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Character association and genetic gain of nine agronomic traits of F_1 populations in onion (*Allium cepa* L.)

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Summary: F_1 populations of half diallel cross were considered for this investigation. Genotypic (σ^2_G), interaction (σ^2_I) and within error (σ^2_w) components of variation were less than phenotypic component of variation (σ^2_P) for all the traits. Bulb weight showed the highest values for σ^2_P, σ^2_G, σ^2_I and σ^2_w. The noticeable amount of phenotypic, genotypic, interaction and within error covariation was found in the combination of BW × BY, possibly indicating wide scope of selection for this pair of characters. Phenotypic correlations were comparatively less than genotypic correlations. This situation was also marked in the path coefficient analysis. Bulb yield/plot showed highly significant and positive correlation coefficient with other characters both at phenotypic and genotypic levels. When all the nine characters were included in an index, it exhibited the highest genetic gain as percentage. For bulb yield, the efficacy was higher than that of direct selection when a combination of two or more characters was studied in a function. The combination of five, six, seven or eight characters showed higher percentage of expected gain. Due to significantly correlated with BY and having high positive direct effect at phenotypic level characters viz., LL, BW, PH and NLs is considered as primary yield components. Again combinations of these four characters gave the commendable expected genetic gain of 330.7290% may be considered as important selection index for this material.

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Key words: correlation, direct-indirect effects, selection indices, onion

Introduction

Onion (*Allium cepa* L.) a spice crop of Alliaceae family has a close relation with the group of garlic, scallion, leek, chieve (Block, 2010) and Chinese onion (AllergyNet, 2010). The use of onion is not limited to any climate or associated with nationality. It is used as vegetable as well as spice and an indispensable item in every kitchen for their flavor, aroma and taste in preparation of different dishes. In terms of production among vegetables, onion ranks as the second highest crop in the world (Lakshmi, 2015). Onion is also used in form of dehydrated, freezing, canning and pickling (in vinegar and brine). Compared with other fresh vegetables, onion is higher in food energy, intermediate in protein content, and rich in calcium and riboflavin. It contributes savoury flavour to dishes without contributing significant caloric content (History of onions, 2011). Onion is also used for preparing Homeopathic, Unani and Ayurvedic medicines. It has a special flavour and pungency because of having sulfur containing compounds *Allyl-propyl disulphide* ($C_6H_{12}S_2$) found in the bulb scales (Udachappa et al., 2019a). Bulb yield of onion is directly associated with the amount of water supply (Gedam et al., 2021). Bangladesh is not sufficient in onion production as per demand of its population though the area, per acre yield and production increases in the subsequent year (BBS, 2019). Mila & Parvin (2019) reported that due to lack of quality seeds and improved varieties as well as improper cultural practices the yield level of onion is quite low in Bangladesh than in other countries. That's why greater attention is needed for the improvement of this corp. Therefore, efforts should be made to develop high yielding varieties through breeding research.

In selection programme the knowledge of genotypic and phenotypic association of yield and yield contributing traits is very important. This knowledge gives the plant breeders more precision and accuracy in their works. The degree and nature of relationship between yield and yield contributing traits is measured by the correlation coefficient. Inclusion of more variables in correlation studies makes indirect effect complex and important (Nandan & Pandya, 1980). As path coefficient partitions the correlation coefficient values into direct and indirect effects so it can be said that path analysis provides a better scope for selection than correlation coefficient (Lakshmi, 2015). Yield by itself is probably not an adequate criterion of economic worth, as because it is a quantitative character and is associated with other components which are influenced by the various environmental conditions (Chaguale, 1967). So the direct selection is not reliable and helpful. Discriminant function technique of Smith (1936) is the good way for simultaneous selection. Thus, construction of selection index will be highly effective to select expected genotypes as better cultivars for future breeding exercise. Therefore, this investigation deals with characters association, path coefficient analysis and construction of selection index using yield and yield contributing characters from 10 crossing materials (F_1) in onion.

Materials and methods

The study was carried out at the central farm of Spices Research Center (SRC) of Bangladesh Agricultural Research Institute (BARI), Shibgonj, Bogura in the winter season (November-April). The experimental field was sandy to loam, organic matter was 1.1 % with a pH value of 6.8. F_1 seeds of different combination of BARI Piaz-1 (P_1), BARI Piaz-2 (P_2), BARI Piaz-3 (P_3), BARI Piaz-4 (P_4) and ON0256 (P_5) were the materials of this part of investigation. Among the materials P_1, P_2, P_3 and P_4 were released as varieties by SRC, BARI and ON0256 was the advance line of onion. They all are open pollinated. P_1, P_4 and ON0256 were winter season materials while P_2 and P_3 were summer season materials. All materials were possessed of distinct characters regarding size, shape, yield and shelf life. So, these materials were considered for crossing to develop high yielding materials having better shelf life.

Land preparation and layout of the experimental field

The land was opened with the help of a tractor driven disk-plough. Field was prepared by ploughing and laddering. For transplanting the seedlings weeds and stables were removed. After removal of trashes and weeds, the soil was mixed up well with rotten cattle manure. The surface of the seedbed was leveled and kept friable.

The experiment was set up in a randomized complete block design with three replications. The size of each plot was 3.0m × 1.0 m. The space between row and plant was 15 × 10 cm. The cross materials were distributed at random within each of the blocks.

