



Correlation and path coefficient analysis in sprouting broccoli (*Brassica oleracea* var *italica*)

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ABSTRACT

The present investigations were conducted on sixteen genotypes of sprouting broccoli (*Brassica oleracea* var *italica* Plenck) in Randomized Complete Block Design in two environments, viz. *rabi* 2010-11 and *rabi* 2011-12. Character association analysis revealed that marketable yield/plant was significantly and positively correlated with terminal head weight/plant, harvest index, gross weight/plant, head size index, days to first harvest, leaf size with leaf stalk, plant frame and leaf size without leaf stalk which could be considered as the important selection criteria in the improvement of marketable yield. The results of path analysis revealed that the maximum positive direct effect on marketable yield/plant was exhibited by terminal head weight per plant followed by harvest index, gross weight per plant and head size index. This indicated that a selection procedure based on high terminal head weight/plant along with high harvest index, high gross weight/plant and high head size index may be effective in improving marketable yield.

Key words : Correlation, Path coefficient analysis, Sprouting broccoli

Broccoli (*Brassica oleracea* L. var *italica* Plenck) a member of family Brassicaceae is one of the nutritious cole crop. The name broccoli has been derived from an Italian word 'brocco' meaning the young shoots. It is known for its taste, flavor, nutritive and medicinal properties. Broccoli contains the compound namely, glucoraphanin, which can be processed into an anti-cancer compound sulphoraphane. In India, broccoli and cauliflower are cultivated over an area of 314 900 hectares with the production of 5988 500 metric tonnes and India ranks second in broccoli production in the world (Anonymous 2010). Further improvement can be brought by the development of genotypes having high yield potential. Since yield depends upon more than one component characters, knowledge of their degree and direction of association is very important. For this purpose, it is important to know the correlation, as it furnishes valuable information about the correlated response for selection. Path analysis revealed, whether, the association of these characters with yield is due to their direct effect or is a consequence of their indirect effect *via* other component characters. Keeping these points in view, the present study on sprouting broccoli was conducted to ascertain the correlation and direct and indirect effects of various characters on marketable yield/plant.

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MATERIALS AND METHODS

The present investigation was conducted at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSK HPKV, Palampur, in two environments, viz. environment I (*Rabi* 2010-11) and environment II (*Rabi* 2011-12). The experimental material comprised 16 genotypes of sprouting broccoli. There were 16 plants in each plot having 4.5 m² area planted at 60 cm distance between and 45 cm with in row in a Randomized Complete Block Design, with three replications. Observations were recorded on five randomly selected competitive plants/replication for fourteen characters, viz. days to first harvest, marketable yield/plant, terminal head weight/plant, gross weight/plant, number of spears/plant, head size index, plant frame, leaf size with leaf stalk, leaf size without leaf stalk, plant height up to longest leaf, plant height up to head, stalk length, weight of spears/plant and harvest index. The data regarding above mentioned characters were averaged and subjected to analysis of variance (Panse and Sukhatme 1985). Correlation coefficient was analyzed as per Al Jibouri *et al.* (1958) and path coefficient analysis was done according to Dewey and Lu (1959).

RESULTS AND DISCUSSION

Yield is a complex character and is a function of several component characters and their interaction with environment. Direct selection based on yield alone will not be very effective in breeding programme. The effectiveness of any breeding/

selection programme depends upon the nature and association between yield and other component characters, as more directly and positively a character is associated with yield in desirable direction, more will be the success of the selection programme. Therefore, it is important to have knowledge on the association of marketable yield with other characters and among themselves and their basis to identify characters for increasing the efficiency of both direct and indirect selection and thereby defining an ideal plant type.

The correlation coefficient among different characters (Table 1, 2 and 3) showed that genotypic correlation coefficients were, in general, higher in magnitude than phenotypic correlation coefficients in environment I, II and pooled over the environments, suggesting strong inherent relationship between various characters which is in conformity with earlier report of Shakuntla *et al.* (1999). At phenotypic level in environment I (Table 1), marketable yield/plant had significant positive association with terminal head weight/plant, harvest index, gross weight/plant, head size index, days to first harvest, leaf size without leaf stalk and leaf size with leaf stalk indicating that these characters have effectively contributed towards an increase in the marketable yield/plant. These findings are in consonance with earlier research work of Shakuntla *et al.* (1999) and Khattra *et al.* (2001). On the other hand, marketable yield/plant showed significant negative association with plant height up to head, stalk length, number of spears/plant and weight of spears/plant. Negative association of marketable yield/plant with stalk length was also observed by Kumar (2010).

In environment II (Table 2), at phenotypic level, marketable yield/plant had significant and positive association with terminal head weight/plant, gross weight/plant, harvest index, head size index, days to first harvest, leaf size with leaf stalk and plant frame indicating that selection on the basis of these traits will lead to higher marketable yield. The results are in conformity with the earlier findings of Jamwal *et al.* (1992), Shakuntla *et al.* (1999), Khattra *et al.* (2001) and Gautam *et al.* (2004). However, marketable yield/plant showed significant and negative correlation with number of spears/plant, weight of spears/plant, stalk length and plant height up to head.

