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Path analysis study and morphological characterization of sweet pepper (*Capsicum annuum* L. *var. grossum*.)

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Abstract
The present study was conducted with seven diverse inbred lines of sweet pepper& five hybrids at Central Research Farm, Gayeshpur, B.C.K.V., Nadia, West Bengal during autumn-winter season of 2017-18 to find out the direct & indirect effects of seventeen important quantitative traits on fruit yield of sweet pepper. The study revealed that fruit length (0.9839) had maximum positive direct effect on fruit yield followed by reducing sugar content (0.6591), fruit weight (0.5129). On the other hand maximum negative direct effect on fruit yield per plant was showed by chlorophyll content at mature green stage (-0.0104) followed by ascorbic acid content at mature green stage (-0.0270), beta carotene content at coloured stage (-0.0342). Parental genotypes & hybrids are also characterized based on some qualitative characters like leaf shape, leaf colour, fruit orientation, flower colour, fruit shape, immature, mature and fully ripe fruit colour. Variability regarding these traits exists among the inbreds and hybrids under study.

Keywords: Sweet pepper, path analysis, direct effects, indirect effects, quantitative traits, qualitative characters

Introduction
Sweet pepper or Bell pepper (*Capsicum annuum* L. var. *grossum*) under the family Solanaceae is an important vegetable crop, grown worldwide for its delicate taste, pleasant flavour and colour. It is used as salad, cooked as vegetable, pickled or processed and is appreciated worldwide for its flavour, aroma and colour. The fruits are generally blocky, thick fleshed, three to four lobed, large and non-pungent. With their beautifully shaped form and diverse colours, bell or sweet peppers have been called "The Christmas ornaments of the vegetable world". The crop was originated in the new world tropics and subtropics and introduced in India by the Britishers in nineteenth century in Shimla and Nilgiri hills. Sweet pepper fruits (*Capsicum spp.*) represent an important part of the fresh vegetable market in the world. The genus Capsicum has 5 domesticated, 10 semi domesticated and 20 wild taxa (Andrews 1984, McLeod *et al*., 1982, Pickersgill 1971) [1, 2, 3]. Botanically, there is no difference between hot peppers and sweet peppers (bell peppers): both are derived from species of *Capsicum* and plants belong to the Solanaceae or tomato family. The bell pepper is the only member of the *Capsicum* genus that does not produce capsaicin ($C_{18}H_{27}NO_3$), a lipophilic chemical that can cause a strong burning sensation when it comes in contact with mucous membranes. The absence of capsaicin in sweet peppers is due to a recessive form of a gene that eliminates capsaicin and consequently, the "hot" taste usually associated with the rest of the *Capsicum* genus. Sweet pepper cultivars produce non-pungent capsaicinoids (Antonio *et al*., 2003) [4] with many physiological effects similar to the more pungent sister compound capsaicin. In India, capsicum is having an area of 45.85 thousand hectares with production of 327.02 thousand tonnes. The productivity is 7.13tonnes/ ha (Annonymouus, 2017) [5]. India is lagging far behind the first world countries in terms of productivity due to unavailability of high yielding improved cultivars and hybrids. Therefore, it is very important to breed the superior cultivars having high fruit yield and expand their area under cultivation as much as possible to narrow down the gap in productivity between India and other countries.

The yield is a complex character, determined by the interaction of several factors, including genetic, physiological and environmental factors (Zecevic *et al*., 2011) [6]. In this way, the knowledge of the correlations of other agronomic characteristics with yield or even among them and the environmental influence in the expression of the studied characteristics are of fundamental importance in choosing the selection strategy. Although correlation studies are helpful in determining important yield contributing traits but when more number of variables in the correlation studies are included then the association becomes more complex. In such cases, two characters may show correlations as because they may correlate with a common third one (Chatterjee *et al.*, 2018) [7]. Path coefficient analysis is being effectively used for determining the rate of various yield components in different crops, leading to the selection of superior genotypes. The technique of path analysis has been helping breeders to develop appropriate strategies to select superior genotypes of different crops, such as sunflower (Amorim *et al*., 2008) [8], maize (Entringer *et al*., 2014, Faria *et al*., 2015) [9, 10], soybean (Alcantara *et al*., 2011; Nogueira *et al*., 2012; Perini *et al*., 2012) [11, 12, 13], tomato (Sobreira *et al*., 2009; Rodrigues *et al*., 2010) [14, 15] and peppers (Luitel *et al*., 2013, Moreira *et al*., 2013, Rohini & Lakshmanan, 2015) [16, 17, 18]. Regarding path analysis studies of sweet pepper not plenty of literature is found. Therefore, the study aimed to understand the direct effects of different independent characters or indirect effect in combination with other characters on dependent character i.e. fruit yield per plant.

