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Original Article

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Genetic Association between Foliage Yield and Contributing Traits in Vegetable Chenopods: Implications for Genetic Improvement

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Abstract

A two-year study was conducted to evaluate the foliage yield potential in 13 germplasm lines of *Chenopodium album* for 3 successive cuttings. Correlations among foliage yield and its contributing traits, along with path analysis was also worked out. Foliage yield was maximum for C. *album* IC 107297, followed by *C. album* H.P. and *C. album amaranticolor*. The genotype × year interaction was non-significant for all the traits except stem diameter and moisture content. Leaf size, plant height and stem diameter showed significant positive correlation with foliage yield both at phenotypic and genotypic levels in all the cuttings. Chlorophyll *a* and chlorophyll *b* showed positive association with carotenoid content and negative association with ascorbic acid in all the cuttings as well as on pooled basis. Significant negative association was observed between leaves/plant and foliage yield at genotypic level in all the cuttings (Ist cutting: -0.472*; IInd cutting: -0.414*; IIIrd cutting: -0.480*) as well as on pooled basis (-0.591**). Protein content negatively affected foliage yield in all the cuttings. Fibre content had high negative value of direct path for pooled data but positively influenced foliage yield indirectly via leaves/plant, stem diameter, chlorophyll *a*, chlorophyll *b* and protein content. Ascorbic acid positively affected yield in Ist cutting as well as on pooled basis. Leaf size had high positive direct effect and significant positive association with foliage yield that indicates a true relationship between these traits. Leaf size also indirectly affected foliage yield in a positive direction through majority of other traits. Thus, direct selection for leaf size should be exercised to bring about improvement in foliage yield in *C. album*.

Keywords: *Chenopodium album*; foliage yield; protein; correlation; path analysis

Introduction

The increasing population of the world demands an increase in food production and cultivation of crops that are nutritious and require minimum inputs (Bhargava *et al.* 2010). Nowadays much attention has been centered on the exploitation and utilization of unusual and underutilized plant material for food (Bhargava *et al.*, 2007a; Fuentes and Paredes-Gónzalez, 2015). Green vegetables have long been recognized as the cheapest and most abundant source of protein, vitamins and minerals (Aletor *et al.*, 2002; Shukla *et al.*, 2006). In recent years chenopods have evoked interest, as a potential food crop for diversification of agriculture to newer areas, environmental sustainability and for combating the nutritional deficiency in many parts of the world (Jacobsen, 2003; Bhargava *et al.*, 2006a; Bhargava and Ohri, 2015, 2016; Bazile *et al.*, 2016). This underutilized crop does not require high inputs and can be easily grown on agriculturally marginal lands (Partap *et al.*, 1998; Bhargava *et al.*, 2003a; Fuentes and Bhargava, 2011). Chenopods are being cultivated in the watersheds of the Chenab, Ravi, Beas, Satluj and Yamuna rivers in the western Himalayas, and in the hilly areas of North Bengal, watershed of Teesta river and several states of north-eastern India (Joshi, 1991; Partap *et al.*, 1998). Although only three species viz. *C. quinoa*, *C. pallidicaule* and *C. berlandieri* subsp. *nuttalliae* are cultivated (Bhargava *et al.*, 2006b), the leaves and tender

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stems of numerous other species are consumed as food and fodder (Tanaka, 1976; Kunkel, 1984, Partap and Kapoor, 1985; Partap, 1990; Moerman, 1998; Partap *et al*., 1998). The foliage of *Chenopodium* constitutes an inexpensive and rich source of protein (26-64 g/kg), carotenoids (78-190 mg/kg) and vitamin C (0.5-2.4 g/kg) (Prakash *et al*., 1993; Fuentes and Paredes-Gónzalez, 2015). Besides this, the plant is recognized as an important medicinal plant in various ancient texts as well as by ethnic communities in many regions of the world (Bakshi *et al.*, 1999; Kirtikar and Basu, 2001; Singh *et al.*, 2003). Thus, vegetable chenopods are gaining importance due to their nutritional superiority and their ability to grow in agriculturally marginal lands with low levels of external inputs (Bhargava *et al.*, 2006a). This makes it a potential crop for future diversification of agriculture in various parts of the world (Bilalis *et al*., 2018).

Yield is a complex quantitative measure being affected by genetic and environmental factors as a result of which direct selection based on yield could be misleading. Most of the traits of interest to the breeders are complex and are the result of interaction of a number of components. Due to this reason, the breeder is interested in understanding the relationship between yield and its components for making the best use of these relationships in selection (Bhargava *et al*., 2008). Correlation coefficient analysis quantifies the relationship between a given pair of traits and is of prime importance in yield improvement. Correlations between different traits have three main causes viz. pleiotropy, linkage and environmental effects (Falconer, 1989; Chen and Lübberstedt, 2010). A pleiotropic gene causes variation in two or more traits when the gene is segregating and is the major cause of correlation in populations, which have mated at random for successive generations (Solovieff *et al*., 2013). Linkage causes transient correlations but is broken by recombination in some populations (Falconer, 1989). Environmental correlations show similarity or dissimilarity in the response of traits to a specific environment and therefore correlations between traits obtained in one environment are not much reliable in predicting the response of the same population in another environment. (Falconer, 1989; Aastveit and Aastveit, 1993; Manenti *et al*., 2016). Knowledge about the magnitude and sign (positive or negative) of genotypic correlation is important for understanding the relationship between traits and fitness in natural populations, for prediction of correlated responses to selection and for formulation of selection indices in breeding programmes (Bhargava *et al*., 2007b; Punzalan *et al*., 2014; Madrid *et al*., 2018). However, correlation alone does not reliably predict the success of selection because high correlation between two traits might be due to the influence of a third trait or a group of traits (Bizeti *et al*., 2004). The information derived from correlation coefficients should therefore be augmented by partitioning of correlation coefficients into direct and indirect effects using the path coefficient analysis (Sincik and Goksoy, 2014).