At phenotypic level, in pooled over the environments (Table 3), marketable yield/plant was significantly and positively correlated with terminal head weight/plant, harvest index, gross weight/plant, head size index, days to first harvest, leaf size with leaf stalk, plant frame and leaf size without leaf stalk. Therefore, suggesting that selection based on high terminal head weight/plant along with high harvest index, high gross weight/plant, high head size index, late maturity, more leaf size with and without leaf stalk and more plant frame would be rewarding in selecting genotypes with high marketable yield. Similar observations have also been recorded by Jamwal *et al.* (1992), Shakuntla *et al.* (1999), Gautam *et al.* (2004) and Dhatt and Garg (2008). However

marketable yield was negatively correlated with number of spears/plant, stalk length, weight of spears/plant and plant height up to head indicating that selection for plant having more number of spears, more stalk length, more weight of spears and more plant height up to head may have adverse effect on yield.

Correlation studies give an idea about the positive and negative associations of different characters with yield and also among themselves. However, the nature and extent of contribution of these characters towards yield is not obtained. Hence, path coefficient analysis was used to make partition of the correlation coefficient in the different characters studied to know the direct and indirect effects on yield. The information obtained helps in giving proper weightage to the various characters during selection or other breeding programme so that the improvement of desirable traits can be achieved effectively.

The path coefficient analysis allows partitioning of correlation coefficients into direct and indirect effects of various traits towards dependent variable and thus, helps in assessing the cause effect relationships as well as effective selection. It plays an important role in determining the degree of relationship between yield and its component effects and also permits critical examination of specific factors that provide a given correlation. The effects of yield components *via* path analysis were examined for significant correlated characters with marketable yield/plant.

The results of path coefficient analysis in environment I (Table 4), revealed that at phenotypic level, the highest positive direct effects on marketable yield/plant were recorded by harvest index (0.500) followed by terminal head weight/plant (0.270), gross weight/plant (0.228) and head size index (0.159). Earlier research workers have also reported direct and positive effects of harvest index (Gautam 2004, Kumar *et al.* 2004, Kumar *et al.* 2005), terminal head weight/plant (Shakuntla *et al.* 1999, Khattra 2001), gross weight/plant (Kanwar and Korla 2002, Gautam 2004, Sharma *et al.* 2006, Dhatt and Garg 2008) and head size index (Gautam 2004) on marketable yield/plant. At phenotypic level, in environment II (Table 5), estimates of direct effects indicated that terminal head weight/plant (0.890) had the highest direct effect on marketable yield/plant followed by leaf size with leaf stalk (0.088), days to first harvest (0.053), harvest index (0.047) and stalk length (0.037).

The data of pooled over the environments (Table 6) revealed that at phenotypic level, the highest and positive direct effect on marketable yield/plant was exhibited by terminal head weight/plant (0.578) followed by harvest index (0.269), gross weight/plant (0.148) and head size index (0.117). Earlier research workers have also reported positive direct effect of terminal head weight/plant (Shakuntla *et al.* 1999, Khattra 2001), harvest index (Kanwar and Korla 2002, Gautam 2004, Kumar *et al.* 2004, Kumar *et al.*, 2005), gross weight/plant (Kanwar and Korla 2002, Gautam 2004, Sharma

Table 1 Estimates of phenotypic (P) and genotypic (G) correlation coefficients for different characters of broccoli in environment I (2010–2011)