Materials and Method

- **Experimental site**

The field experiments were carried out at Central Research Farm, Gayeshpur, Bidhan Chandra Krishi Viswavidyalaya, Nadia, and West Bengal during autumn-winter season of 2017-18. Topographic situation of the experimental site comes under Gangetic new alluvial plains of West Bengal with sandy loam soil.

- **Experimental material, Layout and Observation**

Seven diverse Inbred lines (variety and breeding lines) of sweet pepper *viz*, Baby Bell, 8/4, C/4, C/4(Yellow), Ayesha, Arya, and Royal Wonder maintained at the Department of Vegetable crops, Bidhan Chandra Krishi Viswavidyalaya constituted the parental genotypes for the study. The following five hybrids were developed by crossing diverse parental genotypes following conventional hybridization method *viz*. Royal Wonder x Arya (Medium sized fruit, red x medium sized fruit, yellowish red), Royal Wonder x Ayesha (Medium sized fruit, red x very big fruit, red), Baby Bell x Ayesha (Small fruit, red x Very big sized fruit, red), Baby Bell x C/4 (Small fruit, red x Very big sized fruit, red), 8/4 x Royal Wonder (Medium sized fruit, orange-red x Medium sized fruit, red). The 12 genotypes (7 parental genotypes and 5 hybrids) were evaluated (transplanting in mid to end of the October) underside ventilated low cost poly house. The genotypes were grown in randomized block design with 3 replications keeping 10 plants in each replication in 60 x 60 spacing in both ways to study the manifestation of different characters in them. Management practices for cultivation were followed as suggested by Chattopadhyay *et al*. (2007) [19]. Five random plants per replication in each genotype were selected for recording the data on different characters. The seeds of all the genotypes were sown on 25th September, 2017 in raised bed nursery. The seedlings were transplanted in the main field on 30 October, 2017. In each genotype, 5 selected plants per replication were selected to record different qualitative characters-leaf shape, leaf colour, fruit peduncle orientation, flower colour, fruit shape, immature colour of fruit, mature fruit colour, ripe fruit colour. In each genotype, 5 selected plants per replication were selected to record different vegetative and flowering characters *viz*., plant height, number of primary branches in the main stem per plant, leaves per plant, leaf area (cm^2), days to first flowering and total fruits per plant. Two fruits per genotype per replication were taken from the periodical harvest at full maturity stage with the development of specific colour in the fruits from the randomly selected plants per replication for recording the fruit characters namely fruit weight (g), fruit length (cm), fruit breadth (cm), pericarp thickness (cm), total seeds per fruit, test weight of seed, fruit yield per plant (g). Three randomly selected immature fruit at green stage before turning to particular colour were harvested to make a composite sample for estimation of total chlorophyll content of the fruit. The other proximate compositions of the fruits were estimated from the replication-wise composite samples in both matured green and respective coloured stage using standard methods. The observations were- total chlorophyll contents of immature fruits (mg/100g fresh pulp), total sugar content (%), reducing sugar content (%), β-carotene content (mg/100g fresh pulp) and ascorbic acid content (mg/100 g fresh pulp).

- **Statistical analysis**

Path analysis was carried out using the genotypic correlation coefficient. This procedure was developed by Wright [20] and as per consent used by Li [21] and followed by Dewey and Lu [22]. Path coefficients are the standardized partial regression coefficients and as such measure the direct influence of one variable upon another variable and permits partition of correlation coefficient into components of direct and indirect effects. The sum of the direct and all possible indirect effects via all other traits must be equal to a correlation coefficient of dependent traits with independent characters under consideration. The statistical analysis was carried out by using OP-STAT Software available from the website of CCSHAU, Hisar, Haryana.

The path coefficient was obtained by the simultaneous selection of the following equations, which expressed the basic relationship between genotypic correction (r) and path coefficient (P)

$$r_{14}= P_{14}+ r_{12}\, P_{24}+ r_{13}\, P_{34}$$
$$r_{24}= r_{21}\, P_{14} + P_{24} + r_{23}\, P_{34}$$
$$r_{34}= r_{31}\, P_{14} + P_{32} + r_{24}\, P_{34}$$

Where r_{14}, r_{24} and r_{34} are genotypic correlation of components characters with yield (dependent variable) and r_{13}, r_{23} and r_{24} are genotypic correlations among the component characters (independent variable) and $r_{12}\, P_{24}$, $r_{13}\, P_{34}$, $r_{21}\, P_{14}$, $r_{23}\, P_{34}$, $r_{31}\, P_{14}$ and $r_{24}\, P_{34}$ are indirect effects. The direct effects are calculated by the following set of equations:

$$P_{14}= C_{11}\, r_{14}+ C_{12}\, r_{24}+ C_{13}\, r_{34}$$
$$P_{24}= C_{21}\, r_{14} + C_{22}\, r_{24} + C_{23}\, r_{34}$$
$$P_{34}= C3_{1}\, r_{14} + C_{32}\, r_{32} + C_{24}\, r_{34}$$