Path analysis, an extension of multiple regression (Streiner, 2005), has been widely used in crop breeding to determine the nature of relationships between yield and its contributing components and to identify components with significant effects on yield for potential use as selection criteria. Wright (1921) first used this approach to organize and graphically portray the relationships between predictor variables and response variable through a path diagram based on experimental results. Path analysis, also known as standardized partial-regression coefficient, partitions the correlation coefficients into direct and indirect effects and thereafter allows the separation of direct influence of each trait on yield from the indirect effects caused by mutual association among the traits themselves (Garcia del Morel *et al.*, 2003). In agriculture, path analysis has been extensively used by breeders to assist in the identification of traits that are useful as selection criteria to improve crop yield (dos Santos *et al.*, 2014; Mihretu *et al.*, 2014; Sincik and Goksoy, 2014; Ranjbar *et al.*, 2015; Khan *et al.*, 2016; Siddiqi *et al.*, 2016). Although considerable literature is available on correlation and path analysis in other foliage crops (Kaul *et al.*, 1996; Young *et al.*, 2000; Carpici and Celik 2010; Abel *et al.*, 2017), a limited amount of work has been conducted in *Chenopodium* spp. (Risi and Galwey, 1989; Bhargava *et al.*, 2003b) and that too is limited to grain chenopods. There is no study with regard to foliage yield in vegetable chenopods. Thus, the present investigation was undertaken to gain in-depth knowledge of the interrelationship among various morphological and quality traits in successive cuttings, and to elucidate the extent and direction (positive and negative) of direct and indirect influence of component characters over yield.

Materials and Methods

Experimental site

The experiment was conducted at the experimental field of National Botanical Research Institute (N.B.R.I.), Lucknow, India. The experimental site is situated at an altitude of 120 m above sea level at 26.5°N latitude and 80.5°E longitude. In the Indo-Gangetic Plains of North India there are two main crop seasons, summer (Kharif- March to July) and winter (Rabi- October to February). *Chenopodium* grows mostly during the rabi season during which the minimum and maximum temperature ranges from 2.5-19 °C and 14-29 °C respectively.

Experimental material

A large collection of *Chenopodium* spp. is being maintained at N.B.R.I that contains locally available as well as introduced germplasm lines of *C. album*. Some of them have been collected during many expeditions to the Himalayan region while others have been introduced. The experimental material comprised 13 germplasm lines of *C. album* of which 9 were hexaploid, 1 tetraploid and 3 diploid (Table 1).

The experiment

The material was evaluated for 2 successive years in a randomized block design with 3 replications. The plot size for each replication in each year was 4 m^2 with 6 rows per plot, spaced 30 cm apart. The field was disc ploughed and then harrowed and raked to obtain a good seed bed before sowing. No chemical fertilizer, fungicide or insecticide was applied either before or during the experiment. Weeding followed by hoeing was done at an interval of 20 days during the crop season. Irrigation was applied as and when needed.

Table 1. Germplasm lines, their ploidy level, chromosome number and origin

Germplasm lines	Ploidy level	Chromosome number	Origin
C. album PRC 9802	-	-	Himachal Pradesh, India
C. album IC 107297	-	-	Himachal Pradesh, India
C. album 'Mexico'	4x	36	Mexico
C. album (local red)	2x	18	Lucknow, India
C. album 'Siliguri'	2x	18	Siliguri, India
C. album amaranticolor	6x	54	Himachal Pradesh, India
C. album 'H.P.'	6x	54	Himachal Pradesh, India
C. album 605700	6x	54	Michigan, USA[a]
C. album CHEN 60/76	6x	54	Belgium[b]
C. album CHEN 95/97	6x	54	Unknown[b]
C. album 'Czech'	6x	54	Czech Republic
C. album 'Iowa'	6x	54	Iowa, USA
C. album 'Chandanbathua'	2x	18	India

[a] Source- U.S.D.A.
[b] Source- I.P.K. Gatersleben, Germany.

The germplasm was sown as a winter crop around mid-November in both the years. In each year, 3 foliage cuttings were performed at an interval of 15 days starting after 3rd week of sowing. Data was recorded on 5 randomly selected plants from each replication in each cutting for 5 morphological traits namely plant height (cm), branches / plant, leaves/plant, leaf size (cm^2) and stem diameter (cm), separately for each cutting. Foliage yield was recorded as fresh weight on plot basis for each of the 3 cuttings and pooled for total foliage yield. Besides this, 7-quality traits viz. leaf moisture (%), chlorophyll *a* (mg g^{-1}), chlorophyll *b* (mg g^{-1}), carotenoid (mg $100g^{-1}$), fibre (%), protein (%) and ascorbic acid (%) were also estimated for individual cuttings from the bulked leaves of each replication. Chlorophyll *a*, chlorophyll *b* and carotenoid was estimated in fresh leaves per the method proposed by Jensen (1978). Leaf protein was analysed in dried leaves following the method of Lowry *et al*. (1951), while ascorbic acid was analysed in fresh leaves as Glick (1954). Fibre content was estimated using the method proposed by Watson (1994).

Statistical analysis

The data were subjected to analysis of variance (ANOVA) as per Singh and Chaudhary (1985). The pooled mean values of both the experimental years were subjected to further statistical analysis. Genotypic and phenotypic correlations among different characters were analysed following Johnson *et al*. (1955). Path analysis (Dewey and Lu, 1959) was carried out to study the direct and indirect effects of dependent and independent variables on foliage yield. A trait was considered as effective if it showed significant positive correlation with yield, high positive direct effect and minimal negative indirect effect on yield.