Character	Marketable yield/plant (g)	Days to first harvest	Terminal head weight/plant (g)	Gross weight/plant (g)	Number of spears/plant	Head size index (cm ²)	Plant frame (cm ²)	Leaf size with leaf stalk (cm ²)	Leaf size without leaf stalk (cm ²)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/plant (g)
Days to first harvest	0.5238*	P											
	0.6072*	G											
Terminal head weight/plant (g)	0.9194*	P	0.5202*										
	1.0032*	G	0.6389*										
Gross weight/plant (g)	0.5807*	P	0.2865*	0.6250*									
	0.8179*	G	0.4773*	0.8115*									
Number of spears/plant	-0.5147*	P	-0.5854*	-0.5094*	-0.3527*								
	-0.5406*	G	-0.6557*	-0.5604*	-0.5261*								
Head size index (cm ²)	0.5686*	P	0.3004*	0.4658*	0.2330	-0.1938							
	0.7501*	G	0.2787	0.7842*	0.6331*	-0.2662							
Plant frame (cm ²)	0.1084	P	0.2631	0.1140	0.1958	-0.3884*	-0.0678						
	0.1636	G	0.5648*	0.1020	0.3815*	-0.5916*	-0.2077						
Leaf size with leaf stalk (cm ²)	0.2965*	P	0.3543*	0.3270*	0.2652	0.0434	0.2099						
	0.3509*	G	0.4020*	0.3697*	0.3646*	0.1018	0.3601*						
Leaf size without leaf stalk (cm ²)	0.3006*	P	0.3662*	0.3121*	0.2500	0.1367	0.0683	0.5795*					
	0.3531*	G	0.3865*	0.4053*	0.5204*	0.1164	0.1124	0.7622*					
Plant height up to longest leaf (cm)	0.2175	P	0.2399	0.1926	0.0535	0.0025	0.3822*	0.5757*	0.3694*				
	0.3132*	G	0.5726*	0.2403	0.1297	0.0041	0.2191	1.0310*	0.7668*				
Plant height up to head (cm)	-0.5609*	P	-0.6559*	-0.6076*	-0.4107*	-0.3250*	-0.1709	-0.2038	-0.2780	0.1535			
	-0.7855*	G	-0.8449*	-0.8197*	-0.8111*	-0.6961*	-0.6015*	-0.2574	-0.3121*	-0.2685			
Stalk length (cm)	-0.5150*	P	-0.5279*	-0.5359*	-0.4052*	-0.4302*	-0.1831	-0.2369	-0.2202	0.0038	0.6013*		
	-0.5868*	G	-0.7308*	-0.6242*	-0.6651*	-0.6927*	-0.0890	-0.3205*	-0.3611*	0.0403	0.8746*		
Weight of spears/plant (g)	-0.4444*	P	-0.3512*	-0.4003*	-0.2925*	-0.1243	-0.4514*	-0.1643	-0.0940	-0.0580	0.5000*	0.2901*	
	-0.4554*	G	-0.4004*	-0.4561*	-0.4392*	-0.2213	-0.7854*	-0.1839	-0.0755	-0.1365	0.7056*	0.3929*	
Harvest index (%)	0.8639*	P	0.6012*	0.8307*	0.2938*	0.4695*	0.0806	0.2438	0.1569	0.1663	-0.5468*	-0.5048*	-0.3442*
	0.9228*	G	0.7173*	0.9492*	0.5803*	0.6508*	0.0951	0.3014*	0.1885	0.3049*	-0.7741*	-0.5915*	-0.3505*

*Significant at P= 0.05

Table 2 Estimates of phenotypic (P) and genotypic (G) correlation coefficients for different characters of broccoli in environment II (2011–2012)