Where C_{11}, C_{12}, C23 and C_{33} are constants derived by using abbreviated Doultittle's technique as explained by Goulden (1939) [23] and P_{14}, P_{24} and P_{34} are the estimates of direct effects. Residual effect measures the role of other possible independent variables which were not included in the study on the dependent variable. The residual effect is estimated with the help of direct effect and simple correlation coefficient as given below:

$I = P^2x_4 + P^2_{14} + P^2_{24} + P^2_{34} + 2P_{14}r_{12}P_{24} + 2P_{14}r_{13}P_{34} + 2P_{24}r_{22}P_{34}$

Results and Discussions

Path Analysis

To measure the direct as well as the indirect association of one variable (cause) through another on the end product (effect), path coefficients were calculated at a genotypic level for all the yield attributing traits. The observed correlation coefficients of yield with its contributing traits were partitioned into direct and indirect effects. In the present investigation, important character *viz*., fruit yield per plant has been used as a dependent variable whereas other horticultural traits have been used as an independent variable. The estimates of path coefficient were presented in Table 2. In the present study it was found that vegetative characters like leaf number per plant, primary branches per plant, average leaf area, flowering characters like days to 1st flowering, fruit characters like number of fruits per plant, fruit weight, fruit length, pericarp thickness, average number of seeds per fruit and only one fruit quality trait- reducing sugar content had high positive direct effect on fruit yield so that purposeful and balanced selection based on these traits would be rewarding for improvement of yield in sweet pepper. Similar results were reported by Despestre and Gomez (1992) [24], Deka and Shadeque (1997) [25], Kohli and Chatterjee (2000) [26], Mishra *et al.* (2002) [27], Nazir *et al.* (2005) [28], Sood *et al.* (2009) [29], Johri *et al.* (2010) [30], Naik *et al.* (2010) [31], Sharma *et al.* (2010) [32], Kumari Santosh, (2013) [33] and Sasu *et al.* (2013) [34].

Direct Effects

In present investigation, it was found that fruit length (0.9839) had maximum positive direct effect on fruit yield followed by reducing sugar content (0.6591), fruit weight (0.5129), primary branches per plant (0.3807), leaf number per plant (0.3333), average leaf area (0.2359), average number of seeds per fruit (0.1723), pericarp thickness (0.1674), number of fruits per plant (0.1411) and days to 1st flowering (0.0553). On the other hand maximum, negative direct effect on fruit yield per plant was showed by total chlorophyll content at mature green stage (-0.0104) followed by ascorbic acid content at mature green stage (-0.0270), Beta carotene content at coloured stage (-0.0342), fruit width (-0.0410), 100 seed weight (-0.1320), plant height (-0.1374) and total sugar content (-0.1731).

Indirect Effects

Plant height

Plant height revealed high values of positive indirect effect on fruit length (0.6697), fruit weight (0.1488), leaf number per plant (0.0897), primary branches per plant (0.0861), number of fruits per plant (0.0678), total sugar content (0.0474), total chlorophyll content at mature green stage (0.0102), ascorbic acid content at mature green stage (0.0097), pericarp thickness (0.0091) and fruit width (0.0032). While it showed the high negative indirect effect on the traits average leaf area (-0.0080), days to 1st flowering (-0.0144), Beta carotene content at colored stage (-0.0194), average number of seeds per fruit (-0.0264), 100 seed weight (-0.0397) and reducing sugar content (-0.1217)

Leaf number per plant

Leaf number per plant expressed the highest positive indirect effect via primary branches per plant (0.3410), number of fruits per plant (0.1084), total sugar content (0.0747), 100 seed weight (0.0342), fruit width (0.0229), average number of seeds per fruit (0.0226), reducing sugar content (0.0102), ascorbic acid content at mature green stage (0.0028) and total chlorophyll content at mature green stage (0.0018) on fruit yield per plant. Its negative indirect effect was via days to 1st flowering (-0.0236), beta carotene content at coloured stage (-0.0299), plant height (-0.0369), average leaf area (-0.0506), pericarp thickness (-0.1135), fruit weight (-0.2292) and fruit length (-0.2782)

Primary branches per plant

Primary branches per plant was reported to have a maximum positive indirect effect via leaf number per plant (0.2986), number of fruits per plant (0.1101), total sugar content (0.0640), reducing sugar content (0.0353), fruit width (0.0183), ascorbic acid content at mature green stage (0.0067) and total chlorophyll content at mature green stage (0.0003) on fruit yield per plant. Its negative indirect effect was via 100 seed weight (-0.0073), days to 1st flowering (-0.0229), beta carotene content at coloured stage (0.0309), plant height (-0.0310), pericarp thickness (-0.1088), average number of seeds per fruit (-0.0397), average leaf area (-0.1247), fruit length (-0.2425) and fruit weight (-0.2952).