Results

There were highly significant differences among the germplasm lines for most of the traits in individual cuttings as well as for pooled values except for chlorophyll *b* in IIIrd cutting in Year 1 (range: 0.96-0.217 mg g^{-1}), carotenoid in IInd cutting in Year 2 (range: 8.32-17.16 mg g^{-1}) and pooled data for leaf size in Year 2 (Table 2). These results indicate a high degree of variation for morphological as well as qualitative variation among the lines under study. The genotype × year interaction was non-significant for all the traits except stem diameter and moisture content (Table 2).

A perusal of foliage yield data (Table 3) revealed that mean foliage yield of 13 germplasm lines in both the years generally increased with successive cuttings and was maximum in the IIIrd cutting (2.25±0.25 kg $plot^{-1}$ and 2.09+0.26 kg $plot^{-1}$) (Table 3). Simultaneously, foliage yield increased in successive cuttings in each germplasm line in the year 1, except IC 107297, CHEN 60/76 and CHEN 95/97, which showed decrease after IInd cutting while, in year 2 only six germplasm lines showed increase in successive cuttings. Highest foliage yield for crop year 1 was recorded in IC 107297 (3.13±0.42 kg $plot^{-1}$), followed by 'H.P.' (3.04±0.34 kg $plot^{-1}$) and '*amaranticolor*' (2.56±0.30 kg $plot^{-1}$) while for year 2, IC 107297 (3.03±0.39 kg $plot^{-1}$) gave the highest yield, followed by 'H.P.' (2.94±0.27 kg $plot^{-1}$) and '*amaranticolor*' (2.41±0.20 kg $plot^{-1}$).

Correlation analysis revealed that the values of genotypic correlation were generally higher than corresponding phenotypic values for most of the traits (Table 4). Leaf size, plant height and stem diameter showed consistent positive significant correlation with foliage yield both at phenotypic and genotypic levels in all the cuttings. All these traits were strongly associated with foliage yield on pooled basis, phenotypically (leaf size: 0.866**; plant height: 0.698**; stem diameter: 0.641**) as well as genotypically (leaf size: 0.894**; plant height: 0.714**; stem diameter: 0.682**). At genotypic level, significant negative correlation was observed between leaves / plant and foliage yield in all the cuttings (Ist cutting: -0.472*; IInd cutting: -0.414*; IIIrd cutting: -0.480*) as well as on pooled basis (-0.591**). Branches/plant showed significant positive association with leaves/plant in the first 2 cuttings (genotypic values 0.604** and 0.617** respectively) and on pooled basis (genotypic value 0.417*). The corresponding phenotypic values were also significant, albeit a little lower in comparison to genotypic values. It was observed that among all the quality traits only chlorophyll *a*

and *b* showed consistent correlation with foliage yield in all the cuttings. Chlorophyll *a* was positively associated with foliage yield in all the cuttings, both phenotypically (Ist cutting: 0.680**; IInd cutting: 0.455*; IIIrd cutting: 0.474*) and genotypically (Ist cutting: 0.741**; IInd cutting: 0.480*; IIIrd cutting: 0.484*). Positive association also existed between chlorophyll *b* and foliage yield that decreased with each successive cutting, but was significant in the first 2 cuttings. An interesting observation was that leaf size exhibited highly significant positive association with chlorophyll a and chlorophyll *b* in all the cuttings and on pooled basis. Leaf moisture content was negatively associated with chlorophyll *a*, chlorophyll *b* and carotenoid content in the Ist cutting and on pooled basis. Chlorophyll *a* and *b* were positively correlated between themselves and with stem diameter in all the cuttings and on pooled basis. Chlorophyll *a* and chlorophyll *b* showed positive association with carotenoid content and negative association with ascorbic acid in all the cuttings as well as on pooled basis. The most striking results were obtained in relation to foliage yield and 3 major nutritional traits viz. carotenoid, protein and ascorbic acid. It was noticed that the association between foliage yield and these traits was positively significant in the Ist cutting, then the association decreased and became positive but non-significant in IInd cutting and finally became negative in the IIIrd cutting. Fibre content (range: 7.68-15.82%) showed least association with all other quality traits as well as with foliage yield.

Leaf size showed positive direct effect towards foliage yield in all the cuttings (Ist cutting: 0.183; IInd cutting: 0.280; IIIrd cutting: 0.710) and on pooled basis (1.640) (Table 5). In contrast, leaves/plant exhibited negative path with foliage yield in all the cuttings (-1.791, -0.339 and -0.245 respectively) (Table 5). Stem diameter also exhibited direct negative path with foliage yield in all the cuttings, except in IInd cutting, however it was positively contributing to foliage yield via leaves/plant, moisture content, fibre and ascorbic acid. Branches/plant directly influenced foliage yield in all the cuttings except in IIIrd cutting, and was the only trait, which indirectly influenced all the quality traits positively (Table 5). Plant height, in spite of having significant genotypic correlation with foliage yield, showed direct negative effect in all the cuttings except in IIIrd cutting, as well as on pooled basis. Chlorophyll *a* and chlorophyll *b* positively contributed towards yield for pooled data, while carotenoid showed positive direct effect towards foliage yield in all the cuttings (range: 6.23-18.92 mg 100 g^{-1}). Protein content negatively affected foliage yield in all the cuttings (range: 2.62-5.29%). Fibre content had high negative value of direct path for pooled data but positively influenced foliage yield indirectly via leaves/plant, stem

Table 2. Analysis of variance for different morphological and quality traits in vegetable *Chenopodium* (*C. album* L.) for 3 cuttings and pooled data over 2 years