Character	Marketable yield/plant (g)	Days to first harvest	Terminal head weight/plant (g)	Gross weight/plant (g)	Number of spears/plant	Head size index (cm ²)	Plant frame (cm ²)	Leaf size with leaf stalk (cm ²)	Leaf size without leaf stalk (cm ²)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/plant (g)
Days to first harvest	P 0.4792*												
	G 0.5604*												
Terminal head weight/plant (g)	P 0.9887*	0.4229*											
	G 0.9917*	0.5022*											
Gross weight/plant (g)	P 0.7995*	0.4333*	0.7968*										
	G 0.9535*	0.6178*	0.9487*										
Number of spears/plant	P -0.5580*	-0.3231*	-0.5836*	-0.4939*									
	G -0.6008*	-0.4138*	-0.6266*	-0.0613									
Head size index (cm ²)	P 0.5312*	0.3310*	0.5131*	0.3535*	-0.3258*								
	G 0.6257*	0.5118*	0.6192*	0.3520*	-0.5100*								
Plant frame (cm ²)	P 0.3989*	0.3498*	0.3699*	0.4070*	-0.2975*	-0.0316							
	G 0.4448*	0.6558*	0.3952*	0.7345*	-0.4034*	-0.1431							
Leaf size with leaf stalk (cm ²)	P 0.4607*	0.1769	0.3964*	0.3677*	-0.1071	0.2498	0.3606*						
	G 0.5982*	0.3042*	0.5261*	0.5211*	-0.1481	0.5007*	0.5175*						
Leaf size without leaf stalk (cm ²)	P 0.1558	-0.0505	0.1460	0.0230	-0.1522	0.1693	0.1826	0.4974*					
	G 0.1542	0.0224	0.1355	-0.0163	-0.1566	0.2470	0.1379	0.5206*					
Plant height up to longest leaf (cm)	P -0.0189	-0.0278	-0.0513	-0.0071	0.2211	-0.1104	0.3763*	0.4764*	0.4516*				
	G -0.0583	-0.0826	-0.1098	-0.0128	0.3040*	-0.4141*	0.3680*	0.7854*	0.7466*				
Plant height up to head (cm)	P -0.3356*	0.1155	-0.3853*	-0.2910*	0.5272*	-0.1700	-0.0072	-0.1392	-0.1695	0.1770			
	G -0.6656*	-0.0284	-0.7066*	-0.5415*	0.8589*	-0.9132*	0.2586	-0.1672	-0.2014	0.1970			
Stalk length (cm)	P -0.4590*	-0.3647*	-0.4693*	-0.3297*	0.5032*	-0.4880*	-0.0910	-0.1600	-0.0684	0.2138	0.3763*		
	G -0.6544*	-0.4826*	-0.6531*	-0.6346*	0.6655*	-0.9936*	-0.1704	-0.3460*	-0.0054	0.3637*	0.8223*		
Weight of spears/plant (g)	P -0.5125*	-0.4761*	-0.5315*	-0.4704*	0.7058*	-0.1432	-0.2798	0.0576	0.2119	0.2250	0.2134	0.4450*	
	G -0.5728*	-0.5234*	-0.6014*	-0.5899*	0.8199*	-0.1999	-0.5084*	0.0520	0.2050	0.3747*	0.4397*	0.4933*	
Harvest index (%)	P 0.7899*	0.4655*	0.7735*	0.4683*	-0.4778*	0.5620*	0.1917	0.3951*	0.1404	-0.0365	-0.2905*	-0.6040*	-0.3662*
	G 0.9163*	0.4921*	0.9134*	0.7846*	-0.5730*	0.8408*	0.2929*	0.5229*	0.2099	-0.1052	-0.9808*	-0.8024*	-0.4791*