Average leaf area

Average leaf area exhibited maximum positive indirect effect through fruit weight (0.2717), average number of seeds per plant (0.1014), pericarp thickness (0.0452), 100 seed weight (0.0435), fruit length (0.0335), days to 1st flowering (0.0288), beta carotene content at coloured stage (0.0176), ascorbic acid content at mature green stage (0.0160), total chlorophyll content at mature green stage (0.0048) and plant height (0.0047) on fruit yield per plant. Its negative indirect effect was via total sugar content (-0.0036), fruit width (-0.0037), number of fruits per plant (-0.0673), leaf number per plant (-0.0715), reducing sugar content (-0.0840) and primary branches per plant (-0.2011).

Days to 1st flowering

Days to 1st flowering exhibited maximum positive indirect effect via fruit length (0.2927), fruit weight (0.1509), average leaf area (0.1229), pericarp thickness (0.1017), total sugar content (0.0751), plant height (0.0357), 100 seed weight (0.0305), beta carotene content at coloured stage (0.0059), ascorbic acid content at mature green stage (0.0023). Its negative indirect effect was via total chlorophyll content at mature green stage (-0.0016), average seed number per fruit (-0.0210), fruit width (-0.0245), number of fruits per plant (-0.0542), leaf number per plant (-0.1422), primary branches per plant (-0.1581) and reducing sugar content (-0.4210).

Number of fruits per plant

Number of fruits per plant exhibited significant positive indirect effect via primary branches per plant (0.2970), leaf number per plant (0.2562), fruit length (0.1536), total sugar content (0.0574), reducing sugar content (0.0505), 100 seed weight (0.0283), fruit width (0.0161) and total chlorophyll content at mature green stage (0.0012) on fruit yield per plant. Its negative indirect effect was via ascorbic acid content at mature green stage (-0.0028), days to 1st flowering (-0.0212), beta carotene content at coloured stage (-0.0326), average number of seeds per fruit (-0.0460), plant height (-0.0660), pericarp thickness (-0.0807), average leaf area (-0.1126) and fruit weight (-0.2752).

Fruit weight

Fruit weight exhibited significant positive indirect effect via fruit length (0.3433), average leaf area (0.1250), average number of seeds per fruit (0.0762), pericarp thickness (0.0596), days to 1st flowering (0.0162), beta carotene content at coloured stage (0.0151), ascorbic acid content at mature green stage (0.0150), total chlorophyll content at mature green stage (0.0065) and total sugar content (0.0022) on fruit yield per plant. Whereas, adverse indirect effect was visible to be highest via 100 seed weight (-0.0022), fruit width (-0.0080), plant height (-0.0398), number of fruits per plant (-0.0757), reducing sugar content (-0.1405), leaf number per plant (-0.1489) and primary branches per plant (-0.2191).

Fruit length

Fruit length exhibited significant positive indirect effect via fruit weight (0.1789), pericarp thickness (0.0932), total sugar content (0.0461), number of fruits per plant (0.0220), days to 1st flowering (0.0164), average leaf area (0.0080), ascorbic acid content at mature green stage (0.0071) and total chlorophyll content at mature green stage (0.0043) on fruit yield per plant. Whereas, adverse indirect effect was visible to be highest via beta carotene content at coloured stage (-0.0100), fruit width (-0.0172), 100 seed weight (-0.0214), average number of seeds per

plant (-0.0781), plant height (-0.0935), primary branches per plant (-0.0938), leaf number per plant (-0.0942) and reducing sugar content (-0.3173).

Fruit width

Fruit width was reported to have a maximum positive indirect effect via fruit length (0.4126), fruit weight (0.0999), pericarp thickness (0.0609), days to first flowering (0.0330), average leaf area (0.0214), beta carotene content at coloured stage (0.0128), plant height (0.0109) and ascorbic acid content at mature green stage (0.0086). Highest negative indirect effect was observed through total chlorophyll content at mature green stage (-0.0059), total sugar content (-0.0089), 100 seed weight (-0.0375), average number of seeds per fruit (-0.0540), number of fruits per plant (-0.0554), primary branches per plant (-0.1703), leaf number per plant (-0.1860) and reducing sugar content (-0.2433).