Maintenance of the experimental plants

Sevin powder of Garden Tech is a popular name-brand pesticide containing carbaryl (1-naphthyl methylcarbamate, $C_{12}H_{11}NO_2$), a pest control product was sprayed to the bed just after sowing to save the sprouted seeds from ants. Application of manure and proper management was adopted for raising healthy plants. However, suitable agronomic and cultural practices such as weeding, watering, applying of fertilizers were done and also for crop protection, fungicides and insecticides etc. were sprayed regularly to obtain healthy plants. The crop was harvested when the plants showed the sign of maturity by neck fall, foliage senescence and drying out most of the leaves (Pandita, 1994).

Data recorded

Data was taken from 20 randomly selected plants from F_1 materials of half diallel crosses for leaf length (LL), bulb diameter (BD), bulb length (BL), bulb weight (BW), neck diameter (ND), neck length (NL), plant height (PH), number of leaves (NLs) and bulb yield/plot (BY).

Biometrical analysis of the data

Analysis of variance and covariances are necessary for the purpose of correlation coefficient and path coefficient studies (Miller et al., 1958). Variance and covariance analyses have been done as per Singh & Chaudhary (1979). Correlation coefficient was estimated according to Kwon & Torrie (1964). Path coefficient analysis was carried out according to the method illustrated by Dewey & Lu (1959) and selection index was prepared following the method of Smith (1936).

Results

Components of variation

Estimated values of phenotypic (σ^2_P), genotypic (σ^2_G), interaction (σ^2_I) and within error (σ^2_w) components of variation are presented in ***Table 1***. The phenotypic variation was higher than the genotypic, interaction and within error components of variations for all the characters. The σ^2_P was the joint product of σ^2_G, σ^2_I and σ^2_w. The maximum values for σ^2_P (47.6672) and σ^2_G (46.9179) were recorded for bulb weight. The minimum values for σ^2_P and σ^2_G were found for neck diameter to be 0.0550 and 0.0469 and for neck length to be 0.0865 and 0.0748, respectively. The variance due to interaction (σ^2_I) was found to be the highest as 0.2069 for bulb weight and the lowest as –0.000165 for bulb length. The highest and the lowest within component of variation (σ^2_w) were recorded as 0.6555 and 0.0039 for number of leaves and neck length, respectively.

Table 1. Values of phenotypic (σ^2_P), genotypic (σ^2_G), interaction (σ^2_I) and within error (σ^2_w) components of variation for nine characters in onion

Characters	Components			
	σ^2_P	σ^2_G	σ^2_I	σ^2_w
Leaf length (LL)	8.8072	8.1387	0.0456	0.6229
Bulb diameter (BD)	0.2103	0.1349	0.0581	0.0173
Bulb length (BL)	0.4162	0.3981	-0.000165	0.0183
Bulb weight (BW)	47.6672	46.9179	0.2069	0.5424
Neck diameter (ND)	0.0558	0.0469	0.00205	0.0068
Neck length (NL)	0.0865	0.0748	0.0078	0.0039
Plant height (PH)	17.3635	16.9497	0.00545	0.4084
Number of leaves (NLs)	1.929	1.2079	0.0677	0.6555
Bulb yield (BY)	3.0449	2.9669	0.0386	0.0394

Components of covariation

Components of covariation viz., phenotypic (σ^2P_{12}), genotypic (σ^2G_{12}), interaction (σ^2I_{12}) and within error (σ^2w_{11}) for all possible pairs of characters were calculated and shown in ***Table 2***. In this estimation, total thirty six pairs of combinations were measured. The pairs of any character with bulb weight (BW) and plant height (PH), respectively exhibited the maximum phenotypic and genotypic covariance. Among all the combinations, combination of BW × PH showed the highest phenotypic and genotypic covariance. The pairs of LL × BW as well as LL × PH also exhibited noticeable phenotypic and genotypic covariance. For the purposes of correlation coefficient (r) and path coefficient analyses, these covariances were measured.

Phenotypic correlation coefficient (r_p)

Result of phenotypic correlation coefficient is shown in ***Table 3***. Bulb weight with bulb yield/plot showed the highest significant phenotypic correlation. Bulb weight with the association of number of leaves exhibited the lowest but significant phenotypic correlation coefficient. Only plant height with all pairs of characters as well as number of leaves

Table 2. Values of phenotypic (σ^2P_{12}), genotypic (σ^2G_{12}), interaction (σ^2I_{12}) and within error (σ^2w_{12}) components of covariation of all possible pairs for nine characters in onion

