits yield was determined by path analysis following the method as suggested Dewey and Lu (1959). In the path analysis, fruit yield was the dependent variable and the rest parameters (mentioned above) were considered as independent variables.

RESULTS AND DISCUSSION

There exists a large variation among the germplasm collections of papaya in the fruit yield. The variation, however, has remained unexplored due to lack of information on the relationships between component traits and their contribution towards yield. Information on correlation and path coefficients estimates of yield and yield contributing characters is very much important to define selection criteria for developing high yielding varieties including hybrids. Most former studies concentrated on small number of traits, but in this study, morphological and phenological traits have been investigated simultaneously.

An estimate of genotypic and phenotypic correlation coefficients among different pairs of characters of papaya is presented in Table 2. A perusal of Table 2 showed that out of 153 correlation coefficient between two different characters, 22 at genotypic and phenotypic level, 5 at genotypic level only were noted to be significant either at 5% or 1% level of significance. The data revealed that the fruit yield per plant (kg) was positively and significantly correlated with fruits per plant (r_g = 0.89 and r_p = 0.89), average fruit weight (r_g = 0.59 and r_p = 0.57) and plant girth (r_g = 0.44 and r_p = 0.43), at both genotypic and phenotypic levels indicating the importance of these characters for yield improvement. The results were in agreement with Cynthia *et al*. (2000), Jana *et al*. (2006), Singh and Kumar (2010) , Jambhale *et al*. (2014) and Wegayehu *et al*. (2016), for yield per plant with numbers of fruits per plant; Ghanta and Mondal (1992) and Dwivedi *et al*. (1995) for yield per plant with plant girth, while Auxcilia and Sathiamoorthy (1996), Cynthia *et al*. (2000), Jana *et al*. (2006) and Jambhale *et al*. (2014) reported significant positive association between yield per plant with fruit weight. Fruit yield per plant was found to be positively correlated with almost all other characters under study, except petiole length, leaf

Table 1: Name and source of papaya genotypes utilized in the investigation

Name of genotype	Source
Sel 42 ABF_1, Sel 42ACF_1	South Africa
Pusa Dwarf, PAU Selection , Bangalore Dwarf, Pusa Delicious, Shillong, Farm Selection.	IARI Regional Station, Pusa, Samastipur, Bihar.
CO2, CO5, CO7, Surya, *Carica cauliflora, Carica goudotiana*.	IIHR, Bangalore
CO3, CO6.	TANU, Coimbatore
Red Lady	Nanhems Seeds, Pune.
Local Selection-1, Local Selection- 2	Elite plant collected from Gayeshpur Farm of B.C.K.V
Coorg Honey Dew, KNR Selection, PusaNanha	KVK, Sonamukhi, Bankura,West Bengal.
Ranchi Selection	Birsa Agricultural University, Kanke, Ranchi, Jharkhand.
Thailand Papaya	Thailand.

Table 2: Genotypic (G) and Phenotypic (P) correlation coefficient of seventeen quantitative characters in papaya genotypes

Character		Plant girth (cm)	Height at first flowe ring(cm)	Girth at first flower ing(cm)	Leaves at first flowe ring	Nodes at first flower	Petiole length (cm)	Leaf blade length (cm)	Leaf blade width (cm)
Plant height(cm)	G	0.24	0.68**	0.36	0.3	0.90**	-0.01	0.38	-0.26
	P	0.23	0.63**	0.35	0.08	0.4	-0.01	0.36	-0.25
Plant girth(cm)	G		0.41	0.78**	0.18	0.07	0.45*	0.1	0.25
	P		0.39	0.76**	0.05	0.02	0.44*	0.09	0.24
Height at first flowering (cm)	G			0.62**	0.22	0.61**	0.15	0.08	-0.14
	P			0.59**	0.03	0.28	0.14	0.07	-0.13
Girth at first flowering(cm)	G				0.29	0.32	0.41	0.13	0.11
	P				0.08	0.15	0.4	0.13	0.11
Leaves at first	G					0.32	0.1	-0.36	-0.23
flowering	P					0.05	0.02	-0.08	-0.07
Nodes at first	G						-0.21	0.07	-0.55**
flowering	P						-0.1	0.02	-0.25
Petiole	G							0.43*	0.83**
length (cm)	P							0.42	0.82**
Leaf blade	G								0.54**
length (cm)	P								0.51*
Leaf blade	G								
width (cm)	P								
Canopy spread (cm)	G								
(E-W)	P								
Canopy spread (cm)	G								
(N-S)	P								
Days to first	G								
flowering	P								
Days to first	G								
fruit set	P								
First fruit	G								
height (cm)	P								
Days to first	G								
harvest	P								
Fruits/plant	G								
	P								
Average fruit weight (g)	G								
	P								

blade width, days to first flowering, days to first fruit set and days to first harvest. The results were in agreement with Ghanta and Mondal (1992), Dwivedi *et al*. (1995) and Singh and Kumar (2010). Significant and positive correlation was found in days to first fruit set with days to first flowering; canopy spread at both directions (E-W and N-S) with plant girth, petiole length, leaf blade length and leaf blade width