Pericarp thickness

Pericarp thickness exhibited maximum positive indirect effect through fruit length (0.5479), fruit weight (0.1826), average leaf area (0.0637), total sugar content (0.0547), days to 1st flowering (0.0336), beta carotene content at coloured stage (0.0128), 100 seed weight (0.0059), total chlorophyll content at mature green stage (0.0020) and ascorbic acid content at mature green stage (0.0010) on fruit yield per plant. Highest negative indirect effect was observed through plant height (-0.0074), fruit width (-0.0149), average number of seeds per fruit (-0.0419), number of fruits per plant (-0.0680), leaf number per plant (-0.2260), primary branches per plant (-0.2475) and reducing sugar content (-0.4182).

Average number of seeds per fruit

Average number of seeds per fruit exhibited maximum positive indirect effect through fruit weight (0.2270), reducing sugar content (0.1439), average leaf area (0.1390), 100 seed weight (0.0678), leaf number per plant (0.0438), plant height (0.0210), beta carotene content at coloured stage (0.0194), ascorbic acid content at mature green stage (0.0122), fruit width (0.0128) and total chlorophyll content at mature green stage (0.0036) on fruit yield per plant. Highest negative indirect effect was observed through days to 1st flowering (-0.0067), total sugar content (-0.0292), number of fruits per plant (-0.0377), pericarp thickness (-0.0407), primary branches per plant (-0.0878) and fruit length (-0.4461).

Table 1: Path coefficient analysis of capsicum at genotypic level (Residual effect at genotypic level is- 0.02823)

Characteres	PH	LNPP	PBPP	ALA	DFF	NFPP	FWT	FL	FW	PT	ASPF	SW	TCC	TS	RS	AAC	BCC	GCFYPP
PH	-0.1374	0.0897	0.0861	-0.0080	-0.0144	0.0678	0.1488	0.6697	0.0032	0.0091	-0.0264	-0.0397	0.0102	0.0474	-0.1217	0.0097	-0.0194	0.775^{**}
LNPP	-0.0369	0.3333	0.3410	-0.0506	-0.0236	0.1084	-0.2292	-0.2782	0.0229	-0.1135	0.0226	0.0342	0.0018	0.0747	0.0102	0.0028	-0.0299	0.190^{NS}
PBPP	-0.0310	0.2986	0.3807	-0.1247	-0.0229	0.1101	-0.2952	-0.2425	0.0183	-0.1088	-0.0397	-0.0073	0.0003	0.0640	0.0353	0.0067	-0.0309	-0.003^{NS}
ALA	0.0047	-0.0715	-0.2011	0.2359	0.0288	-0.0673	0.2717	0.0335	-0.0037	0.0452	0.1014	0.0435	0.0048	-0.0036	-0.0840	0.0160	0.0176	0.372^{*}
DFF	0.0357	-0.1422	-0.1581	0.1229	0.0553	-0.0542	0.1509	0.2927	-0.0245	0.1017	-0.0210	0.0305	-0.0016	0.0751	-0.4210	0.0023	0.0059	0.051^{NS}
NFPP	-0.0660	0.2562	0.2970	-0.1126	-0.0212	0.1411	-0.2752	0.1536	0.0161	-0.0807	-0.0460	0.0283	0.0012	0.0574	0.0505	-0.0028	-0.0326	0.364^{*}
FWT	-0.0398	-0.1489	-0.2191	0.1250	0.0162	-0.0757	0.5129	0.3433	-0.0080	0.0596	0.0762	-0.0022	0.0065	0.0022	-0.1405	0.0150	0.0151	0.538^{**}
FL	-0.0935	-0.0942	-0.0938	0.0080	0.0164	0.0220	0.1789	0.9839	-0.0172	0.0932	-0.0781	-0.0214	0.0043	0.0461	-0.3173	0.0071	-0.0100	0.634^{**}
FW	0.0109	-0.1860	-0.1703	0.0214	0.0330	-0.0554	0.0999	0.4126	-0.0410	0.0609	-0.0540	-0.0375	-0.0059	-0.0089	-0.2443	0.0086	0.0128	-0.143^{NS}
PT	-0.0074	-0.2260	-0.2475	0.0637	0.0336	-0.0680	0.1826	0.5479	-0.0149	0.1674	-0.0419	0.0059	0.0020	0.0547	-0.4182	0.0010	0.0128	0.048^{NS}
ASPF	0.0210	0.0438	-0.0878	0.1390	-0.0067	-0.0377	0.2270	-0.4461	0.0128	-0.0407	0.1723	0.0678	0.0036	-0.0292	0.1439	0.0122	0.0194	0.215^{NS}
SW	-0.0413	-0.0864	0.0210	-0.0778	-0.0127	-0.0303	0.0085	0.1598	-0.0116	-0.0075	-0.0885	-0.1320	0.0002	-0.0586	0.1373	-0.0078	0.0018	-0.226^{NS}
TCC	0.1359	-0.0582	-0.0138	-0.1103	0.0085	-0.0162	-0.3238	-0.4082	-0.0236	-0.0332	-0.0600	0.0035	-0.0104	-0.0708	0.0541	-0.0055	0.0010	-0.931^{**}
TS	0.0377	-0.1440	-0.1407	0.0049	-0.0240	-0.0468	-0.0066	-0.2621	-0.0021	-0.0529	0.0291	-0.0447	-0.0042	-0.1731	0.5782	-0.0055	0.0268	-0.230
RS	0.0253	0.0051	0.0204	-0.0300	-0.0353	0.0108	-0.1093	-0.4736	0.0152	-0.1062	0.0376	-0.0275	-0.0008	0.1518	0.6591	-0.0090	0.0133	-0.157^{NS}
AAC	0.0497	-0.0353	0.0952	-0.1401	-0.0047	0.0149	-0.2855	-0.2610	0.0131	-0.0066	-0.0780	-0.0383	-0.0021	-0.0357	0.2209	-0.0270	-0.0040	-0.452^{**}
BCC	-0.0779	0.2907	0.3436	-0.1217	-0.0096	0.1343	-0.2271	0.2873	0.0153	-0.0628	-0.0976	0.0070	0.0003	0.1354	-0.2564	-0.0031	-0.0342	0.323^{NS}

