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RESEARCH ARTICLE

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Variability, heritability and genetic association in vegetable amaranth (*Amaranthus tricolor* L.)

Umakanta Sarker[1], Md Tofazzal Islam[2], Md Golam Rabbani[3] and Shinya Oba[4]

[1] *Bangabandhu Sheikh Mujibur Rahman Agricultural University, Faculty of Agriculture, Department of Genetics and Plant Breeding. Gazipur-1706, Bangladesh* [2] *Bangabandhu Sheikh Mujibur Rahman Agricultural University, Faculty of Agriculture, Department of Biotechnology. Gazipur-1706, Bangladesh* [3] *Bangladesh Agricultural University, Faculty of Agriculture, Department of Horticulture. Mymensingh-2202, Bangladesh* [4] *Gifu University, Faculty of Applied Biological Science, Laboratory of Field Sciences. Gifu, Japan*

Abstract

Forty three vegetable amaranth (*Amaranthus tricolor* L.) genotypes selected from different eco-geographic regions of Bangladesh were evaluated during 3 years (2012-2014) for genetic variability, heritability and genetic association among mineral elements and quality and agronomic traits in randomized complete block design (RCBD) with five replications. The analysis showed that vegetable amaranth is a rich source of K, Ca, Mg, proteins and dietary fibre with average values among the 43 genotypes (1.014%, 2.476%, 2.984, 1.258% and 7.81%, respectively). Six genotypes (VA13, VA14, VA16, VA18, VA26, VA27) showed a biological yield >2000 g/m^2 and high mineral, protein and dietary fibre contents; eleven genotypes had high amount of minerals, protein and dietary fibre with above average biological yield; nine genotypes had below average biological yield but were rich in minerals, protein and dietary fibre. Biological yield exhibited a strong positive correlation with leaf area, shoot weight, shoot/root weight and stem base diameter. Insignificant genotypic correlation was observed among mineral, quality and agronomic traits, except K *vs.* Mg, protein *vs.* dietary fibre and stem base diameter *vs*. Ca. Some of these genotypes can be used for improvement of vegetable amaranth regarding mineral, protein and dietary fibre content without compromising yield loss.

Additional key words: mean performance; genetic parameter; correlation; mineral; protein; dietary fibre; agronomic traits

Abbreviations used: CD (critical difference); GAMP (genetic advance in percent of mean); GCV (genotypic coefficient of variation); PCV (phenotypic coefficient of variation); RCBD (randomized complete block design); σ^2g (genotypic variance); σ^2p (phenotypic variance); h^2_b (heritability in broad sense)

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Correspondence should be addressed to Umakanta Sarker: umakanta_sarker@yahoo.com

Introduction

Amaranths (*Amaranthus* sp.) include a group of versatile food crops exhibiting high adaptability to new environments, even in the presence of different biotic and abiotic stresses (Rana *et al.*, 2007). Amaranths are dicotyledonous herbaceous plants including approximately 70 species, of which seventeen produce edible leaves and three produce food grains (Jansen, 2004). The edible amaranth is a popular leafy vegetable in the South-East Asia and is becoming increasingly popular in the rest of the continent and elsewhere due to its attractive leaf color, taste and nutritional value. The genus has also been reported to have anticancer properties (Dusgupta & De, 2007). Unlike other leafy vegetables, amaranth does not require a cold climate and can be cultivated during mild summers (Singh & Whitehead, 1996). It can also grow successfully under varied soil and agro-climatic conditions (Katiyar *et al*., 2000; Shukla & Singh, 2000). Amaranth leaves are a rich and inexpensive source of dietary fibre, proteins, vitamins and a wide range of minerals (Prakash & Pal, 1991; Shukla *et al.*, 2003; Routray *et al*., 2012; Venskutonis & Kraujalis; 2013). They serve as an alternative source of nutrition for vegetarian people in developing countries where the bulk of the population has little access to protein-rich food.

