

## Identification of field assayable surrogate traits to aid indirect selection for green fruit yield in chilli (*Capsicum annuum* L.)

**C.B. Siddu\*, Channabasava, P. Ganesh, B. Susmitha, M.P. Kalpana, A. Mohan Rao and S. Ramesh**

Department of Genetics and Plant Breeding, University of Agricultural Sciences, GKVK, Bengaluru - 560065, Karnataka, India. \*E-mail: [siddubc16@gmail.com](mailto:siddubc16@gmail.com)

### Abstract

As is true in other crops, selection for quantitative traits such as fruit yield is less effective in chilli, as it is a quantitatively inherited trait controlled by a large number of genes with a large genotype-by-environment interaction. Furthermore, assessing fruit yield is a laborious and time-consuming process based on destructive sampling. The identification of non-destructive, field-assayable proxy or surrogate traits is most likely to enhance the effectiveness of selection for fruit yield. The proxy traits should not only be highly correlated with fruit yield but also be highly heritable. Under these premises, the present study aimed to identify field-assayable, highly heritable traits with a significant correlation with green fruit yield. Sixteen diverse chilli genotypes were used to develop ten eight-parent multi-parent (MP) populations. These populations were evaluated in experimental plots at the University of Agricultural Sciences (UAS), Bangalore. The data were recorded on six quantitative traits, namely plant height, fruit length, fruit width, average fruit weight, fruit yield per plant, and green fruit yield per plant. The correlation coefficients of the five traits with green fruit yield per plant were estimated. Results showed considerable genetic variability in all the populations for fruits plant<sup>-1</sup>, average fruit weight, and green fruit yield plant<sup>-1</sup>. These traits were also highly heritable with high expected genetic advance. However, two of these traits, namely plant height and fruit yield, were significantly correlated with a high magnitude. These two traits, being easily assayed in the field without destructive sampling, could be reliably used as proxies for fruit yield per plant in chilli.

**Key words:** Multi-parent populations, selection, quantitative traits, proxy traits, coefficient of variation

### Introduction

Hot pepper is one of the most important economic spices-cum-vegetable crop worldwide (Poulos, 1992). In India it has great export potential contributing 42 % of the total spice export to various countries like China, Vietnam, Thailand, Sri Lanka, Indonesia and Malaysia (Anonymous, 2022). Being a high value commercial crop (Dewitt and Bosland, 1993), chilli offer immense benefits for smallholders, significantly increasing family income and socio-economic status (Weinberger and Lumpkin, 2007). Chilli is cultivated throughout the world for its economic and nutritional importance. It became an essential component of human diet because of culinary and medicinal qualities. For convenience, the utility and consumption patterns were classified into seven types. These are, culinary purpose (green and dried chilli), snacks preparations, natural color extraction, sauce preparation, pharmaceutical active ingredient extraction and as ornamental plants (Ambrose *et al.*, 2025). Green fruits are harvestable and marketable economically important products. Relatively large portion of chilli breeding programme focus on improvement of green fruit yield related traits as it has high marker share. Green fruits are harvestable and marketable economically important products. Hence, developing cultivars with high green fruit yield is one of the major objectives of chilli breeding.

Direct phenotype-based selection for green fruit yield especially in early segregating generations is less rewarding. This is because, fruit yield is controlled by a large number of genes

each with small effects. Environment has a profound influence on these genes which leads to high cross over genotype × environment interaction when evaluated over multi-environment. Therefore, direct selection for such complex traits is misleading. Further, fruit yield is an amalgam of various component traits which indirectly contributes for attaining higher yield levels. Correlation coefficient is a measure of degree and direction of relationship between two or more variables. In plant breeding, correlation analysis is important as it provides an estimate of the mutual relationship between various plant characters. It helps in determining the characters that can serve as a surrogate to indirectly select for yield. Many scientists have reported inter-trait association of yield and its attributing traits. A significant positive correlation of economic traits like fruits plant<sup>-1</sup>, fruit length, fruit weight with yield in sweet pepper was found by Sreelathakumary and Rajamony (2002). Further, the study also suggested, selection for aforesaid characters would lead to improvement in yield both in open and 25 per cent shade. Singh *et al.* (2009) noticed a predominant role of average dry fruit weight, numbers of total and marketable fruits plant<sup>-1</sup>, seed weight fruit<sup>-1</sup> and harvest duration in predicting the fruit yield by studying correlation and path analysis in chilli peppers.