*Significant at P= 0.05

Tables 3 Estimates of phenotypic (P) and genotypic (G) correlation coefficients for different characters of broccoli in pooled over the environments

Character	Marketable yield/plant (g)	Days to first harvest	Terminal head weight/plant (g)	Gross weight/plant (g)	Number of spears/plant	Head size index (cm ²)	Plant frame (cm ²)	Leaf size with leaf stalk (cm ²)	Leaf size without leaf stalk (cm ²)	Plant height up to longest leaf (cm)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/plant (g)
Days to first harvest	P 0.4805*												
	G 0.5736*												
Terminal head weight/plant (g)	P 0.9507*	0.4440*											
	G 0.9967*	0.5472*											
Gross weight/plant (g)	P 0.6925*	0.3830*	0.7052*										
	G 0.8826*	0.5532*	0.8867*										
Number of spears/plant	P -0.5353*	-0.4130*	-0.5433*	-0.4264*									
	G -0.5992*	-0.6064*	-0.6137*	-0.5485*									
Head size index (cm ²)	P 0.5490*	0.3132*	0.4870*	0.3010*	-0.2602*								
	G 0.7193*	0.4068*	0.7347*	0.4447*	-0.4594*								
Plant frame (cm ²)	P 0.2505*	0.3094*	0.2354*	0.3134*	-0.3432*	-0.0490							
	G 0.3142*	0.5941*	0.2744*	0.5378*	-0.4885*	-0.1512							
Leaf size with leaf stalk (cm ²)	P 0.3736*	0.2392*	0.3585*	0.3173*	-0.1960	0.1459	0.2833*						
	G 0.4996*	0.4053*	0.4676*	0.4501*	-0.2403*	0.2979*	0.4326*						
Leaf size without leaf stalk (cm ²)	P 0.2029*	0.0609	0.2017*	0.0936	-0.1647	0.1536	0.1366	0.5075*					
	G 0.3191*	0.1706	0.2957*	0.2205*	-0.2626*	0.2704*	0.2281*	0.8063*					
Plant height up to longest leaf (cm)	P 0.0950	0.0662	0.0696	0.0176	0.0156	-0.0590	0.3785*	0.5223*	0.4156*				
	G 0.1462	0.2307*	0.0932	0.1245	0.0168	-0.1709	0.3565*	0.9754*	0.8746*				
Plant height up to head (cm)	P -0.4466*	-0.1646	-0.4968*	-0.3402*	0.5757*	-0.2426*	-0.0854	-0.1710	-0.2029*	0.1663			
	G -0.7689*	-0.4901*	-0.8185*	-0.7629*	0.8635*	-0.9170*	-0.1911	-0.2713*	-0.2107*	0.1270			
Stalk length (cm)	P -0.4890*	-0.4148*	-0.5059*	-0.3595*	0.4575*	-0.4576*	-0.1384	-0.2013*	-0.0423	0.1102	0.4882*		
	G -0.6184*	-0.5744*	-0.6534*	-0.6372*	0.6585*	-0.8826*	-0.2005	-0.3715*	-0.3722*	0.1166	0.9295*		
Weight of spears/plant (g)	P -0.4769*	-0.4142*	-0.4606*	-0.3870*	0.7667*	-0.1337	-0.3661*	-0.0589	0.0926	0.0894	0.3538*	0.3627*	
	G -0.5363*	-0.4360*	-0.5443*	-0.5219*	0.9388*	-0.2421*	-0.5653*	-0.0632	0.0323	0.1710	0.7048*	0.4735*	
Harvest index (%)	P 0.8290*	0.4940*	0.8056*	0.3704*	-0.4590*	0.5061*	0.1290	0.3069*	0.1373	0.0696	-0.4245*	-0.5449*	-0.3519*
	G 0.9319*	0.6376*	0.9470*	0.7314*	-0.5945*	0.8337*	0.2335*	0.4619*	0.2671*	0.1103	-0.8087*	-0.6733*	-0.4662*