Combinations	Components				Components				
	σ^2P_{12}	σ^2G_{12}	σ^2I_{12}	σ^2w_{12}	Combinations	σ^2P_{12}	σ^2G_{12}	σ^2I_{12}	σ^2w_{12}
LL × BD	0.5645	0.5728	-0.0054	-0.0028	BL × PH	2.2104	2.2059	0.0004	0.0041
LL × BL	1.5447	1.528	0.000905	0.0075	BL × NLs	0.6046	0.6039	-0.0012	0.0018
LL × BW	16.1787	16.1620	-0.0351	0.0518	BL × BY	0.07858	0.7845	0.0014	-0.000092
LL × ND	0.4722	0.4723	0.0044	0.0043	BW × ND	0.9424	0.9428	0.0008	-0.0012
LL × NL	0.2167	0.2523	-0.00716	-0.0284	BW × NL	0.3951	0.5255	0.6082	-0.7386
LL × PH	10.8230	10.8342	0.00253	-0.0136	BW × PH	24.18	24.21	-0.01153	-0.0156
LL × NLs	0.05761	0.0537	0.00211	0.0018	BW× NLs	4.9530	4.96765	0.0099	-0.0335
LL × BY	4.0902	4.1002	-0.00984	-0.0002	BW × BY	11.8857	11.8105	0.0664	0.0088
BD × BL	0.12732	0.12674	-0.000099	0.00068	ND × NL	0.0101	-0.0087	0.02297	-0.0111
BD × BW	1.954	1.957	-0.0034	0.0003	ND × PH	0.6703	0.6706	-0.0015	0.0012
BD × ND	0.0461	0.0455	0.000453	0.00014	ND × NLs	0.2154	0.2109	0.0087	0.0036
BD × NL	0.00603	0.01999	0.00094	-0.0149	ND × BY	0.2393	0.2372	0.0025	-0.0004
BD × PH	0.9934	0.9959	0.00022	-0.0027	NL × PH	0.2419	0.4337	0.0026	-0.1944
BD × NLs	0.2309	0.2387	-0.000621	0.0016	NL × NLs	0.05761	0.0537	0.0021	0.0018
BD × BY	0.4898	0.4881	0.0041	0.0013	NL × BY	0.0993	0.1804	0.0070	-0.0881
BL × BW	3.1125	3.1029	0.0005	0.0091	PH × NLs	3.6463	3.6598	-0.0126	-0.0009
BL × ND	0.1156	0.1164	-0.0003	0.0005	PH × BY	6.1005	6.1122	-0.0115	-0.0002
BL × NL	0.1156	0.0284	-0.0003	-0.0015	NLs × BY	1.2617	1.2590	0.0076	-0.0049

Table 3. Values of phenotypic (upper values) and genotypic (lower values) correlation coefficients for nine quantitative characters in onion

Characters	Bulb diameter (BD)	Bulb Length (BL)	Bulb weight (BW)	Neck diameter (ND)	Neck length (NL)	Plant height (PH)	Number of leaves (NLs)	Bulb yield /plot(BY)	
Leaf length (LL)	0.4148^{NS}	0.8068^{***}	0.7896^{***}	0.6736^{***}	0.2483^{NS}	0.8752^{***}	0.6556^{***}	0.7898^{***}	r_p
	0.5493^{*}	0.8535^{***}	0.8271^{***}	0.7645^{***}	0.3234^{NS}	0.9224^{***}	0.8535^{***}	0.8344^{***}	r_g
Bulb diameter (BD)		0.4394^{NS}	0.6281^{**}	0.4256^{NS}	0.0447^{NS}	0.5212^{*}	0.3625^{NS}	0.6121^{**}	r_p
		0.5469^{*}	0.7779^{***}	0.5720^{**}	0.1990^{NS}	0.6586^{**}	0.5913^{**}	0.7716^{***}	r_g
Bulb length (BL)			0.6980^{***}	0.7586^{**}	0.1402^{NS}	0.8222^{***}	0.6748^{**}	0.6980^{***}	r_p
			0.7180^{***}	0.8519^{**}	0.1646^{NS}	0.8492^{***}	0.8709^{***}	0.7218^{***}	r_g
Bulb weight (BW)				0.5779^{**}	0.1946^{NS}	0.8405^{***}	0.5165^{**}	0.966^{***}	r_p
				0.6356^{*}	0.2806^{NS}	0.8585^{***}	0.6611^{*}	1.000^{***}	r_g
Neck diameter (ND)					0.1454^{NS}	0.6810^{***}	0.6565^{*}	0.5805^{**}	r_p
					-0.0152^{NS}	0.7521^{***}	0.8861^{***}	0.6359^{**}	r_g
Neck length (NL)						0.4974^{*}	0.1411^{NS}	0.1934^{NS}	r_p
						0.3852^{NS}	0.1787^{NS}	0.3829^{NS}	r_g
Plant height (PH)							0.6300^{**}	0.8389^{***}	r_p
							0.8088^{***}	0.8619^{***}	r_g
Number of leaves (NLs)								0.5206^{*}	r_p
								0.6650^{**}	r_g

*, ** and *** indicates significant at 5%, 1% and 0.1% level, respectively and NS indicate non-significant; r_p and r_g indicates correlation at phenotypic and genotypic level, respectively.

Table 4. Path coefficient analysis showing direct (bold diagonal) and indirect effects of yield components on bulb yield of onion at phenotypic level

Characters	Leaf length (LL)	Bulb diameter (BD)	Bulb length (BL)	Bulb weight (BW)	Neck diameter (ND)	Neck length (NL)	Plant height (PH)	Number of leaves (NLs)	Total effect
Leaf length (LL)	**4.8010**	0.6050	-0.0843	-0.7873	-0.1231	0.2552	-4.360	0.3306	0.6371
Bulb diameter (BD)	0.7806	**1.1500**	0.2409	-1.5871	-0.1550	0.0978	-1.0615	-0.0773	-0.6116
Bulb length (BL)	-0.0954	0.2113	**4.0459**	0.5103	-0.7325	0.4080	-4.9246	-0.2113	-0.7883
Bulb weight (BW)	-0.6303	-0.9841	0.3610	**39.8794**	0.2413	0.1662	-2.6593	0.2992	36.6734
Neck diameter (ND)	-0.1675	-0.1634	-0.8807	0.4100	**1.5464**	0.0024	-0.1743	-0.3205	0.2524
Neck length (NL)	1.0424	0.3098	1.4727	0.8479	0.0071	**0.6027**	-5.2758	0.0578	-0.9357
Plant height (PH)	-4.1052	-0.7745	-4.0975	-3.1275	-0.1206	-1.2163	**16.3237**	-0.1926	2.3895
Number of leaves (NLs)	-0.5015	-0.0908	-0.2833	0.5669	-0.3574	0.0215	-0.3104	**1.1224**	0.1674