Based on this premise, identification and use of proxy traits that are easily assayable with high heritability as proxies for green fruit yield is considered highly effective. Improvement of such surrogate traits is easier in comparison to complex traits (green fruit yield in our study) as these proxy trait's expression governed

by major genes. Therefore, indirect selection of these proxy traits will enable the breeder to effectively select the high yielding genotypes. The response to indirect selections based on proxy traits relies on their strong association with green fruit yield. Based on these facts, objective of the present investigation was to identify the field assayable non – destructive proxy traits for indirect selection of plants for green fruit yield in segregating populations derived from the crosses involving multiple parents (MP).

### Materials and methods

**Experimental material:** Ten, eight parents’ derived multi-parent (MP) populations, developed involving 16 working collections constituted the genetic material for the study. Initially, single cross hybrids were synthesized and later they were used to develop seven double cross hybrids (D1 through D7). These double cross hybrids were further involved in synthesizing ten MP cross derived populations (Table 1). These 10 MP populations were evaluated at the experimental plots of the Department of Genetics and Plant Breeding, UAS, Bangalore, which is situated at an altitude of 930 meters above mean sea level (MSL).

**Sampling of plants and data collection:** Forty-day old seedlings of the each of the ten MP cross derived populations were planted

Table 1. Parentage of 10 multi-parent (MP) derived populations

MP No.	Multi parent population code	Parentage
1	D4 × D2	[(LG 174×BD) × (Vang×CA14)] × [(PC1×CMS 10B) × (JL×CMS 8B)]
2	D2 × D1	[(PC1×CMS 10B) × (JL×CMS 8B)] × [(LG 174×BD) × (Ti×CA14)]
3	D3 × D2	[(UA×PJ) × (PS×CMS 6B)] × [(PC1×CMS 10B) × (JL×CMS 8B)]
4	D5 × D2	[(LG 174×BK) × (Vang×CA14)] × [(PC1×CMS 10B) × (JL×CMS 8B)]
5	D1 × D3	[(LG 174×BD) × (Ti×CA14)] × [(UA×PJ) × (PS×CMS 6B)]
6	D6 × D3	[(GB×BK) × (Vang×LG 181)] × [(UA×PJ) × (PS×CMS 6B)]
7	D5 × D3	[(LG 174×BK) × (Vang×CA14)] × [(UA×PJ) × (PS×CMS 6B)]
8	D4 × D3	[(LG 174×BD) × (Vang×CA14)] × [(UA×PJ) × (PS×CMS 6B)]
9	D6 × D2	[(GB×BK) × (Vang×LG 181)] × [(PC1×CMS 10B) × (JL×CMS 8B)]
10	D7 × D2	[(GB×CA14) × (Vang×LG 181)] × [(PC1×CMS 10B) × (JL×CMS 8B)]

Table 3. Estimates of mean and standardised range for six quantitative traits in multi-parent chilli populations