Days to first flowering, days to first fruit set and days to first harvest were negatively correlated with average fruit weight. Therefore, early flowering and early fruit setting genotypes results big size fruit and were comparatively high yielder. The results are in agreement with Jana *et al*. (2006), Karunakaran *et al*. (2010), Kumar *et al*. (2013), Arunkumar (2014) and Jambhale *et al*. (2014).

When we select characters having direct bearing on yield, their associations with other characters also need to be considered simultaneously as this will indirectly affect yield. Positive correlation at both phenotypic and genotypic levels were noted in case of plant height with plant girth, height at first flowering, girth at first flowering, leaves at first flowering, nodes at first flowering, leaf blade length, canopy spread (E-W, N-S), first fruiting height, fruits per plant and average fruit weight. Positive correlation at both phenotypic and genotypic levels was observed in case of plant girth with all the characters. Hence selection based on plant girth will have maximum bearing on yield.

The results of correlation coefficient in the present investigation, implies that fruits per plant, average fruit weight, plant girth along with days to first flowering, days to first fruit set should be taken into consideration while going for selection for yield improvement in papaya.

In the present investigation, in general the genotypic and phenotypic correlations showed similar trend but genotypic correlation were at higher magnitude than phenotypic correlation in most of the cases. Very close values of genotypic and phenotypic correlation were also observed between some character combinations which might be due to reduction in error (environmental) variance to minor proportions as reported by Dewey and Lu (1959). Wide difference between genotypic and phenotypic correlations between two characters is due to dual nature of phenotypic correlation, which is determined by genotypic and environmental correlation, and heritabilities of the character (Falconer, 1960).

The correlation coefficient becomes more evident when genotypic correlations are partitioned into its components through path analysis in order to determine the relative

Table 2 : continued...

Character	Canopy spread (cm) (E-W)	(N-S)	Days to first flowering	Days to first fruit set	first fruit height	Days to first harvest	Fruits plant	Average fruit weight (g)	Yield/ /plant (kg)
Plant height(cm)	0.11	0.11	-0.23	-0.32	0.58**	-0.1	0.2	0.29	0.27
	0.1	0.11	-0.22	-0.3	0.56**	-0.09	0.19	0.27	0.25
Plant girth(cm)	0.47*	0.50*	0.24	0.19	0.13	0.16	0.34	0.35	0.44*
	0.46*	0.49*	0.23	0.19	0.12	0.16	0.33	0.34	0.43*
Height at first flowering (cm)	0.16	0.19	0.27	0.15	0.68**	-0.05	0.11	0.08	0.06
	0.15	0.18	0.26	0.14	0.64**	-0.04	0.1	0.07	0.07
Girth at first flowering(cm)	0.41	0.45*	0.09	0.03	0.15	-0.07	0.15	0.38	0.28
	0.4	0.44*	0.09	0.03	0.15	-0.06	0.13	0.36	0.26
Leaves at first	0.11	0.12	-0.12	-0.17	-0.03	-0.35	0.23	0.12	0.29
flowering	0.03	0.03	-0.02	-0.04	-0.01	-0.08	0.12	0.03	0.11
Nodes at first	-0.08	-0.09	-0.18	-0.26	0.50*	-0.12	0.03	0.04	0.05
flowering	-0.03	-0.04	-0.08	-0.12	0.22	-0.04	0.02	0.01	0.02
Petiole	0.96**	0.97**	0.09	0.14	0.13	0.08	-0.11	-0.01	-0.04
length (cm)	0.96**	0.96**	0.09	0.14	0.12	0.08	-0.11	-0.01	-0.04
Leaf blade	0.55**	0.56**	-0.33	-0.3	0.25	0.09	0.11	0.34	0.25
length (cm)	0.54**	0.54**	-0.31	-0.29	0.23	0.09	0.1	0.32	0.23
Leaf blade	0.78**	0.80**	0.03	0.12	-0.09	0.25	-0.17	0.01	-0.1
width (cm)	0.77**	0.79**	0.03	0.12	-0.08	0.24	-0.16	0.01	-0.1
Canopy spread (cm)		0.99**	0.07	0.11	0.19	0.13	-0.07	0.05	0.02
(E-W)		0.99**	0.07	0.11	0.18	0.13	-0.07	0.05	0.02
Canopy spread (cm)			0.05	0.09	0.18	0.14	-0.06	0.07	0.03
(N-S)			0.05	0.08	0.17	0.14	-0.06	0.07	0.03
Days to first				0.98**	0.38	0.29	0.05	-0.12	-0.02
flowering				0.98**	0.36	0.29	0.05	-0.12	-0.02
Days to first					0.31	0.32	0.01	-0.1	-0.05
fruit set					0.3	0.32	0.01	-0.1	-0.05
First fruit						0.09	0.08	0.13	0.09
height (cm)						0.07	0.07	0.11	0.08
Days to first							-0.03	-0.1	-0.12
harvest							-0.02	-0.1	-0.11
Fruits/plant								0.23	0.89**
								0.19	0.89**
Average fruit weight (g)									0.59**
									0.57**