Diagonal bold figures denote direct effect and bulb yield/plot showed significant phenotypic correlation coefficient. But other characters viz., leaf length, bulb length, bulb weight and neck diameter with all possible pairs of characters showed significant phenotypic correlation coefficient except at least one pair of character association. The phenotypic correlation coefficient was found to be non-significant in maximum pairs of characters with bulb diameter. Neck length with number of leaves and bulb yield/plot also showed non-significant phenotypic correlation coefficient.

Genotypic correlation coefficient (r_g)

The association of bulb weight and bulb yield/plot showed significant and the highest positive genotypic correlation coefficient (***Table 3***) as in phenotypic level. Traits neck diameter, plant height and number of leaves significantly correlated with bulb weight. The lowest significant genotypic correlation coefficient was recorded in the association of bulb length and bulb diameter with a value of 0.5469 followed by bulb diameter × leaf length with 0.5493. Neck length with all possible pairs viz., plant height, number of leaves and bulb yield/plot showed non-significant genotypic correlation, whilst, except neck length, leaf length with all possible pairs viz., bulb diameter, bulb length, bulb weight, neck diameter, plant height, number of leaves and bulb yield/plot exhibited significant genotypic correlation coefficient. Again, bulb diameter with all possible characters showed significant genotypic correlation except with neck length. Similarly, bulb length and neck diameter showed non-significant genotypic correlation with neck length. Bulb yield/plot with plant height and number of leaves as well as plant height with number of leaves showed significant genotypic correlation.

Path coefficient at phenotypic level

Result of the path coefficient analysis at phenotypic level is presented in ***Table 4 and Figure 1***. It showed that bulb weight had the highest positive direct effect of 39.8794 on bulb yield/plot followed by plant height, leaf length, bulb length, neck diameter, bulb diameter, number of leaves and neck length. Leaf length showed the direct positive effect of 4.8010 on bulb yield/plot. The character had high indirect positive effect via bulb diameter followed by number of leaves and neck length. These effects via bulb length, bulb weight, neck diameter and were negative. Value 0.6371 noted as total effect. The positive direct effect of bulb diameter on bulb yield was 1.1500. Bulb diameter exerted high indirect positive effect of 0.7806 through leaf length and the lowest positive indirect effect of 0.0978 via neck length but negative indirect effect through bulb weight, neck diameter, plant height and number of leaves. Bulb length showed the positive direct effect on bulb yield/plot at this level. This trait via bulb diameter, bulb weight and neck length exhibited positive indirect effect and the rest of the characters showed negative effective. Bulb weight had maximum positive direct effect. The highest indirect effect of this character via bulb length was 0.3610 followed by number of leaves, neck diameter and neck length. The character bulb weight showed negative indirect effect via the rest of the characters viz., leaf length, bulb diameter and plant height. Neck diameter showed positive direct effect. The indirect positive effect was found in this character via bulb weight and neck length. Results of neck diameter on bulb yield/plot via leaf length, bulb diameter, bulb length, plant height and number of leaves showed negative indirect effects at phenotypic level. Neck length had positive direct effect on bulb yield/plot of 0.6027. This trait via all of the characters except plant height showed positive indirect effect. The total effect was –0.9357. Plant height had noticeable direct effect on bulb yield/plot, but this character via all other characters showed negative indirect effects are shown in ***Table 4***. The direct effect of number of leaves on bulb yield/plot was recorded as 1.1224. The character via bulb weight and neck length showed positive indirect effect. But the effect was found to be negative in all other remaining characters on bulb yield/plot.

Path coefficient at genotypic level

Result of path coefficient analysis at genotypic level is shown in ***Table 5 and Figure 2***. It was observed that leaf length had the highest positive direct effect on bulb yield followed by plant height, number of leaves, bulb length, neck diameter and neck length. Bulb diameter and bulb weight showed negative direct effect on bulb yield at this level. Leaf length via bulb diameter and neck diameter showed only positive indirect effect on bulb yield. Though bulb diameter had negative direct effect, but it contributed to bulb yield greatly through leaf length followed by bulb length. The lowest indirect effect was exerted by neck length. Bulb diameter via bulb weight, neck diameter, plant height and number of leaves showed negative indirect effect. Bulb length had the positive direct effect of 4.7278. This character via bulb diameter and neck length showed positive indirect effect on bulb yield. Bulb weight showed negative direct effect. Indirect effect of bulb weight via most of the traits was found to be negative. Neck diameter exhibited positive indirect effect through leaf length and neck length. In this level, neck diameter through all other characters showed negative indirect effect. Character neck length showed positive direct effect with the least value of 0.0766. The indirect effect of this character via bulb diameter, bulb length, and neck diameter was found to be positive, the total effect of which was –8.8140. The direct effect of plant height on bulb yield/plot was recorded as positive. This character only via number of leaves showed positive indirect effect at genotypic level. Rest of other characters showed negative indirect effect on bulb yield. Number of leaves had direct positive effect. The indirect effect of number of leaves on bulb yield via bulb weight and plant height was found to be positive, while it was negative for all other remaining characters.