Statistics	Trait	D4 × D2	D2 × D1	D3 × D2	D5 × D2	D1 × D3	D6 × D3	D5 × D3	D4 × D3	D6 × D2	D7 × D2
Mean	Plant height	76.16	83.68	63.84	82.32	76.29	81.30	75.45	74.09	78.13	72.71
	Fruit length	11.34	10.63	9.97	11.12	9.97	9.71	10.42	10.04	10.07	10.21
	Fruit width	1.21	1.13	1.07	1.02	1.15	1.05	1.18	1.38	0.98	1.07
	Fruit weight	5.10	4.19	3.38	4.06	3.85	3.30	4.09	5.35	3.00	3.78
	Fruits plant <sup>-1</sup>	88.27	88.79	94.65	109.22	92.78	102.00	84.09	74.93	102.00	81.98
	Green fruit yield	432.36	366.41	313.73	425.99	345.58	333.35	341.48	382.04	294.65	299.20
Standardized range	Plant height	0.84	0.99	1.02	0.95	1.13	1.09	1.05	0.92	1.00	1.14
	Fruit length	0.56	0.62	0.64	0.62	0.81	0.72	0.63	0.85	0.58	0.79
	Fruit width	0.7	0.49	0.47	0.69	0.65	0.43	0.81	0.43	0.67	0.56
	Fruit weight	2.35	1.39	1.35	1.54	1.03	1.23	1.05	1.38	2.09	1.21
	Fruits plant <sup>-1</sup>	2.36	2.21	2.52	2.80	2.25	2.80	2.81	2.42	3.29	3.86
	Green fruit yield	2.06	2.04	2.18	2.42	2.16	2.74	2.87	2.05	4.63	3.12

separately in contiguous blocks with a spacing of 0.75 m between rows and 0.45 m between plants within a row. Recommended package of practices were followed to raise a healthy crop. The number of plants survived to maturity varied from 82 to 155. Data were recorded on six quantitative traits namely, plant height (PH), fruit length (FL), fruit width (FW), average fruit weight (AFW), fruits plant<sup>-1</sup> (FP) and green fruit yield plant<sup>-1</sup> (GFY) (Table 2) on each of the survived plants from each of the MP cross derived population.

Table 2. Procedure of recording the data on six quantitative traits

S I No.	Trait	Procedure
1	Plant height (cm)	The height of individual plants in each of the MP population were measured and expressed in centimeters.
2	Fruit length (cm)	The length of ten green fruits chosen at random from each plant in each MP population were measured from the tip to the base including the pedicel and expressed as mean of ten fruits in centimeters.
3	Fruit width (cm)	The width of ten randomly chosen green fruits from each plant in each MP population were measured at their maximum width and expressed as mean centimeters fruit <sup>-1</sup> .
4	Average fruit weight (g)	Ten green fruits chosen at random from each plant in each of the MP population were weighed to the nearest decimal and expressed as mean weight in grams fruit <sup>-1</sup> .
5	Fruits plant <sup>-1</sup>	Total number of fruits over all pickings were counted and expressed on individual plant basis in each MP population
6	Green fruit yield plant <sup>-1</sup> (g)	Cumulative weight of green fruits over all pickings from each plant in each of the MP population were recorded and expressed as grams fruit <sup>-1</sup> .

**Statistical analysis:** Data recorded on individual plants of each of the ten MP cross derived populations were used for statistical analysis. Methods outlined by Singh and Chaudhary (1977) for estimating various genetic parameters were as follows. The general mean ( $\bar{X}$ ) was calculated by summing the trait values for each individual within the population and dividing by the total number of individuals. The standard deviation ( $\sigma$ ) was computed based on the variation of individual trait values around the mean. Key genetic parameters like the phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), and broad-sense heritability (h<sup>2</sup>bs) were estimated. Genetic advance (GA) was calculated to predict the expected genetic gain at a 5% selection intensity, and genetic advance as a percentage of the mean (GAM) was also determined. Furthermore, the correlation

Table 4. Estimates of mean and standardized range for six quantitative traits in multi-parent chilli populations