*Significant at P= 0.05

Table 4 Estimates of direct and indirect effects of different characters on marketable yield per plant at phenotypic (P) and genotypic (G) levels in environment I (2010–2011)

Character		Days to first harvest	Terminal head weight plant (g)	Gross weight/plant (g)	Number of spears/plant	Head size index (cm ²)	Plant frame (cm ²)	Leaf size with leaf stalk	Leaf size without leaf stalk	Plant height up to longest leaf (cm ²)	Plant height up to head	Stalk length (cm)	Weight of spears/plant (g)	Harvest index (%)
Days to first harvest	P	-0.0663	-0.0345	-0.0190	0.0388	-0.0199	-0.0174	-0.0235	-0.0243	-0.0159	0.0435	0.0350	0.0233	-0.0399
	G	-0.5962	-0.3809	-0.2846	0.3909	-0.1661	-0.3367	-0.2397	-0.2304	-0.3413	0.5037	0.4357	0.2387	-0.4277
Terminal head weight/plant (g)	P	0.1406	0.2702	0.1689	-0.1377	0.1259	0.0308	0.0884	0.0843	0.0521	-0.1642	-0.1448	-0.1082	0.2245
	G	-0.0303	-0.0474	-0.0385	0.0266	-0.0372	-0.0048	-0.0175	-0.0192	-0.0114	0.0389	0.0296	0.0216	-0.0450
Gross weight/plant (g)	P	0.0655	0.1428	0.2285	-0.0806	0.0533	0.0448	0.0606	0.0571	0.0122	-0.0939	-0.0926	-0.0668	0.0671
	G	0.0335	0.0569	0.0701	-0.0369	0.0444	0.0267	0.0256	0.0365	0.0091	-0.0568	-0.0466	-0.0308	0.0407
Number of spears/plant	P	-0.0343	-0.0298	-0.0206	0.0585	-0.0113	-0.0227	-0.0162	-0.0118	-0.0122	0.0367	0.0244	0.0482	-0.0263
	G	0.0422	0.0360	0.0338	-0.0643	0.0171	0.0380	0.0203	0.0133	0.0243	-0.0532	-0.0306	-0.0563	0.0319
Head size index (cm ²)	P	0.0479	0.0743	0.0372	-0.0309	0.1596	-0.0108	0.0069	0.0218	0.0004	-0.0519	-0.0687	-0.0198	0.0749
	G	-0.0105	-0.0297	-0.0239	0.0101	-0.0378	0.0079	-0.0038	-0.0044	0.0002	0.0263	0.0262	0.0084	-0.0246
Plant frame (cm ²)	P	-0.0197	-0.0085	-0.0147	0.0291	0.0051	-0.0750	-0.0157	-0.0051	-0.0287	0.0128	0.0137	0.0338	-0.0060
	G	0.0517	0.0093	0.0349	-0.0541	-0.0190	0.0915	0.0329	0.0103	0.0200	-0.0550	-0.0081	-0.0719	0.0087
Leaf size with leaf stalk (cm ²)	P	-0.0254	-0.0234	-0.0190	0.0198	-0.0031	-0.0150	-0.0717	-0.0415	-0.0413	0.0146	0.0170	0.0118	-0.0175
	G	-0.0004	-0.0003	-0.0003	0.0003	-0.0001	-0.0003	-0.0009	-0.0007	-0.0009	0.0002	0.0003	0.0002	-0.0003
Leaf size without leaf stalk (cm ²)	P	0.0298	0.0254	0.0203	-0.0164	0.0111	0.0056	0.0471	0.0813	0.0300	-0.0226	-0.0179	-0.0076	0.0128
	G	0.0186	0.1139	0.1463	-0.0580	0.0327	0.0316	0.2142	0.2810	0.2155	-0.0877	-0.1051	-0.0212	0.0530
Plant height up to longest leaf (cm)	P	0.0307	0.0247	0.0068	-0.0267	0.0003	0.0489	0.0737	0.0473	0.1280	0.0197	0.0005	-0.0074	0.0213
	G	-0.0286	-0.0120	-0.0065	0.0189	0.0002	-0.0109	-0.0515	-0.0383	-0.0500	0.0134	-0.0020	0.0068	-0.0152
Plant height up to head (cm)	P	0.0049	0.0045	0.0031	-0.0047	0.0024	0.0013	0.0015	0.0021	-0.0011	-0.0075	-0.0045	-0.0037	0.0041
	G	0.5174	0.5020	0.4968	-0.5063	0.4263	0.3684	0.1576	0.1912	0.1645	-0.6124	-0.5356	-0.4322	0.4741
Stalk length (cm)	P	-0.0151	-0.0153	-0.0116	0.0119	-0.0123	-0.0052	-0.0068	-0.0063	0.0001	-0.0172	0.0286	0.0083	-0.0145
	G	-0.1186	-0.1013	-0.1079	0.0773	-0.1124	-0.0144	-0.0520	-0.0586	0.0065	0.1419	0.1623	0.0638	-0.0960
Weight of spears/plant (g)	P	0.0646	0.0737	0.0538	-0.1516	0.0229	0.0831	0.0302	0.0173	0.0107	-0.0920	-0.0534	-0.1841	0.0633
	G	-0.0644	-0.0734	-0.0707	0.1408	-0.0356	-0.1264	-0.0296	-0.0121	0.0220	0.1136	0.0632	0.1609	-0.0564
Harvest index (%)	P	0.3006	0.4153	0.1469	-0.2244	0.2348	0.0403	0.1219	0.0785	0.0832	-0.2734	-0.2524	-0.1721	0.5000
	G	0.7028	0.9300	0.5685	-0.4858	0.6376	0.0932	0.2953	0.1847	0.2987	-0.7584	-0.5795	-0.3434	0.9797
Correlation with marketable yield/plant	P	0.5238*	0.9194*	0.5807*	-0.5147*	0.5686*	0.1084	0.2965*	0.3006*	0.2175	-0.5609*	-0.5150*	-0.4444*	0.8639*
	G	0.6072*	1.0032*	0.8179*	-0.5406*	0.7501*	0.1636	0.3509*	0.3531*	0.3132*	-0.7855*	-0.5868*	-0.4554*	0.9228*