Selection index

Result of selection index is presented in ***Table 6***. In this study, nine characters combination gave the maximum expected genetic gain of 336.6004%, followed by 333.7103% and 333.0884% obtained when eight characters were included in the function. Neck diameter (5) and bulb diameter (2), respectively were not included in above functions. When individual character was considered separately, such as NL (6) showed the highest expected genetic gain (409.2957) followed by ND (5), BL (3) and BD (2) in the index. Table 6 also revealed that any character associated with BW (4) / PH (7) / NLS (8) or BY (9) gave the maximum genetic gain of more than 300%. Considering three characters association in discriminant function (BW, PH and BY), the highest expected gain of 278.5264% was found. On the other hand, LL (1) in association with BW (4) and PH (7) gave 247.3390% and BL (3) associated with BW (4) and PH (7) gave 255.5630% genetic gain. In the present study, when four characters

Table 5. Path coefficient analysis showing direct (bold diagonal) and indirect effects of yield components on bulb yield of onion at genotypic level

Characters	Leaf length (LL)	Bulb diameter (BD)	Bulb length (BL)	Bulb weight (BW)	Neck diameter (ND)	Neck length (NL)	Plant height (PH)	Number of leaves (NLs)	Total effect
Leaf length (LL)	**11.7036**	3.2868	-0.1140	-5.5369	0.4807	-0.0986	-4.9221	-4.1839	0.2156
Bulb diameter (BD)	3.5547	**-3.1504**	0.6782	-2.4452	-0.1183	0.0287	-1.2912	-1.8181	-4.5616
Bulb length (BL)	-0.1291	0.7261	**4.7278**	-2.8599	-1.3024	0.0142	-1.9115	-1.3432	2.8780
Bulb weight (BW)	-4.6162	-1.8875	-2.0759	**-54.6608**	-3.5937	-3.3455	6.508	3.4497	-60.2219
Neck diameter (ND)	0.6300	-0.1444	-1.4819	-5.6611	**3.6527**	0.0938	-0.1738	-2.4384	-5.5231
Neck length (NL)	-0.2146	0.0570	0.0223	-8.7427	0.1531	**0.0766**	-0.1043	-0.0614	-8.8140
Plant height (PH)	-4.7660	-1.1552	-1.5976	7.5502	-0.0858	-0.0471	**8.4649**	7.995	16.3584
Number of leaves (NLs)	-5.2505	-2.1096	-1.4557	5.1854	-2.3332	-0.0361	0.7133	**6.4409**	1.1545

Diagonal bold figures denote direct effect

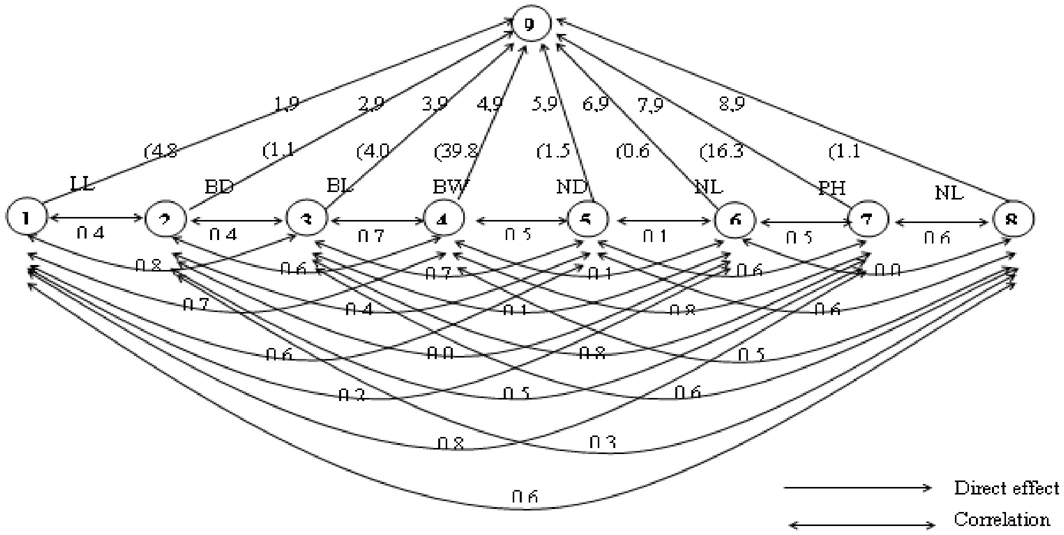

Figure 1. Path diagram of different yield contributing factors on bulb yield at phenotypic level