Traits/Years	Ist Cutting		IInd Cutting		IIIrd Cutting		Pooled data		G × Y[a]
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	
Plant height (cm)	46.30**	51.13**	120.10**	139.42**	88.53**	104.21**	18.60**	21.49**	13.44
Branches/plant	7.92**	7.48**	13.07**	11.15**	12.19**	16.55**	4.11**	3.70**	4.90
Leaves/plant	114.50**	133.17**	155.24**	178.19**	81.46**	121.24**	39.15**	44.16**	21.13
Leaf size (cm^2)	249.11**	204.51**	351.87**	384.16**	293.40**	306.92**	163.92**	119.05	108.32
Stem diameter (cm)	0.034**	0.012**	0.021**	0.016**	0.029**	0.016**	0.012**	0.017**	0.027*
Moisture (%)	11.53**	19.49**	15.22**	28.28**	9.02**	21.38**	3.13**	4.72**	6.19*
Chlorophyll *a* (mg g^{-1})	0.22**	0.31**	0.26**	0.15**	0.09*	0.12**	0.06**	0.10**	0.06
Chlorophyll *b* (mg g^{-1})	0.04**	0.06**	0.03**	0.04**	0.003	0.02**	0.01**	0.02**	0.01
Carotenoid (mg 100g^{-1})	0.007**	0.004**	0.005**	0.009	0.006**	0.010**	0.004**	0.002**	0.004
Fibre (%)	7.44**	6.30**	9.31**	8.19**	11.53**	14.24**	3.49**	4.03**	4.92
Protein (%)	0.94**	0.79**	0.32**	0.42**	0.46**	0.41**	0.32**	0.39**	0.24
Ascorbic acid (%)	0.005**	0.004**	0.004**	0.004*	0.004**	0.005**	0.002	0.003**	0.001
Foliage yield (kg/plot)	1.39**	1.53**	2.41**	2.30**	2.84**	2.76**	2.03**	2.24**	1.17

[a] Genotype x year interaction; * Significant at P≤ 0.05; ** Significant at P≤ 0.01.

Table 3. Foliage yield of 13 germplasm lines of vegetable *Chenopodium* (*C. album*) for 2 successive years

Genotype	Year 1				Year 2			
	Ist cutting	IInd cutting	IIIrd cutting	Mean	Ist cutting	IInd cutting	IIIrd cutting	Mean
C. album PRC 9802	0.8	2.4	3.35	2.18	0.69	2.17	3.64	2.16
C. album IC 107297	2.3	3.71	3.4	3.14	2.24	3.5	3.36	3.03
C. album 'Mexico'	1.46	1.85	2.03	1.78	1.54	2.04	2.29	1.96
C. album (local red)	0.98	1.2	1.64	1.27	1.11	1.13	0.88	1.04
C. album 'Siliguri'	1.45	1.72	2.04	1.74	1.22	1.55	1.84	1.54
C. album amaranticolor	1.96	2.8	2.94	2.57	2	2.66	2.58	2.41
C. album 'H.P.'	2.35	3.31	3.48	3.05	2.48	3.43	2.91	2.94
C. album 605700	0.8	1.49	2.27	1.52	0.71	1.87	2.35	1.64
C. album CHEN 60/76	0.96	1.4	1.23	1.20	1.04	1.09	0.92	1.02
C. album CHEN 95/97	0.7	1.89	0.95	1.18	0.59	1.68	1.23	1.17
C. album 'Czech'	0.39	0.64	0.78	0.60	0.24	0.4	0.58	0.41
C. album 'Iowa'	2.16	2.6	2.72	2.49	2.06	2.37	2.09	2.17
C. album 'Chandanbathua'	1.32	2.41	2.5	2.08	1.43	2.06	2.61	2.03

Table 4. Phenotypic and genotypic correlation coefficients between foliage yield and its 5 agronomic and 7 quality traits in vegetable *Chenopodium*