Trait	D4 × D2		D2 × D1		D3 × D2		D5 × D2		D1 × D3		D6 × D3		D5 × D3		D4 × D3		D6 × D2		D7 × D2	
	PCV	GCV	PCV	GCV	PCV	GCV	PCV	GCV	PCV	GCV	PCV	GCV	PCV	GCV	PCV	GCV	PCV	GCV	PCV	GCV
Plant height	18.04	17.15	17.52	16.80	22.82	21.80	18.52	17.79	20.55	19.77	19.68	19.01	17.83	16.85	19.33	18.4	20.81	20.17	22.35	21.57
Fruit length	12.06	10.98	10.74	9.07	11.95	11.00	12.94	11.82	13.41	12.07	11.69	10.75	11.23	9.87	12.77	11.61	12.3	11.34	13.77	12.71
Fruit width	11.14	10.32	9.72	8.47	10.36	6.35	10.99	10.17	12.38	9.10	8.81	8.40	12.34	9.61	9.12	6.01	9.53	8.17	9.89	8.65
Fruit weight	30.65	29.14	23.03	12.05	25.92	24.37	22.06	19.81	22.81	8.13	22.03	19.72	21.50	19.22	24.03	22.26	26.58	24.28	23.49	21.74
Fruits plant <sup>-1</sup>	51.68	48.66	41.06	38.03	53.8	50.61	54.77	52.74	45.37	41.86	51.56	47.93	54.59	50.06	53.38	47.91	58.51	55.98	73.22	70.14
Green fruit yield	47.91	45.57	41.99	38.44	53.75	51.98	50.23	48.17	43.03	39.14	52.92	50.94	56.74	53.90	48.04	45.05	61.29	59.09	69.29	66.13
Plant height	90.44		91.93		91.25		92.21		92.51		93.37		89.40		90.68		93.99		93.10	
Fruit length	82.96		71.34		84.65		83.38		81.01		84.63		77.29		82.67		84.91		85.10	
Fruit width	85.87		75.97		37.56		85.62		54.00		90.92		60.75		43.45		73.39		76.59	
Fruit weight	90.36		27.39		88.42		80.61		12.69		80.14		79.93		85.79		83.44		85.64	
Fruits plant <sup>-1</sup>	88.64		85.78		88.47		92.71		85.14		86.41		84.10		80.56		91.54		91.77	
Green fruit yield	90.49		83.80		93.52		91.96		82.76		92.68		90.25		87.96		92.94		91.10	
Plant height	33.61		33.18		42.89		35.18		39.17		37.85		32.83		36.10		40.29		42.87	
Fruit length	20.61		15.78		20.84		22.23		22.39		20.38		17.88		21.75		21.52		24.15	
Fruit width	19.71		15.21		8.02		19.38		13.77		16.50		15.44		8.16		14.41		15.60	
Fruit weight	57.05		13.00		47.20		36.63		5.96		36.36		35.40		42.47		45.69		41.44	
Fruits plant <sup>-1</sup>	94.37		72.55		98.05		104.61		79.56		91.77		94.57		88.59		110.33		138.42	
Green fruit yield	89.31		72.49		103.56		95.15		73.36		101.03		105.49		87.04		117.35		130.03	

Parentage of crosses are mentioned in Table 1.

Table 5. Estimates of phenotypic correlation coefficients of field assayable component traits with green fruit yield

Trait	Green fruit yield									
	D4 × D2	D2 × D1	D3 × D2	D5 × D2	D1 × D3	D6 × D3	D5 × D3	D4 × D3	D6 × D2	D7 × D2
Plant height	0.482**	0.453**	0.539**	0.607**	0.463**	0.384**	0.559**	0.478**	0.502**	0.678**
Fruit length	0.020	0.312**	0.361**	0.489**	0.148	0.220**	0.173	0.272**	0.176	0.413**
Fruit width	-0.024	0.212**	0.085	0.094	-0.054	0.288	0.131	-0.075	0.072	-0.088
Fruit weight	0.259**	0.366**	0.270**	-0.047	0.194*	0.283**	0.322**	0.134	0.312**	0.092
Fruits plant <sup>-1</sup>	0.855**	0.838**	0.890**	0.928**	0.843**	0.911**	0.907**	0.833**	0.769**	0.931**

\*. Significance at  $P=0.05$  level. \*\*. Significance at  $P=0.01$  level.

coefficients between five traits and green fruit yield per plant were calculated to assess the relationships among traits (Al-Jibouri *et al.*, 1958). These methods provided comprehensive insights into the genetic variability and heritability of the traits under investigation.