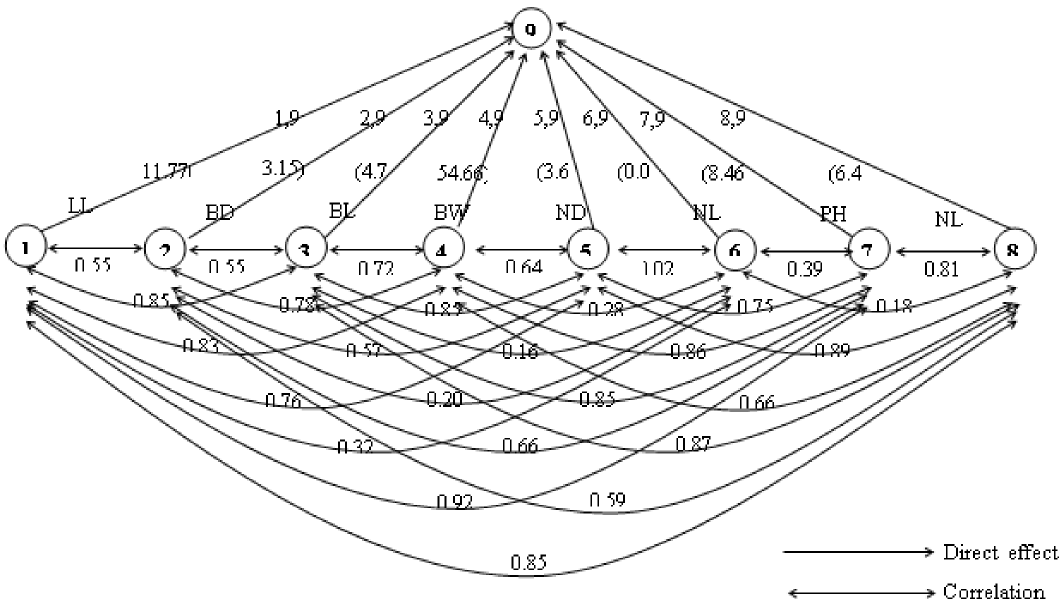

Figure 2. Path diagram of different yield contributing factors on bulb yield at genotypic level

Table 6. Expected genetic gain in percent of bulb yield over straight selection from the use of various selection indices in onion. Index showing values over 245 are shown only

Selection Index	Genetic Gain	Selection Index	Genetic Gain	Selection Index	Genetic Gain	Selection Index	Genetic Gain
LL (1)	-43.3232	1+3+6+7+9	263.1703	1+2+4+6+7+8	269.1024	1+2+3+4+5+6+9	254.8990
BD (2)	170.56	1+3+7+8+9	258.1294	1+2+4+6+7+9	307.6140	1+2+3+4+5+7+8	284.9304
BL (3)	208.8027	1+4+5+6+7	262.2805	1+2+4+7+8+9	303.1278	1+2+3+4+5+7+9	321.9960
BW (4)	-33.241	1+4+5+7+8	257.2278	1+2+5+6+7+9	246.3494	1+2+3+4+5+8+9	249.7388
ND (5)	263.8386	1+4+5+7+9	296.8907	1+2+6+7+8+9	249.1321	1+2+3+4+6+7+8	292.0995
NL (6)	409.2957	1+4+6+7+8	264.9432	1+3+4+5+6+7	285.6854	1+2+3+4+6+7+9	329.6067
PH (7)	-13.1155	1+4+6+7+9	303.8491	1+3+4+5+6+9	250.5713	1+2+3+4+6+8+9	257.6191
NLs (8)	10.4878	2+3+4+5+7	263.1703	1+3+4+5+7+8	280.9414	1+2+3+4+7+8+9	324.3082
BY (9)	5.4998	2+3+4+6+7	270.7607	1+3+4+5+7+9	318.3629	1+2+3+5+6+7+9	270.7590
1+4+7	247.339	2+3+4+7+8	265.8262	1+3+4+5+8+9	245.3467	1+2+3+5+7+8+9	265.8222
3+4+7	255.5630	2+3+4+7+9	304.6479	1+3+4+6+7+8	288.1869	1+2+3+6+7+8+9	273.3607
4+7+9	278.5264	2+3+6+7+9	250.8847	1+3+4+6+7+9	324.9688	1+2+4+5+6+7+8	272.4965
1+2+4+7	251.7072	2+3+7+8+9	245.6638	1+3+4+6+8+9	253.3216	1+2+4+5+6+7+9	310.6879
1+3+4+7	271.6842	2+4+5+6+7	260.1095	1+3+4+7+8+9	320.6714	1+2+4+5+7+8+9	306.2365
1+3+7+9	251.8588	2+4+5+7+9	285.8134	1+3+5+6+7+9	266.6173	1+2+4+6+7+8+9	313.0372
1+4+5+7	250.9421	2+4+5+8+9	285.1029	1+3+5+7+8+9	261.6246	1+2+5+6+7+8+9	252.7183
1+4+7+8	330.7290	2+4+6+7+8	252.8666	1+3+6+7+8+9	269.2480	1+3+4+5+6+7+8	291.4119
1+4+7+9	293.7072	2+4+6+7+9	292.9690	1+4+5+6+7+8	268.3744	1+3+4+5+6+7+9	327.9180
2+3+4+7	259.6919	2+4+7+8+9	288.3144	1+4+5+6+7+9	306.9534	1+3+4+5+6+8+9	256.8641
2+4+6+7	246.4997	3+4+5+6+7	285.6820	1+4+5+7+8+9	302.4605	1+3+4+5+7+8+9	323.6493
2+4+7+9	282.5406	3+4+5+7+8	306.5754	1+4+6+7+8+9	309.3242	1+3+4+6+7+8+9	330.1753
2+7+8+9	250.6757	3+4+5+7+9	304.1087	1+5+6+7+8+9	248.3602	1+3+5+6+7+8+9	272.6381
3+4+5+7	259.0818	3+4+6+7+8	272.7803	2+3+4+5+6+7	274.1414	1+4+5+6+7+8+9	312.3867
3+4+6+7	266.7599	3+4+6+7+9	310.9440	2+3+4+5+8+9	269.2507	2+3+4+5+6+7+8	280.0431
3+4+7+8	261.7681	3+4+7+8+9	267.8705	2+3+4+5+7+9	307.7455	2+3+4+5+6+7+9	317.5435
3+4+7+9	301.0819	3+5+6+7+9	250.2612	2+3+4+6+7+8	276.7198	2+3+4+5+6+8+9	237.7363
4+5+6+7	245.7244	3+5+7+8+9	245.0335	2+3+4+6+7+9	314.5236	2+3+4+5+7+8+9	313.1680
4+5+7+9	281.8362	3+6+7+8+9	253.0149	2+3+4+7+8+9	310.1122	2+3+4+6+7+8+9	319.8571
4+6+7+8	248.5085	4+5+6+7+8	252.1015	2+3+5+6+7+9	254.4541	2+3+5+6+7+8+9	260.6782
4+6+7+9	288.7660	4+5+6+7+9	292.2848	2+3+5+7+8+9	249.2871	2+4+5+6+7+8+9	301.7358
4+7+8+9	284.3641	4+6+7+8+9	246.8998	2+3+6+7+8+9	257.1742	3+4+5+6+7+8+9	282.0081
1+2+3+4+7	275.7693	1+2+3+4+5+7	279.1028	2+4+5+6+7+8	256.4124	1+2+3+4+5+6+7+8	291.7657
1+2+3+7+9	256.1731	1+2+3+4+6+7	286.3830	2+4+5+6+7+9	296.1576	1+2+3+4+5+6+7+9	331.4739
1+2+4+5+7	255.2630	1+2+3+4+6+9	251.3364	2+4+5+7+8+9	291.5407	1+2+3+4+5+6+8+9	261.1142
1+2+4+6+7	263.0220	1+2+3+4+8+9	281.6441	2+4+6+7+8+9	298.5878	1+2+3+4+5+7+8+9	327.2385
1+2+4+7+8	257.9797	1+2+3+4+7+8	319.0063	3+4+5+6+7+8	276.1401	1+2+3+4+6+7+8+9	333.7103
1+2+4+7+9	297.5698	1+2+3+5+7+9	259.6886	3+4+5+6+7+9	313.9944	1+2+3+5+6+7+8+9	276.7144
1+3+4+5+7	275.0514	1+2+3+6+7+9	267.3498	3+4+5+7+8+9	309.5797	1+2+4+5+6+7+8+9	315.9526
1+3+4+6+9	246.9648	1+2+3+7+8+9	262.3715	3+4+6+7+8+9	316.6605	1+3+4+5+6+7+8+9	333.0884
1+3+4+7+8	277.6265	1+2+4+5+6+7	266.3420	3+5+6+7+8+9	256.5607	2+3+4+5+6+7+8+9	322.8420
1+3+4+7+9	315.3460	1+2+4+5+7+8	261.4770	4+5+6+7+8+9	297.9170	1+2+3+4+5+6+7+8+9	336.6004
1+3+5+7+9	255.4181	1+2+4+5+7+9	300.7199	1+2+3+4+5+6+7	289.6255		