Residual effect (P); 0.25; (G); 0.17, *Significant at P=0.05. The bold values indicate direct effects

Table 5 Estimates of direct and indirect effects of different characters on marketable yield per plant at phenotypic (P) and genotypic (G) levels in environment II (2011–2012)

Character	Days to first harvest	Terminal head weight plant (g)	Gross weight/plant (g)	Number of spears/plant	Head size index (cm ²)	Plant frame (cm ²)	Leaf size with leaf stalk (cm ²)	Leaf size without leaf stalk (cm ²)	Plant height up to longest leaf (cm ²)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/plant (g)	Harvest index (%)
Days to first harvest	P	0.0531	0.0225	0.0230	0.0176	0.0186	0.0094	-0.0027	-0.0015	0.0061	-0.0194	-0.0253	0.0247
Terminal head weight/plant (g)	G	0.0568	0.0285	0.0351	0.0291	0.0372	0.0173	0.0013	-0.0047	-0.0016	-0.0274	-0.0297	0.0297
Gross weight/plant (g)	P	0.3766	0.8905	0.7096	0.4569	0.3294	0.3530	0.1300	-0.0457	-0.3431	-0.4180	-0.4733	0.6889
Number of spears/plant	G	0.4537	0.9035	0.8571	0.5594	0.3570	0.4753	0.1224	-0.0992	-0.6384	-0.5901	-0.5434	0.8253
Head size index (cm ²)	P	0.0063	0.0117	0.0147	0.0052	0.0060	0.0054	0.0003	-0.0001	-0.0043	-0.0048	-0.0069	0.0069
Plant frame (cm ²)	G	-0.0285	-0.0438	-0.0462	0.0278	-0.0339	-0.0241	0.0008	0.0006	0.0250	0.0293	0.0272	-0.0362
Leaf size with leaf stalk (cm ²)	P	-0.0026	-0.0047	-0.0040	0.0080	-0.0024	-0.0009	-0.0012	0.0018	0.0042	0.0040	0.0057	-0.0038
Leaf size without leaf stalk (cm ²)	G	0.0246	0.0372	0.0357	0.0303	0.0240	0.0088	0.0093	-0.0181	-0.0510	-0.0395	-0.0487	0.0341
Plant height up to longest leaf (cm)	P	0.0092	0.0143	0.0098	0.0279	-0.0009	0.0070	0.0047	-0.0031	-0.0047	-0.0136	-0.0040	0.0157
Plant height up to head (cm)	G	0.0393	0.0475	0.0270	0.0768	-0.0110	0.0384	0.0190	-0.0318	-0.0701	-0.0763	-0.0154	0.0646
Stalk length (cm)	P	0.0072	0.0077	0.0084	-0.0007	0.0207	0.0075	0.0038	0.0078	-0.0001	-0.0019	-0.0058	0.0040
Weight of spears/plant (g)	G	0.0430	0.0259	0.0482	-0.0094	0.0656	0.0340	0.0091	0.0242	0.0170	-0.0112	-0.0334	0.0192
Harvest index (%)	P	0.0157	0.0352	0.0326	0.0222	0.0320	0.0887	0.0441	0.0423	-0.0123	-0.0142	0.0051	0.0351
Correlation with marketable yield/plant	G	0.0295	0.0511	0.0506	0.0486	0.0503	0.0971	0.0505	0.0763	-0.0162	-0.0336	0.0050	0.0508
Residual effect (P): 0.10; (G): 0.06, *Significant at P= 0.05. The bold values indicate direct effects	P	0.0010	-0.0028	-0.0004	-0.0033	-0.0035	-0.0097	-0.0194	-0.0088	0.0033	-0.0013	-0.0041	-0.0027
	G	-0.0019	-0.0112	0.0013	0.0205	-0.0114	-0.0432	-0.0829	-0.0619	0.0167	0.0004	-0.0170	-0.0174
	P	0.0006	0.0011	0.0001	0.0023	-0.0078	-0.0098	-0.0093	-0.0207	-0.0037	-0.0044	-0.0046	0.0008
	G	0.0005	0.0007	0.0001	0.0025	-0.0022	-0.0047	-0.0045	-0.0060	-0.0012	-0.0022	-0.0023	0.0006
	P	0.0022	-0.0075	-0.0057	0.0103	-0.0001	-0.0027	-0.0033	0.0034	0.0194	0.0073	0.0042	-0.0057
	G	0.0001	0.0028	0.0021	0.0036	-0.0010	0.0007	0.0008	-0.0008	-0.0039	-0.0032	-0.0017	0.0038
	P	-0.0136	-0.0174	-0.0123	-0.0181	-0.0034	-0.0059	0.0025	0.0079	0.0140	0.0372	0.0165	-0.0225
	G	-0.0653	-0.0884	-0.0859	0.0901	-0.0231	-0.0468	-0.0007	0.0492	0.1113	0.1354	0.0654	-0.1086
	P	0.0011	0.0013	0.0011	0.0003	0.0007	-0.0001	-0.0005	-0.0005	-0.0005	-0.0011	-0.0024	0.0009
	G	-0.0313	-0.0359	-0.0353	0.0490	-0.0304	0.0031	0.0122	0.0224	0.0263	0.0289	0.0598	-0.0286
	P	0.0223	0.0370	0.0224	-0.0228	0.0092	0.0189	0.0067	-0.0017	-0.0139	-0.0289	-0.0175	0.0478
	G	0.0398	0.0739	0.0634	-0.0463	0.0237	0.0423	0.0170	-0.0085	-0.0793	-0.0649	-0.0387	0.0809
	P	0.4792*	0.9887*	0.7995*	0.5312*	0.3983*	0.4607*	0.1558	-0.0189	-0.3356*	-0.4590*	-0.5125*	0.7899*
	G	0.5604*	0.9917*	0.9555*	0.6257*	0.4448*	0.5982*	0.1542	-0.0583	-0.6656*	-0.6544*	-0.5728*	0.9163*