Where, PH= Plant height, LNPP= Leaf number per plant, PBPP= Primary branches per plant, ALA= Average leaf area, DFF= Days to first flowering, NFPP= Number of fruits per plant, FWT= Fruit weight, FL= Fruit length, FW= Fruit width, PT= Pericarp thickness, ASPF= Average number of seeds/ fruit, SW= 100 seed weight, TCC= Total chlorophyll content at mature green stage, TS= Total sugar, RS= Reducing sugar, AAC= Ascorbic acid content at mature green stage, BCC= Beta carotene content at coloured stage, GCFYPP= Genotypic correlation coefficient with fruit yield per plant.

(Red coloured diagonal values indicate positive or negative direct effect)

100 seed weight

100 seed weight revealed high values of positive indirect effect on fruit length (0.1598), reducing sugar content (0.1373), primary branches per plant (0.0210), fruit weight (0.0085), total chlorophyll content at mature green stage (0.002), and beta carotene content at coloured stage (0.0018). While it showed the high negative indirect effect on the traits pericarp thickness (-0.0075), ascorbic acid content at mature green stage (-0.0078), fruit width (-0.0116), days to 1st flowering (-0.0127), number of fruits per plant (-0.0303),

plant height (-0.0413), total sugar content (-0.0586), average leaf area (-0.0778), leaf number per plant (-0.0864) and average number of seeds per plant (0-00885).

Total chlorophyll content at mature green stage

Total chlorophyll content at mature green stage revealed high values of positive indirect effect on plant height (0.1359), reducing sugar content (0.00541), days to 1st flowering (0.0085), 100 seed weight (0.0035) and beta carotene content at coloured stage (0.0010). While it showed the high negative indirect effect on the traits ascorbic acid content at mature green stage (-0.0055), primary branches per plant (-0.0138), number of fruits per plant (-0.0162), fruit width (-0.0236), pericarp thickness (-0.0332), leaf number per plant (-0.0582), average number of seeds per plant (-0.0600), total sugar content (-0.0708), average leaf area (-0.1103), fruit weight (-0.3238) and fruit length (-0.4082).

Total sugar content

Total sugar content expressed the highest positive indirect effect via reducing sugar (0.5782), plant height (0.0377), average number of seeds per fruit (0.0291), beta carotene content at coloured stage (0.0268) and average leaf area (0.0049) on fruit yield per plant. Its negative indirect effect was via fruit width (-0.0021), total chlorophyll content at mature green stage (-0.0042), ascorbic acid content at mature green stage (-0.0055), fruit weight (-0.0066), days to 1st flowering (-0.0240), 100 seed weight (-0.0447),number of fruits per plant (-0.0468), pericarp thickness (-0.0529), primary branches per plant (-0.1407), leaf number per plant (-0.1440) and fruit length (-0.2621).

Reducing sugar content

Reducing sugar content expressed the highest positive indirect effect via total sugar (0.1518), average number of seeds per fruit (0.0376), plant height (0.0253), primary branches per plant
(0.0204), fruit width (0.0152), 0.0133), number of fruits per plant (0.0108) and leaf number per plant (0.0051) on fruit yield per plant. Its negative indirect effect was via total chlorophyll content at mature green stage (-0.0008), ascorbic acid content at mature green stage (-0.0090), 100 seed weight (-0.0275), average leaf area (-0.0300), days to 1st flowering (-0.0353), pericarp thickness (-0.1062), fruit weight (-0.1093) and fruit length (-0.4736).