Characters	Phenotypic				Genotypic			
	I	II	III	P	I	II	III	P
Plant height vs								
Branches/plant	0.178	0.589**	0.744**	0.648**	0.196	0.611**	0.760**	0.690**
Leaves/plant	-0.230	0.277	0.071	-0.021	-0.249	0.303	0.093	-0.018
Leaf size	0.350	0.548**	0.487**	0.559**	0.364	0.560**	0.497**	0.570**
Stem diameter	-0.294	0.712**	0.319	0.561**	-0.310	0.685**	0.330	0.594**
Moisture	0.231	-0.153	0.436*	0.224	0.245	-0.170	0.453*	0.260
Chlorophyll a	-0.139	-0.449*	0.191	0.289	-0.156	-0.460*	0.205	0.301
Chlorophyll b	-0.044	-0.547**	0.269	0.220	-0.059	-0.571**	0.283	0.249
Carotenoid	-0.160	-0.214	-0.255	0.019	-0.174	-0.230	-0.291	0.035
Fibre	0.393*	0.219	-0.054	0.024	0.410*	0.226	-0.076	0.050
Protein	0.020	0.439*	-0.431*	0.430*	0.049	0.460*	-0.449*	0.465*
Ascorbic acid	0.246	0.081	0.024	0.199	0.265	0.105	0.070	0.240
Foliage yield	0.429*	0.510**	0.618**	0.698**	0.449*	0.581**	0.653**	0.714**
Branches/plant vs								
Leaves/plant	0.578**	0.589**	0.183	0.389*	0.604**	0.617**	0.202	0.417*
Leaf size	0.024	0.257	0.211	0.091	0.051	0.289	0.203	0.114
Stem diameter	0.303	0.284	-0.158	0.214	0.320	0.310	-0.169	0.240
Moisture	-0.569**	-0.120	0.379	0.008	-0.586**	-0.139	0.394*	0.026
Chlorophyll a	0.521**	-0.610**	-0.132	0.159	0.539**	-0.634**	-0.130	0.164
Chlorophyll b	0.499**	-0.446*	-0.080	0.178	0.530**	-0.480**	-0.061	0.213
Carotenoid	0.470*	-0.090	0.101	0.231	0.429*	-0.068	0.136	0.240
Fibre	-0.284	-0.042	0.081	0.140	-0.299	-0.064	0.104	0.131
Protein	0.502**	0.248	-0.126	0.360	0.519**	0.232	-0.147	0.378
Ascorbic acid	0.069	0.510**	0.194	0.461*	0.096	0.547**	0.202	0.476*
Foliage yield	0.297	0.421*	0.270	0.371	0.309	0.443*	0.293	0.348
Leaves/plant vs								
Leaf size	-0.420*	-0.384*	-0.490**	-0.603**	-0.439*	-0.410	-0.511**	-0.636**
Stem diameter	0.006	-0.223	-0.594**	-0.340	0.017	-0.240	-0.617**	-0.337
Moisture	-0.440*	-0.046	0.547**	-0.093	-0.451*	-0.070	0.561**	-0.087
Chlorophyll a	-0.091	-0.370	-0.436*	-0.131	-0.114	-0.310	-0.460*	-0.153
Chlorophyll b	-0.070	-0.080	-0.299	0.099	-0.095	-0.097	-0.341	0.112
Carotenoid	0.120	-0.399*	-0.140	-0.176	0.143	-0.424*	-0.163	-0.195
Fibre	-0.464*	-0.160	0.229	-0.250	-0.480*	-0.191	0.246	-0.294
Protein	-0.191	0.439*	0.440*	0.180	-0.214	0.460*	0.481*	0.197
Ascorbic acid	-0.397*	0.449*	0.510**	0.247	-0.410*	0.463*	0.591**	0.260
Foliage yield	-0.423*	-0.402*	-0.459*	-0.562**	-0.472*	-0.414*	-0.480*	-0.591**
Leaf size vs								
Stem diameter	0.523**	0.729**	0.684**	0.860**	0.536**	0.760**	0.710**	0.874**
Moisture	-0.027	0.159	0.173	0.123	-0.040	0.178	0.201	0.149
Chlorophyll a	0.590**	0.621**	0.635**	0.569**	0.620**	0.702**	0.754**	0.675**
Chlorophyll b	0.619**	0.637**	0.670**	0.617**	0.646**	0.650**	0.691**	0.633**
Carotenoid	0.503**	0.260	-0.329	0.080	0.531**	0.246	-0.346	0.104
Fibre	0.196	0.120	-0.040	-0.016	0.183	0.114	-0.096	-0.043
Protein	0.350	-0.251	-0.331	-0.109	0.369*	-0.240	-0.374	-0.126
Ascorbic acid	-0.069	-0.153	-0.120	0.149	-0.109	-0.165	-0.104	-0.180
Foliage yield	0.701**	0.740**	0.890**	0.866**	0.740**	0.769**	0.865**	0.894**
Stem diameter vs								
Moisture	-0.121	0.150	-0.290	-0.144	-0.140	0.164	-0.309	-0.165
Chlorophyll a	0.643**	0.605**	0.590**	0.630**	0.631**	0.623**	0.610**	0.621**
Chlorophyll b	0.630**	0.581**	0.410*	0.596**	0.680**	0.614**	0.484*	0.649**
Carotenoid	0.491*	-0.190	-0.173	0.281	0.475*	-0.213	-0.199	0.308
Fibre	-0.130	0.241	-0.211	-0.152	-0.156	0.265	-0.254	-0.169
Protein	0.547**	-0.053	-0.504**	0.051	0.580**	-0.042	-0.539**	0.074
Ascorbic acid	-0.161	-0.314	-0.294	-0.324	-0.190	-0.334	-0.270	-0.349
Foliage yield	0.243	0.579**	0.653**	0.641**	0.280	0.624**	0.680**	0.682**
Moisture vs								
Chlorophyll a	-0.452*	-0.189	-0.446*	-0.574**	-0.470*	-0.162	-0.464*	-0.583**
Chlorophyll b	-0.403*	-0.061	-0.249	-0.519**	-0.429*	-0.103	-0.273	-0.540**
Carotenoid	-0.740**	-0.094	-0.617**	-0.499**	-0.781**	-0.124	-0.640**	-0.526**
Fibre	0.471*	0.008	0.316	0.610**	0.485*	-0.063	0.360	0.645**
Protein	-0.291	-0.480*	-0.484*	-0.261	-0.320	-0.463*	0.480*	-0.299
Ascorbic acid	-0.171	0.123	0.264	0.134	-0.195	0.140	0.290	0.166
Foliage yield	-0.391*	-0.074	0.239	0.056	-0.414*	-0.102	0.271	0.095