associated in different combinations, gave more than 300% genetic gain which are either LL (1), BW (4), PH (7) and NLs (8) or BL (3), BW (4), PH (7) and BY (9). It was also found that LL (1), in the association with BW (4), PH (7) and BY (9) gave 293.7072%, while BD (2) with above characters gave 282.5406% genetic gain. Whereas BW (4) in association with ND (5), PH (7) and BY (9); with NL (6), PH (7) and BY (9), and with PH (7), NLS (8) and BY (9) gave 281.8362%, 288.7660% and 284.3641% genetic gain, respectively. Genetic gain was noted as 315.3460% for the five characters combination of LL (1), BL (3), BW (4), and PH (7) and BY (9). The additional five indices were found of five characters combination, the genetic gain of which are 303.8491, 304.1087, 304.6479, 306.5754 and 310.9440. The six characters combination gave more than 300% genetic gain in sixteen selection indices. Among them the maximum percent gain of 324.9688 was found for the combinations of LL (1), BL (3), BW (4), NL (6), PH (7) and BY (9). The fourteen selection indices with seven characters association gave more than 300% expected genetic gain, which ranged from 301.7358to 330.1753.Most of the eight character combinations exhibited the highest gain of more than 300%. However, when nine characters such as, LL (1), BD (2), BL (3), BW (4), ND (5), NL (6), PH (7), NLs (8) and BY (9) were combined gave the highest genetic gain of 336.6004% in the discriminant function selection.

Discussion

For different traits components of variation varied differently. In this study, phenotypic component of variation (σ^2_P) was higher than genotypic (σ^2_G), interaction ((σ^2_I) and within error (σ^2_w) components of variation. Mohanty (2001) recorded higher values of σ^2_P than respective σ^2_G for all the studied traits in onion denoting environmental factors influencing their expression to some degree or other. Chatto et al. (2018) observed high genotypic and phenotypic coefficient of variation (>25%) for double bulb percentage, split bulb percentage and neck thickness as well as moderate genotypic and phenotypic coefficient of variation (10-25%) for polar diameter, equatorial diameter and yield in onion. Udachappa et al. (2019b) noted very less environmental influence on expression of the studied traits as it was evident by narrow gap between genotypic and phenotypic coefficients of variation. In the present study, the highest σ^2_P and σ^2_G were obtained for leaf length, bulb weight, plant height and bulb yield. High phenotypic values results of high genotypic values, so for effective selection larger genotypic values for any trait is always helpful. Trait bulb weight also showed the highest values for σ^2_P, σ^2_G, σ^2_I and σ^2_w which indicated the higher probability for development of the character through selection. The noticeable amount of phenotypic, genotypic, interaction and within error covariation was found in BW × BY, possibly indicating wide scope of selection for these pair of characters for improvement of yield.