***Significant at 5%level **Significant at 1% level**

contribution of various attributes towards correlation. Path coefficient provides an effective means of entangling direct and indirect causes of association and measures the relative importance of each causal factor. Partitioning of total correlation into direct and indirect effect would be worthwhile for effective selection programme.

Shrivastava and Sharma (1976) suggested that the only direct yield components should be used for path analysis. The results of the path analysis have been presented in Table 3. Among the seventeen yield components studied in path analysis, positive direct effect on fruit yield were noted for nine characters, out of which four characters *viz*., canopy spread (N-S), days to first flowering, fruits per plant, plant height and average fruit weight had high direct values (1.83, 1.40, 0.94 and 0.50, respectively) while the same was moderate for average fruit weight (0.47), leaf blade width (0.31) and girth at first flowering (0.29).

Negative direct values were noted for seven characters *viz*., days to first fruit set (-1.27), canopy spread (E-W) (-1.04), height at first flowering (-0.67), leaf blade length (-0.62), petiole length (-0.45), plant girth (-0.37), leaves at first flowering (-0.31) and days to harvest (-0.16).

The main effect (1.83) of canopy spread (N-S) showed very low magnitude of genotypic correlation (0.03) with yield and this reduction was due to cancellation through negative indirect effect via canopy spread (E-W) (-1.03), petiole length (-0.44) and leaf blade length (-0.34).

The main effect of days to first flowering was negatively correlated and resulted mainly from the negative indirect effect *via* days to first fruit set, plant height, plant girth *etc*., whereas the main effects of number of fruits per plant itself explained its significant positive correlation with fruit yield. Similarly direct effect of average fruit weight on fruit yield could be the main reason for its positive and significant correlation with fruit yield.

The results, thus, indicate that direct selection of these traits would be rewarding at least for the present situation.Plant height, having positive direct effect (0.501), showed positive but non-significant correlation(0.27) with fruit yield resulting due to negative indirect effects *via*, among other characters, mainly from height at first flowering(-0.46), leaf blade length(-0.24) and days to first flowering (-0.33) emphasizing that plant height would be one of the important components in selection for higher yield.

Plant girth had negative direct effect on fruit yield, but due to high positive indirect effects mainly through canopy spread (N-S) and days to first flowering the correlation was significantly

Table 3: Genotypic path coefficient of seventeen quantitative characters on fruit yield in papaya genotypes