Chlorophyll *a* vs								
Chlorophyll *b*	0.934**	0.920**	0.758**	0.872**	0.956**	0.911**	0.802**	0.910**
Carotenoid	0.741**	0.219	0.169	0.637**	0.760**	0.202	0.193	0.680**
Fibre	-0.183	0.054	-0.396*	-0.303	-0.164	0.090	-0.419*	-0.340
Protein	0.856**	-0.194	-0.578**	0.104	0.901**	-0.220	-0.594**	0.110
Ascorbic acid	0.083	-0.656**	-0.139	-0.549**	0.070	-0.690**	-0.161	-0.560**
Foliage yield	0.680**	0.455*	0.474*	0.250	0.741**	0.480*	0.484*	0.292
Chlorophyll *b* vs								
Carotenoid	0.879**	0.218	0.159	0.629**	0.900**	0.256	0.140	0.645**
Fibre	-0.103	-0.141	-0.093	-0.313	-0.109	-0.160	-0.123	-0.386*
Protein	0.870**	-0.271	-0.480*	-0.029	0.853**	-0.299	-0.455*	-0.080
Ascorbic acid	0.290	-0.450*	-0.391*	-0.410*	0.320	-0.481*	-0.405*	-0.437*
Foliage yield	0.658**	0.648**	0.293	0.083	0.708**	0.624**	0.269	0.105
Carotenoid vs								
Fibre	-0.267	0.098	-0.051	-0.101	-0.290	0.106	-0.049	-0.156
Protein	0.690**	-0.248	0.443*	0.014	0.714**	-0.298	0.470*	-0.054
Ascorbic acid	0.282	-0.351	-0.164	-0.098	0.321	-0.377	-0.195	-0.114
Foliage yield	0.575**	0.393*	-0.469*	0.149	0.546**	0.410*	-0.481**	0.190
Fibre vs								
Protein	-0.130	0.569**	0.130	-0.449*	-0.154	0.544**	0.185	-0.492**
Ascorbic acid	0.173	-0.281	-0.057	-0.140	0.211	-0.319	-0.041	-0.179
Foliage yield	0.149	0.350	-0.143	-0.082	0.156	0.379	-0.194	-0.127
Protein vs								
Ascorbic acid	0.439*	0.059	0.369	0.460*	0.459*	0.110	0.377	0.484*
Foliage yield	0.611**	0.020	-0.529**	0.256	0.650**	0.084	-0.619**	0.290
Ascorbic acid vs								
Foliage yield	0.396*	0.149	-0.014	0.176	0.417*	0.163	-0.085	0.188

* Significant at P≤ 0.05; ** Significant at P≤ 0.01.

Table 5. Path coefficient analysis for 5 agronomic and 7 quality traits of foliage yield in vegetable *Chenopodium*

Characters		Plant height	Branch. /plant	Leaves /plant	Leaf size	Stem diam.	Moisture content	Chl. *a*	Chl. *b*	Carote-noid	Fibre	Protein	Ascorbic acid	Genotypic correlation
Plant height (cm)	I	**-0.436**	-0.068	0.113	-0.153	0.153	-0.140	0.077	0.029	0.087	-0.168	-0.013	-0.130	0.449*
	II	**-0.274**	-0.170	-0.066	-0.138	-0.184	0.040	0.127	0.364	0.058	-0.069	-0.090	-0.031	0.581**
	III	**0.369**	0.280	0.031	0.168	0.124	0.181	0.084	0.113	-0.084	-0.030	-0.162	0.013	0.653**
	P	**-0.765**	-0.541	0.030	-0.436	-0.441	-0.196	-0.240	-0.199	-0.025	-0.014	-0.330	-0.140	0.714**
Branches/ plant	I	0.277	**1.650**	0.980	0.026	0.480	-1.140	0.849	0.860	0.721	-0.582	0.810	0.131	0.309
	II	0.369	**0.483**	0.288	0.114	0.152	-0.067	-0.330	-0.240	-0.060	-0.031	0.133	0.261	0.443*
	III	-0.180	**-0.220**	-0.060	-0.041	0.041	-0.087	0.031	0.037	-0.034	-0.019	0.034	-0.064	0.293
	P	1.151	**1.685**	0.649	0.161	0.390	0.084	0.281	0.428	0.490	0.221	0.601	0.746	0.348
Leaves/ plant	I	0.441	-1.084	**-1.791**	0.743	-0.019	1.171	0.140	0.132	-0.170	0.891	0.381	0.710	-0.472*
	II	-0.102	-0.205	**-0.339**	0.136	0.080	0.010	0.289	0.230	0.126	0.057	-0.140	-0.130	-0.414*
	III	-0.021	-0.049	**-0.245**	0.112	0.130	-0.142	0.128	0.084	0.040	-0.047	-0.165	-0.120	-0.480*
	P	0.034	-0.314	**-0.840**	0.541	0.301	0.103	0.143	-0.084	0.202	0.240	-0.175	-0.206	-0.591**
Leaf size (cm^2)	I	0.106	0.032	-0.070	**0.183**	0.096	-0.009	0.109	0.104	0.102	0.050	0.070	-0.014	0.740**
	II	0.146	0.076	-0.117	**0.280**	0.211	0.039	-0.049	-0.099	0.071	0.048	-0.081	-0.035	0.769**
	III	0.365	0.152	-0.350	**0.710**	0.483	0.129	0.254	0.205	-0.244	-0.033	-0.281	-0.094	0.865**
	P	0.940	0.163	-1.042	**1.640**	1.430	0.183	0.540	0.371	0.130	-0.026	-0.160	-0.210	0.894**
Stem diameter (cm)	I	0.172	-0.163	-0.021	-0.253	**-0.463**	0.034	-0.322	-0.329	-0.236	0.081	-0.264	0.097	0.280
	II	0.149	0.073	-0.051	0.153	**0.186**	0.036	-0.030	-0.090	-0.059	0.053	-0.016	-0.064	0.624**
	III	-0.040	0.020	0.098	-0.112	**-0.163**	0.064	-0.113	-0.070	0.031	0.041	0.079	0.053	0.680**
	P	-0.825	-0.316	0.537	-1.245	**-1.452**	0.244	-0.970	-0.870	-0.488	0.296	-0.039	0.480	0.682**
Moisture content (%)	I	0.052	-0.016	-0.040	-0.004	-0.014	**0.030**	-0.028	-0.024	-0.081	0.033	-0.021	-0.012	-0.414**
	II	0.063	0.027	0.011	-0.057	-0.053	**-0.271**	0.252	0.271	0.031	0.021	0.143	-0.028	-0.102
	III	0.010	0.013	0.022	0.009	-0.014	**0.048**	-0.021	-0.024	-0.024	0.014	0.004	0.020	0.271
	P	0.182	0.032	-0.070	0.080	-0.120	**0.702**	-0.502	-0.481	-0.513	0.465	-0.194	0.091	0.095
Chl. *a* ($mg\ g^{-1}$)	I	0.074	-0.301	0.049	-0.306	-0.394	0.328	**-0.536**	-0.514	-0.430	0.097	-0.440	-0.034	0.741**
	II	-0.090	-0.140	-0.079	-0.050	-0.048	-0.059	**0.203**	0.321	0.056	0.020	-0.040	-0.140	0.480*
	III	-0.014	0.012	0.043	-0.029	-0.048	0.044	**-0.070**	-0.081	0.025	0.033	0.054	0.016	0.484**
	P	0.023	0.014	-0.075	0.024	0.036	-0.035	**0.045**	0.045	0.083	-0.024	0.015	-0.030	0.292