## Results and discussion

**Arithmetic mean:** Arithmetic mean depicts the tendency of the individuals in the populations to congregate in the distribution. On an average, individual plants of D4 × D2 bore longer fruits and exhibited higher fruit yield compared to other populations. The two MP populations namely D4 × D3 and D5 × D2 bore heavier and large number of fruits plant<sup>-1</sup>, respectively than others (Table 3). Higher estimates of trait's mean could be attributed to effect of the genes which intensifies trait's phenotype (Bernardo 2020).

**Standardised range (SR):** Absolute range (AR) a unit free measure of dispersion, denotes variability present in the population. All the populations exhibited lower magnitude of SR for plant height, fruit length and fruit width. However, D7 × D2 population was highly variable in terms of SR for plant height and fruit plant<sup>-1</sup> than other populations. Similarly, the population D4 × D3 closely followed by D1 × D3, D4 × D2 and D6 × D2 were highly variable for average fruit weight and green fruit yield plant<sup>-1</sup> compared to the other populations. (Table 3).

**Genetic variability parameters:** Narrow difference between the estimate of PCV and GCV suggested less influence of environment for all the populations for all the traits. High

magnitude of PCV and GCV suggested the existence of wide range of genetic variability for fruits plant<sup>-1</sup>, average fruit weight and green fruit yield plant<sup>-1</sup> (Table 4). These results suggest greater scope for improvement of these traits through simple selection. However, MP populations D3 × D2 and D1 × D3 exhibited considerable differences between PCV and GCV which was manifested as lower heritability and low GAM for fruit width. Similar trends were observed in D2 × D1 and D1 × D3 populations which also exhibited lower magnitude of heritability and GAM for average fruit weight. High magnitude of heritability and expected GAM indicated effectiveness of selection for plant height, fruits plant<sup>-1</sup> and green fruit yield plant<sup>-1</sup> (Table 4). D7 × D2 population with high genetic gain for fruit length, fruits plant<sup>-1</sup> and green fruit yield plant<sup>-1</sup> could be regarded as that with higher breeding potential. This population is suggested for advancing to fix the selected traits. Similar kind of results were reported by Mahantesh *et al.* (2017) and Janaki *et al.* (2015) for fruits plant<sup>-1</sup>, green fruit yield plant<sup>-1</sup> in biparental cross derived segregating populations of chilli.

**Identification of easily field assayable proxy traits:** Green fruit yield is the result of combined effect of several component traits and environment. It is therefore likely that a few component traits which are easily assayable and exhibit high heritability bear strong influence on green fruit yield. Such traits could be used as proxy for difficult-to-select green fruit yield.

Plant height showed a significant and positive high magnitude correlation with fruit yield in all the MP populations (Table 5).

Shwetha *et al.* (2018) also documented significant correlation for plant height with fruit yield in biparental derived segregating populations of chilli. Similarly, fruits plant<sup>-1</sup> showed a significant and positive high magnitude of correlation with fruit yield in all the MP populations (Table 5). These results are similar to those reported by Shwetha *et al.* (2018); Dixitha *et al.* (2015); Pradeep *et al.* (2014); Baseerat *et al.* (2013); Bijalwan and Mishra (2013); Datta and Jana (2010); Gupta *et al.* (2009); Sarkar *et al.* (2009); Singh *et al.* (2009) and Sreelathakumary and Rajamony (2002) in biparental derived segregating populations of chilli. Both plant height and fruit plant<sup>-1</sup> also showed high heritability. From these results, it could be concluded that plant height, and fruits plant<sup>-1</sup> could be used as field assayable proxy traits to select for green fruit yield.

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