It was observed from correlation studies that genotypic correlations were higher than the respective phenotypic correlations. Similar condition was also noted in the path coefficient studies. The high genotypic correlation does not reflect nature and magnitude of phenotypic variation. Aklilu et al. (2001), Trivedi et al. (2006) and Lakshmi (2015) noticed higher values of genotypic correlations in their studied material onion. Characters showed highly significant correlation with each other in maximum cases except with neck length in this study. Bulb yield/plot showed highly significant positive correlation with others at both levels indicating that characters were genetically related with bulb yield. Among all the associations, BW and BY showed the strongest correlation at both levels. Singh et al. (1995) found that bulb yield had the highest and positive correlation with neck girth and plant height and also bulb diameter with plant height. Pandian and Muthukrishnan (1979) also observed the effective correlation coefficient of bulb yield with bulb diameter, bulb weight, number of leaves, plant height etc. Total bulb yield (kg ha^{-1}) had significant positive correlation with plant height, leaf number per plant, bulb diameter and bulb yield per plant but had significant negative association with plant spacing (Rahman et al., 2002). Sahu et al. (2018) observed that total bulb yield significantly correlated with number of leaves per plant, leaf length (cm), polar diameter (cm), plant establishment (%), TSS (%) and average weight of marketable bulb (g). Hanci & Gokce (2018) found positive significant correlation of bulb weight with the diameter of pseudo stem and the length of the tallest leaf. Udachappa et al. (2019b) observed that individual bulb weight had positive and highly significant association with plant height, number of leaves, neck thickness and bulb diameter. Gedam et al. (2021) reported that bulb yield was strongly positively correlated with membrane stability index (MSI), relative water content (RWC), total chlorophyll content, antioxidant enzyme activity and leaf area under drought stress. Results of the present study were found to be similar with the above findings of different researchers.

Although the characters bulb diameter and bulb weight correlated with bulb yield/plot positively, but their direct effect was positive at phenotypic level only and negative at genotypic level. Both positive and negative direct effects were noted by Rajalingam & Haripriya (2000), Dewangan & Sahu (2014), Solanki et al. (2015), Lakshmi (2015) and Hanci & Gokce, 2018) in onion. The correlation coefficient of neck length was low and non-significant for all the characters, which may be due to the lowest direct effect of this character at both levels. According to Mohanty (2000) 1000-seed weight and the number of seed stalks per plant had high positive direct effect, while each of these characters had relatively high and positive indirect effect, on seed yield which agreed well to the present findings. Through the path analysis Rahman et al. (2002) and Aliyu et al. (2007) indicated that bulb diameter, plant height and leaf number per plant were the principal components of yield in onion. Basha & Lakshmi (2018) noticed that that plant height, neck thickness, total sugars, polar and equatorial diameter of bulb, average bulb weight and bulb yield per plot exhibited positive direct effect on total bulb yield.

Being a complex variable yield is highly affected by numerous genetic factors and environmental fluctuations (Naskar et al., 1982; Uddin et al., 1985). Thus, direct selection for yield is very confusing. Still, to gain the high yield, the multiple selection criteria on the basis of selection index would be more effective. For this purpose, to estimate relative efficiency of the character and character combinations through discriminant function selection is necessary. In the present investigation, when all the nine characters were included in an index, it exhibited the highest genetic gain as percentage. However, practically, it is not possible to study as many as nine characters in selection program and thus every one might get maximum genetic gain by using a minimum number of characters. Keeping this view in mind, different selection indices were studied. When a combination of two or more characters was studied in a function, the efficacy was higher than that of direct selection of bulb yield. When four characters LL (1), BW (4), PH (7) and NLs (8) or BL (3), BW (4), PH (7) and BY (9) associated in different combinations gave more than 300% genetic gain. The combination of five, six, seven or eight characters in this material showed higher percentage of expected gain. Deb & Khaleque (2007) and Hasan & Deb (2014) obtained the highest expected gain in five and two characters combinations, respectively in chickpea. On the basis of discriminant function analysis in opium poppy, Yadav et al., (2008) concluded that maximum gain for opium yield can be achieved for making selection of relatively big capsules with more weight, high seed yield and husk yield. Characters LL, BW, PH and NLs are considered as primary yield components because they are significantly correlated with BY at both levels as well as having high positive direct effect at phenotypic level. Except that, combinations of these four characters gave the commendable expected genetic gain of 330.7290% may be considered as important selection index for this material. These results indicated that the application of discriminant function selection through the above four traits can lead to an improvement of onion yield.

Conclusions

All the traits except neck length have shown positive and significant correlation both at phenotypic and genotypic levels with bulb yield per plot. Therefore, these traits are useful in direct selection for the uplift of onion yield. Path analysis exhibited that three traits viz., leaf length, bulb length and plant height had high positive direct effects at both levels. Thus, these traits could be used as effective selection for gaining high yield through the breeding procedure. Besides, leaf length, bulb weight, plant height and number of leaves are the important component of higher yield as they showed appreciated amount of genetic gain among the combinations of selection indices and also exhibited significant correlation with bulb yield as well as positive direct effect at phenotypic level, therefore selection of these traits may increase the good amount of onion yield.

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