	I	-0.036	0.537	-0.093	0.633	0.683	-0.518	0.960	**0.938**	0.842	-0.130	0.904	0.240	0.708**
Chl. *b*	II	0.325	0.271	0.056	0.203	0.233	0.029	-0.534	**-0.584**	-0.121	0.068	0.183	0.312	0.624**
(mg g^{-1})	III	0.016	-0.008	-0.016	0.007	0.026	-0.009	0.034	**0.024**	-0.007	-0.021	-0.007	-0.017	0.269
	P	0.039	0.029	0.017	0.030	0.086	-0.090	0.136	**0.103**	0.133	-0.056	0.040	-0.059	0.105
	I	-0.074	0.209	0.034	0.239	0.219	-0.522	0.370	0.364	**0.482**	-0.148	0.332	0.149	0.546**
Carotenoid	II	-0.016	-0.012	-0.031	0.014	-0.017	-0.010	0.219	0.324	**0.070**	0.028	-0.022	-0.028	0.410*
(mg 100 g^{-1})	III	-0.006	0.004	-0.010	-0.008	-0.009	-0.014	-0.008	-0.022	**0.020**	-0.007	0.015	-0.090	-0.481**
	P	-0.012	-0.009	0.020	-0.005	-0.012	0.033	-0.022	-0.029	**-0.020**	0.006	0.035	0.014	0.190
	I	-0.034	0.053	0.024	-0.016	0.064	-0.043	0.031	0.063	0.019	**-0.062**	0.016	-0.019	0.156
Fibre	II	0.080	-0.024	-0.060	0.068	0.115	-0.019	0.221	-0.050	0.050	**0.407**	0.260	-0.118	0.379
(%)	III	0.017	-0.005	-0.021	0.004	0.041	-0.015	0.023	0.017	0.009	**-0.058**	-0.012	0.021	-0.194
	P	-0.013	-0.150	0.290	0.034	0.210	-0.780	0.424	0.480	0.080	**-1.190**	0.610	0.120	-0.127
	I	-0.019	-0.514	0.231	-0.374	-0.564	0.341	-0.870	-0.874	-0.680	0.154	**-1.024**	-0.460	0.650**
Protein	II	-0.103	-0.060	-0.130	0.079	0.024	0.143	0.263	0.289	0.079	-0.170	**-0.270**	-0.026	0.084
(%)	III	0.128	0.036	-0.142	0.081	0.155	-0.018	0.184	0.170	-0.162	-0.040	**-0.280**	-0.093	-0.619**
	P	0.115	0.096	0.063	-0.034	0.020	-0.064	0.066	0.015	-0.011	-0.130	**0.240**	0.131	0.290
Ascorbic	I	-0.074	-0.026	0.112	0.022	0.039	0.054	-0.039	-0.041	-0.110	-0.060	-0.101	**-0.241**	0.417*
acid	II	0.034	0.124	0.104	-0.033	-0.075	0.027	-0.151	-0.112	-0.091	-0.053	0.024	**0.190**	0.163
(%)	III	0.009	0.058	0.170	-0.036	-0.086	0.090	-0.042	-0.184	-0.051	-0.027	0.102	**0.270**	-0.085
	P	-0.155	-0.341	-0.170	0.104	0.234	-0.089	0.391	0.326	0.129	0.085	-0.353	**-0.749**	0.188

* Significance at P≤ 0.05; ** Significance at P≤ 0.01; I- Ist cutting; II- IInd cutting; III- IIIrd cutting; P- Pooled values.

diameter, chlorophyll *a*, chlorophyll *b* and protein content (Table 5). Ascorbic acid positively affected yield in Ist cutting as well as on pooled basis.

Discussion

Only 1 out of the 3 diploid lines viz. *C. album* 'Chandanbathua' gave high foliage yield, while the sole exotic tetraploid line (*C. album* 'Mexico') gave marginally higher yield than the mean value. All the 4 indigenous hexaploid lines performed better than most of the exotic lines giving high yields in both the environments and on overall mean basis.