Table 6 Estimates of direct and indirect effects of different characters on marketable yield per plant at phenotypic (P) and genotypic (G) levels in pooled over the environments

Character	Days to first harvest	Terminal head weight plant (g)	Gross weight/plant (g)	Number of spears/plant	Head size index (cm ²)	Plant frame (cm ²)	Leaf size with leaf stalk	Leaf size without leaf stalk	Plant height up to longest leaf (cm ²)	Plant height up to head (cm)	Stalk length (cm)	Weight of spears/plant (g)	Harvest index (%)
Days to first harvest	P	-0.0089	-0.0039	-0.0034	0.0037	-0.0028	-0.0027	-0.0021	-0.0005	0.0015	0.0037	0.0037	-0.0044
	G	-0.0949	-0.0519	-0.0525	0.0575	-0.0386	-0.0564	-0.0384	-0.0162	0.0465	0.0545	0.0414	-0.0605
Terminal head weight/plant (g)	P	0.2568	0.5784	0.4079	-0.3143	0.2817	0.1362	0.2074	0.1167	-0.2874	-0.2926	-0.2664	0.4660
	G	0.0316	0.0578	0.0512	-0.0354	0.0424	0.0158	0.0270	0.0171	-0.0473	-0.0377	-0.0314	0.5470
Gross weight/plant (g)	P	0.0570	0.1049	0.1487	-0.0634	0.0448	0.0466	0.0472	0.0139	-0.0506	-0.0535	-0.0575	0.0551
	G	0.1328	0.2129	0.2401	-0.1317	0.1068	0.1291	0.1080	0.0529	-0.1832	-0.1530	-0.1253	0.1756
Number of spears/plant	P	-0.0213	-0.0280	-0.0220	0.0516	-0.0134	-0.0177	-0.0101	-0.0085	0.0297	0.0236	0.0396	-0.0237
	G	-0.2546	-0.2577	-0.2303	0.4199	-0.1929	-0.2051	-0.1009	-0.1103	0.3626	0.2765	0.3942	-0.2496
Head size index (cm ²)	P	0.0369	0.0574	0.0355	-0.0306	0.1178	-0.0058	0.0172	0.0181	-0.0286	-0.0539	-0.0157	0.0596
	G	-0.3527	-0.6369	-0.3856	0.3983	-0.8669	0.1311	-0.2583	-0.2344	0.1481	0.7651	0.2099	-0.7228
Plant frame (cm ²)	P	0.0045	0.0034	0.0046	-0.0050	-0.0007	0.0146	0.0041	0.0020	-0.0055	-0.0020	-0.0053	0.0019
	G	-0.2665	-0.1231	-0.2412	0.2191	0.0678	-0.4485	-0.1940	-0.1023	0.0857	0.0899	0.2536	-0.1047
Leaf size with leaf stalk (cm ²)	P	0.0038	0.0057	0.0050	-0.0031	0.0023	0.0045	0.0158	0.0080	-0.0027	-0.0032	-0.0009	0.0048
	G	0.0042	0.0049	0.0047	-0.0025	0.0031	0.0045	0.0104	0.0084	-0.0028	-0.0039	-0.0007	0.0048
Leaf size without leaf stalk (cm ²)	P	0.0016	0.0054	0.0025	-0.0044	0.0041	0.0037	0.0137	0.0269	0.0112	-0.0055	0.0025	0.0037
	G	0.0139	0.0241	0.0180	-0.0214	0.0221	0.0186	0.0658	0.0816	-0.0172	-0.0304	-0.0026	0.0218
Plant height up to longest leaf (cm)	P	0.0010	0.0010	0.0003	0.0002	-0.0009	0.0057	0.0078	0.0062	0.0150	0.0017	0.0013	0.0010
	G	0.0114	0.0046	0.0061	0.0008	-0.0084	0.0176	0.0481	0.0431	0.0493	0.0063	0.0058	0.0054
Plant height up to head (cm)	P	-0.0028	-0.0084	-0.0058	0.0097	-0.0041	-0.0014	-0.0029	-0.0034	0.0028	0.0169	0.0060	-0.0072
	G	-0.1714	-0.2863	-0.2669	0.3020	-0.3207	-0.0669	-0.0949	-0.0737	0.0444	0.3498	0.2465	-0.2829
Stalk length (cm)	P	-0.0283	-0.0345	-0.0245	0.0312	-0.0312	-0.0094	-0.0137	-0.0029	0.0075	0.0332	0.0247	-0.0371
	G	0.4356	0.4955	0.4832	-0.4994	0.6693	0.1520	0.2818	0.2823	-0.0885	-0.7049	-0.3591	0.5106
Weight of spears/plant (g)	P	0.0472	0.0525	0.0441	-0.0873	0.0152	0.0417	0.0067	-0.0105	-0.0102	-0.0403	-0.1139	0.0401
	G	0.2422	0.3024	0.2899	-0.5215	0.1345	0.3140	0.0351	0.0180	-0.0950	-0.3915	-0.5555	0.2590
Harvest index (%)	P	0.1330	0.2168	0.0997	-0.1235	0.1362	0.0347	0.0826	0.0370	0.0187	-0.1143	-0.0947	0.2692
	G	0.8418	1.2504	0.9658	-0.7849	1.1009	0.3083	0.6099	0.3526	0.1457	-1.0678	-0.6156	1.3204
Correlation with marketable yield/plant	P	0.4805*	0.9507*	0.6925*	-0.5353*	0.5490*	0.2505*	0.3736*	0.2029*	0.0950	-0.4466*	-0.4769*	0.8290*
	G	0.5736*	0.9967*	0.8826*	-0.5992*	0.7193*	0.3142*	0.4996*	0.3191*	0.1462	-0.7689*	-0.5363*	0.9319*

Residual effect (P): 0.24; (G): 0.18,*Significant at P= 0.05. The bold values indicate direct effects

et al. 2006, Dhatt and Garg 2008), head size index (Gautam 2004, Garg and Lal 2004) and stalk length (Kumar *et al.* 2005, Dhatt and Garg 2008) on marketable yield/plant. These characters had also shown highly positive correlation values with marketable yield/plant. Terminal head weight/plant, harvest index and gross weight/plant had the maximum indirect contribution for enhancing the magnitude of association of majority of the characters with marketable yield/plant. Keeping in view the direct and indirect contributions of the component characters towards marketable yield/plant, the selection based on terminal head weight/plant, harvest index, gross weight/plant and head size index in the genotypes under study would be rewarding.

The study revealed that the values of residual effect were very less, i.e. variation 0.25 (environment I), 0.10 (environment II) and 0.24 (pooled over the environments). This indicated that the characters selected for the present study are the main components of yield and that the variability in the yield is accounted by the characters chosen for this investigation to a considerable extent.

The results on correlation and path coefficient analysis suggested that the selection should be primarily based on the component characters which exhibited significant positive correlations with marketable yield and had either direct or indirect effects on marketable yield.

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