Ascorbic acid content at mature green stage

Ascorbic acid content at mature green stage expressed the highest positive indirect effect via reducing sugar content (0.2209), primary branches per plant (0.0952), plant height (0.0497), number of fruits per plant (0.0149) and fruit width (0.0131). Its negative indirect effect was via total chlorophyll content at mature green stage (-0.0021), beta carotene content at coloured stage (-0.0040), days to 1st flowering (-0.0047), pericarp thickness (-0.0066), leaf number per plant (-0.0353), total sugar content (-0.0357), 100 seed weight (-0.0383), average number of seeds per fruit (-0.0780), average leaf area (-0.1401), fruit length (-0.2610) and fruit weight (-0.2855).

Beta carotene content at coloured stage

Beta carotene content at coloured stage expressed the highest positive indirect effect via primary branches per plant (0.3436), leaf number per plant (0.2907), fruit length (0.2873), total sugar content (0.1354), number of fruits per plant (0.1343), fruit width (0.0153), 100 seed weight (0.0070) and total chlorophyll content at mature green stage (0.0003) on fruit yield per plant. Its negative indirect effect was via Ascorbic acid content at mature green stage (-0.0031), days to 1st flowering (-0.0096), pericarp thickness (-0.0628), plant height (-0.0779), average number of seeds per fruit (-0.0976), average leaf area (-0.1217), fruit weight (-0.2271) and reducing sugar content (-0.2564).

Characterization of the parental genotypes and hybrids based on different morphological characters

Based on different leaf and flower characters: Seven diverse variety and breeding lines of sweet pepper *viz*., Royal Wonder, Arya, C/4-yellow, 8/4, C/4, Ayesha and Baby Bell and their five hybrids were employed in the present investigation has been characterized on the basis of 5 leaf, flower and fruit peduncle character (Table 2). Three leaf shape shapes could be recorded in genotypes *viz*., ovate, lanceolate and elliptical. Ovate leaf shape showed dominance because the hybrids, Royal Wonder x Arya, Royal Wonder x Ayesha and Baby Bell x C/4 (Lanceolate x Ovate) produced ovate leaf shape. 8/4 x Royal Wonder (Elliptical x Lanceolate) produced elliptical leaf shape. It was interesting to note that Baby Bell x Ayasha (Ovate x Ovate) produced lanceolate leaf shape which suggested possible epistatic effect for the expression of leaf shape. Leaf colour of the parental genotypes and hybrids were different shades of green colour (dark green, green and light green)**.**

Table 2: Different leaf and flower characters of the parental lines and F_1 hybrids

Variety/ Line	Leaf shape	Leaf colour	Fruit peduncle orientation	Flower colour	Fruit shape
Parental genotypes					
Arya	Ovate	Green	Pendant	White	Cordate
Ayesha	Ovate	Light Green	Pendant	White	Blocky
8/4	Elliptical	Green	Semi-pendant	White	Elongated
Royal Wonder	Lanceolate	Light Green	Semi-pendant	White	Blocky
C/4	Lanceolate	Dark Green	Pendant	White	Blocky
C/4-yellow	Lanceolate	Green	Pendant	White	Blocky
Baby Bell	Ovate	Light Green	Semi-pendant	White	Roundish Blocky
Hybrids					
Royal Wonder x Arya	Ovate	Dark Green	Pendant	White	Cordate
Royal Wonder x Ayesha	Ovate	Green	Pendant	White	Cordate
8/4 x Royal Wonder	Elliptical	Dark Green	Pendant	White	Blocky
Baby Bell x Ayasha	Lanceolate	Green	Pendant	White	Blocky
Baby Bell x C/4	Ovate	Dark Green	Pendant	White	Blocky

Most of the parental genotypes and hybrids showed pendant orientation of fruit peduncle. Three parental genotype *viz*., 8/4 and Royal Wonder, Baby Bell had semi-pendant orientation of fruit peduncle. It is to be noted in this respect that fruit peduncle orientation of the widely divergent genotypes under *Capsicum annuum* shows erect, semi-erect, semi-pendant and pendant orientation of fruit peduncle. Corolla colour of all the genotypes and their hybrids was white, typical to the basic character of *Capsicum annuum*. Fruit shape of the parental genotypes and hybrids varied widely from elongated, blocky, roundish-blocky and cordate. Fruit shape appeared to have governed by few major genes and blocky or cordate fruit shape being predominant because the hybrids of Elongated x Blocky (8/4 x Royal Wonder), Blocky x Blocky (Baby Bell x Ayasha, Baby Bell x C/4) fruit shape produced blocky fruit in the hybrids. Similarly, hybrids of Cordate x Blocky (Royal Wonder x Arya) and Blocky x Blocky (Royal Wonder x Ayesha) produced cordate fruit shape in the hybrids (Table 2).