The higher values of genotypic correlation with respect to their corresponding phenotypic correlations were probably due to the modifier effect of environment on character association at the genetic level. The different cuttings showed low values of residual effect indicating that the characters under study are sufficient to account for variability in the crop. The consistently high positive association between foliage yield and leaf size in all the cuttings and pooled data indicates the utility of this trait for selection with respect to foliage yield. Matteucci (1998) and Sarker *et al*. (2015) have also reported significant correlation between plant biomass and leaf area in *Amaranthus*. Such strong association has also been reported in in other crops like coriander, forage maize, cotton and oil palm (Awal *et al*., 2004; Akram-Ghaderi and Soltani, 2007; Carpici and Celik 2010; Chaulagain *et al*., 2011). It is evident from Table 4 that leaf size was significantly correlated with chlorophyll *a* and chlorophyll *b*. This presents a very interesting interwoven relationship. An increase in leaf size would lead to increase in chlorophyll content resulting in higher photosynthesis and in turn enhanced foliage yield. Simultaneously, significant positive correlation of stem diameter with foliage yield plays an important role in enhancing foliage yield, as with large stem diameter, the plant would be more vigorous and bear larger leaves. High genetic correlation between total yield and basal diameter of stalks has also been reported in other vegetable crops (Lopez-Anido *et al*., 1997). Leaves/plant was negatively associated with foliage yield and leaf size that suggests that increase in the number of leaves might lead to small leaf size and decreased foliage yield. Earlier, Shukla *et al*. (2004) have reported significant negative correlation between leaves/plant and foliage yield in *Amaranthus tricolor*. Significant positive association between leaves/plant and branches/plant has been reported for individual cuttings and for pooled data in vegetable amaranth (*Amaranthus tricolor*) (Shukla *et al*., 2004) and is quite understandable, as more branches would lead to more number of leaves/plant. Plant height observed significant positive correlation with branches/plant and leaf size in the IInd and IIIrd cuttings as well as on pooled basis. These results are in conformation with those obtained by Batta *et al*. (1995) who reported high positive correlation of plant height with leaf area in *Amaranthus* spp. Despite this, plant height maintained high significant positive association with stem diameter on pooled basis and in IInd cutting. This suggests that increase in plant height would lead to increase in branches/plant and leaf size along with enhancement in stem girth. This is in accordance with Shukla *et al*. (2004) who reported close association of plant height with branches/plant and stem diameter. Moisture content had negative correlation with chlorophyll *a*, chlorophyll *b* and carotenoid content in all the cuttings, except in IInd cutting suggesting that increase in moisture leads to decrease in these quality traits. There are reports of the existence of a negative genetic correlation between yield and quality components in forage grasses (Wilkins and Humphreys, 2003; Annicchiarico and Romani, 2005) as well as in cereals (Jenner *et al*., 1991; Pleijel *et al*., 1999). It was interesting to note that carotenoid, protein and ascorbic acid had significant positive association with foliage yield only in the Ist cutting when yield was minimum. The non-significant association of fibre content with foliage yield has also been reported in forage maize (Iptas and Acar, 2006). However, as yield increased with progression of successive cuttings, this association became negative. This is a general expectation since yield is known to be inversely proportional to quality.

However, in our study, analysis of pooled data revealed that no correlation existed between foliage yield and any of the major quality traits viz. fibre, carotenoid, protein or ascorbic acid. Thus, it is possible to increase yield in *C. album* without adversely affecting quality of the foliage. Such non-association of quality traits with foliage yield has also been reported in vegetable amaranth (Shukla *et al*., 2004).

Although correlation estimates are helpful in determining the components of complex traits such as yield, they do not provide an exact picture of the relative importance of the component traits (Santos *et al*., 2014). Correlation coefficients are not sufficient to describe relationship when the causal relationship among traits is needed and may be often misleading due to mutual cancellation of the component traits. Thus, study of path coefficient analysis becomes necessary, which takes into account the causal relationship of the components in addition to the degree of relationship. Path coefficient analysis developed by Wright (1921, 1923) permits the separation of correlation coefficient into components of direct and indirect effects and helps the breeder to decide on the use of correlated responses or of selection indices in breeding programs (Dewey and Lu, 1959; Santos *et al*. 2018). The advantage of path analysis is that it permits the partitioning of correlation coefficient into two components, the first being the path coefficient that measures the direct effect of a predictor variable upon its response variable, and the second is the indirect effect of a predictor variable on the response variable through other predictor variables (Dewey and Lu, 1959). Therefore, in the present study, genotypic correlations were partitioned into direct and indirect effects to know the relative importance of the components.

Path coefficient analysis was conducted taking foliage yield as dependent variable. Path analysis showed that branches/plant had highest positive direct influence on foliage yield followed by leaf size, moisture content, protein, chlorophyll *a* and chlorophyll *b*. Both branches/plant and moisture content did not exhibit association with foliage yield due to high negative indirect effect via plant height, ascorbic acid, stem diameter and leaves/plant on branches/plant, and fibre and plant height on moisture content. Branches/plant was also the only trait that exerted positive indirect influence over all other traits. The path analysis also revealed that plant height and stem diameter shared highly negative direct relationship with foliage yield. The correlation analysis, however, revealed significant positive correlation of foliage yield with both plant height and stem diameter due to the presence of positive indirect effect via leaf size and branches/plant. Apart from exerting high negative direct effect, plant height and stem diameter also indirectly influenced most of the traits negatively. Surprisingly, neither chlorophyll *a* nor chlorophyll *b* showed high direct or indirect effect on foliage yield. Fibre and ascorbic acid displayed high negative direct effect on yield in the Ist cutting and on pooled basis. In fact none of the quality traits seemed to majorly influence foliage yield and therefore selection based on quality traits is less likely to lead to yield enhancement in vegetable chenopods. Leaves/plant had high negative direct effect as well as significant negative correlation with foliage yield that makes it logical to select plants having less number of leaves for the improvement of foliage yield. These results are in accordance with those obtained by Shukla *et al.* (2004) who reported negative correlation of leaves/plant with foliage yield as well as negative direct path value for leaves/plant in vegetable amaranth (*A. tricolor* L.). Leaf size had high positive direct effect and significant positive association with foliage yield that indicates a true relationship between these traits. Leaf size also indirectly affected foliage yield in a positive direction through majority of other traits. Thus, direct selection for leaf size should be exercised to bring about improvement in foliage yield in *C. album*.

Conclusions

This investigation is significant since it is the first such study on correlation and path analysis among foliage yield and different contributing traits in *C. album* over successive cuttings. The present study has proved that the leaves of *C. album* can serve as an important source of cheap nutrients and successive harvests can be made in this crop that adds to its utility. An important outcome is the conclusion that plant type for increased yield should have less number of large sized leaves.

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