Characters	Plant height (cm)	Plant girth (cm)	Height at first flowering (cm)	Girth at first flowe ring(cm)	Leaves at first flowering	Nodes a t first flowering	Petiole length (cm)	Leaf blade length (cm)	Leaf blade width (cm)	Canopy spread (cm) (E-W)	Canopy spread (cm) (N-S)	Days to first flowering	Days to first fruit set	First fruit height (cm)	Days to first harvest	Fruits /plant	Average fruit weight (g)	Correlation with fruit yield
Plant height (cm)	0.501*	-0.09	-0.459*	0.104	-0.091	0.043	0.006	-0.236	-0.08	-0.11	0.21	-0.326	0.402	0.05	0.016	0.19	0.137	0.27
Plant girth (cm)	0.12	-0.376	-0.28	0.227	-0.057	0.003	-0.202	-0.06	0.077	-0.48*	0.91**	0.334	-0.242	0.011	-0.027	0.323	0.163	0.44*
Height at first flowering (cm)	0.34	-0.156	-0.676**	0.181	-0.069	0.029	-0.068	-0.05	-0.044	-0.17	0.35	0.382	-0.189	0.059	0.008	0.101	0.039	0.06
Girth at first flowering (cm)	0.18	-0.294	-0.423*	0.29	-0.088	0.015	-0.187	-0.081	0.035	-0.430*	0.83**	0.13	-0.044	0.013	0.011	0.139	0.179	0.28
Leaves at first flowering	0.149	-0.069	-0.151	0.083	-0.308	0.015	-0.047	0.223	-0.071	-0.115	0.21	-0.168	0.21	-0.003	0.058	0.214	0.056	0.29
Nodes at first flowering	0.452	-0.026	-0.412	0.092	-0.098	0.047	0.096	-0.042	-0.172	0.086	-0.17	-0.249	0.333	0.043	0.02	0.029	0.018	0.05
Petiole length (cm)	-0.007	-0.168	-0.102	0.12	-0.032	-0.01	-0.452*	-0.267	0.26	-0.99**	1.77**	0.132	-0.179	0.011	-0.013	-0.107	-0.003	-0.04
Leaf blade length (cm)	0.191	-0.037	-0.055	0.038	0.111	0.003	-0.196	-0.617**	0.167	-0.57**	1.02**	-0.461*	0.38	0.021	-0.015	0.099	0.161	0.25
Leaf blade width (cm)	-0.128	-0.093	0.095	0.033	0.07	-0.026	-0.375	-0.331	0.313	-0.81**	1.46**	0.04	-0.155	-0.007	-0.041	-0.157	0.005	-0.1
Canopy Spread (E-W)	0.053	-0.175	-0.111	0.12	-0.034	-0.004	-0.434*	-0.339	0.243	-1.04**	1.82**	0.103	-0.141	0.016	-0.021	-0.067	0.022	0.02
Canopy Spread (N-S)	0.057	-0.187	-0.129	0.132	-0.035	-0.004	-0.437*	-0.345	0.249	-1.03**	1.83**	0.065	-0.108	0.015	-0.023	-0.057	0.034	0.03
Days to first flowering	-0.116	-0.089	-0.184	0.027	0.037	-0.008	-0.043	0.203	0.009	-0.07	0.08	1.402**	-1.245**	0.033	-0.049	0.051	-0.055	-0.02
Days to first fruit set	-0.159	-0.072	-0.101	0.01	0.051	-0.012	-0.064	0.185	0.038	-0.12	0.15	1.375**	-1.270**	0.027	-0.054	0.006	-0.048	-0.05
First fruit height (cm)	0.291	-0.048	-0.460*	0.044	0.01	0.024	-0.059	-0.154	-0.027	-0.2	0.32	0.536*	-0.4	0.086	-0.015	0.08	0.059	0.09
Days to first harvest	-0.05	-0.06	0.031	-0.02	0.108	-0.006	-0.036	-0.055	0.077	-0.13	0.25	0.412	-0.412	0.008	-0.166	-0.024	-0.048	-0.12
Fruits/plant	0.101	-0.129	-0.073	0.043	-0.07	0.001	0.052	-0.065	-0.052	0.07	-0.11	0.076	-0.009	0.007	0.004	0.940**	0.106	0.89**
Average fruit weight (g)	0.147	-0.131	-0.056	0.111	-0.037	0.002	0.003	-0.212	0.003	-0.05	0.13	-0.163	0.13	0.011	0.017	0.212	0.468*	0.59**

Residual effect = 0.195 ; Diagonal values (Bold) indicate direct effect ; * Significant at 5% level, ** Significant at 1% level

positive. So for the character like plant girth, the indirect causal factors are to be considered simultaneously for selection, since indirect effects seem to be the cause of correlation.

The results were in conformity with Cynthia *et al*. (2000), Singh *et al*. (2001), Jana *et al*. (2006), Oliver *et al*. (2010) and Jambhale *et al*. (2014) for fruits per plant on yield; Cynthia *et al*. (2000) for fruit weight on yield; whereas Jana *et al*. (2006) reported negative direct effect of fruit weight on yield which was contradictory with the present findings. The result was in agreement with Jana *et al*. (2006) and Jambhale *et al*. (2014) for negative direct effect of plant height on yield.

For the characters like number of fruits per plant and average fruit weight, direct selection would be rewarding whereas for the character days to first flowering for which correlation coefficient was negative but the direct effect was positive, a restricted simultaneous selection model is to be followed, *i.e.* restrictions are to be imposed to nullify the undesirable indirect effects *viz.,* plant height in order to make use of the direct effect (Singh *et al*., 2001).

The residual effect (0.19) indicated that all the seventeen characters included in this study explain moderate to high percentage of variation in fruit yield in this population. Moreover, majority of the values of path coefficients are less than unity indicating that inflation due to multi-colinearity is minimal (Gravois and Helms, 1992).

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