Based on fruit colour at different stages

Seven diverse variety and breeding lines of sweet pepper which expressed four distinct fruit colour at fully matured stage *viz*., deep green (Royal Wonder), yellow (Arya, C/4-yellow), orange-red (8/4) and red (C/4, Ayesha and Baby Bell) and their five hybrids were employed in the present investigation (Table 3). Fruit colours of all these 7 breeding lines and their hybrids were green in different intensities (light green, green, and dark green) at the immature stage. Distinct colour in the fruits started developing after 55 to 69 days after anthesis depending on the genotype. In the ripe stage, fruits of all the genotypes turned different shades of red colour depending on the genotype.

Table 3: Fruit colour of the parental lines and F_1 hybrids at different stages

Variety/ Line	Immature fruit colour	Fully matured fruit colour	Ripe fruit colour
Parental genotypes			
Arya	Green	Yellow	Reddish- orange
Ayesha	Deep green	Red	Red
8/4	Light green	Orange-red	Deep reddish brown
Royal Wonder	Deep green	Deep green	Red
C/4	Deep green	Red	Red
C/4-yellow	Light green	Yellow	Reddish- orange
Baby Bell	Light green	Red	Red
Hybrids			
Royal Wonder X Arya	Green	Light green	Red
Royal Wonder X Ayesha	Deep green	Red	Red
8/4 X Royal Wonder	Light green	Red	Red
Baby Bell x Ayasha	Green	Red	Deep red
Baby Bell X C/4	Dark green	Red	Deep red

The yellow fruited genotype (Arya, C/4-yellow) turned to reddish-orange, orange-red fruited genotype (8/4) turned to deep reddish orange, red and green fruited genotype turned to either red or deep red in colour. Capsicum species produce fruits that synthesize and accumulate carotenoid pigments, which are responsible for the fruits' yellow, orange and red colours. Chilli peppers have been used as an experimental model for studying the biochemical and molecular aspects of carotenoid biosynthesis. Both chilli and sweet pepper fruits undergo profound morphological, physiological and metabolic transformations in terms of pigment composition and content during ripening. These changes in fruit composition are affected by the genotype, maturity and growth conditions (Howard *et al*., 2000; Marín *et al*., 2004) [35, 36]. Chlorophyll is responsible for the green colour of chilli and sweet pepper fruits, anthocyanins are violet/purple pigments, and the yellow-orange colors are provided by α- and β-carotene, zeaxanthin, lutein and β-cryptoxanthin and Carotenoids such as capsanthin, capsorubin and capsanthin-5,6-epoxide confer the red colours (Sun *et al*., 2007) [37]. According to the most accepted theory, the synthesis of carotenoids in chili peppers is controlled by three loci: c1, c2 and y. Several enzymes participating in carotenoid biosynthesis in chili and sweet pepper fruits have been isolated and characterized, and the corresponding gene sequences have been reported. However, there is currently limited information on the molecular mechanisms that regulate this biosynthetic pathway. Fruits of all the 5 hybrids *viz*., Royal Wonder X Arya (Green x Yellow), Royal Wonder X Ayesha (Green x Red), 8/4 x Royal Wonder (Orange-red x Green), Baby Bell x Ayesha (Red x Very Red), and Baby Bell x C/4 (Red x Red) turned to red at full matured stage (Table 3) which clearly suggested that the single gene corresponding to the y locus which determine to be the capsanthin-capsorubin synthase (Ccs) gene for producing red fruit colour (Lefebvre *et al*., 1998; Popovsky and Paran, 2000; Lang *et al*., 2004) [38, 39, 40] showed complete dominance over both green, yellow and orange-red fruit colour (Table 3).

Conclusion

From above study it can be concluded that low magnitude of residual effect (0.02823) at genotypic level indicated that the traits included in the present investigation accounted for most of the variation present in the dependent variable that is fruit yield per plant.The selection of sweet pepper lines for high yielding breeding programme can be directly achieved through the variables like fruit length, reducing sugar content, fruit weight, primary branches per plant, leaf number per plant, average leaf area, average number of seeds per fruit, pericarp thickness, number of fruits per plant and days to 1st flowering since these traits showed high correlation and high positive direct effect on pepper lines yield. On the other hand, study on morphological characters revealed that fruit shape appeared to have governed by few major genes and blocky or cordate fruit shape is predominant. During the process of fruit ripening fruits of all the genotypes turned different shades of red colour. Fruits of all the 5 hybrids turned to red at full matured stage which clearly indicated that red colour showed complete dominance over green, yellow and orange-red fruit colour.

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