The species *Amaranthus tricolor* L. grown as leafy vegetable is loosely termed as vegetable amaranth; it is a self-pollinated C4 crop with wide genetic diversity and phenotypic plasticity (Rajan & Markose, 2007). In Bangladesh, *A. tricolor* is grown year-round and it is the only crop available in the hot summer months when no other foliage crop grows in the field. The species used as vegetable has short plants with large smooth leaves, small auxiliary inflorescences, and succulent stems. In this country, we have found in this plant a high variability respect to antioxidant, yield and yield-related traits (Sarker *et al*., 2014). Generally the success of any crop improvement program largely depends on the magnitude of genetic variability, heritability, genetic advance, and character association. Genetic variability is important for selection of parents with transgressive segregation (Patro & Ravisankar, 2004). Heritability estimates provide information on the proportion of phenotypic variance that is due to genetic factors for different traits, but these estimates alone are not a sufficient measure of the level of possible genetic progress. Effective selection can be made when the value of broad sense heritability estimates is considered together with the selection differential or genetic advance (Ibrahim & Hussein, 2006). Information on the amount and direction of association between yield and yield-related characteristics is important for rapid progress in selection and genetic improvement of a crop (Asish *et al*., 2008). Correlations between two or more plant characters and yield provide suitable means for indirect selection for yield.

Extensive research efforts have been carried out to ascertain the mineral composition of vegetable amaranth. Although some reports on its nutritional aspects are available (Shukla *et al.*, 2003, 2005, 2006), there are few works on mineral composition of leaves along with qualitative improvement of foliage with special reference to leaf attributes (Wu-Leung *et al*., 1968; Freiberger *et al.*, 1998). So, the present investigation was carried out (i) to estimate quality, biological yield and composition of minerals in 43 different cultivated genotypes of vegetable amaranth available in Bangladesh, and (ii) to find out possible ways for improvement of protein, dietary fibre, K, Ca and Mg compositions without compromising biological yield.

Material and methods

The experiment was conducted at the experimental field of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Bangladesh. The experimental site was located in the centre of the Madhupur Tract (AEZ-28), about 24°23´N 90°08´E, with a mean elevation of 8.4 masl. The experimental field was a high land having silty clay soil. The soil was slightly acidic (pH 6.4) and low in organic matter (0.87%), total N (0.09%) and exchangeable K (0.13 cmol/kg). The site falls under the subtropical zone and has mean temperatures of 29 °C (summer) and 18 °C (winter).

In a preliminary study, we collected 122 genotypes of vegetable amaranth (*Amaranthus tricolor* L.) from different eco-geographic regions of Bangladesh (unpublished data). From these, 43 accessions were selected due to their high yield potential as well as quality aspect; they were locally well adapted and cultivated as varieties by local farmers.

The genotypes were sown in a randomized complete block design (RCBD) with five replications, during three successive years (2012, 2013 and 2014). Each accession was sown in two unit plots, one of 1 m^2 for the biological yield and other of 0.6 m^2 for the mineral, quality and agronomic traits study. The spacing was 20 cm from row-to-row and 5 cm from plant-to-plant, respectively. Total compost (10 ton/ha) was applied during land preparation. Urea, triple super phosphate, murate of potash and gypsum were applied at 200, 100, 150 and 30 kg/ha, respectively. Appropriate cultural practices were also maintained. Thinning was done to maintain appropriate plant density within rows. Weeding and hoeing was done at 7 days interval. Day temperature during experimental period ranged from 25 to 38 °C. Irrigation (by narrow hose pipe from underground water) was provided at 5-7 days interval. To record the data on biological yield, plants were cut at the base of the stem (base of ground-level).

Data were collected at 30 days after seed sowing, on 10 randomly selected plants in each replication for four agronomic traits such as leaf area (cm^2), shoot weight (g), shoot/root weight and stem base diameter (cm). Biological yield was recorded on whole plot basis. Beside this, content percentages of three minerals, K, Ca and Mg and of protein and dietary fibre, were estimated.

Proteins

Proteins were estimated following the method of Lowry *et al*. (1951). For extraction of proteins, 500 mg of fresh vegetable amaranth leaves were washed and grinded in 1 mL of 20% trichloroacetic acid and placed overnight. Next day supernatant was discarded and the residue washed thoroughly 2-3 times with distilled water. The chlorophyll was removed from the residue by adding sufficient amount of 80% acetone solution and centrifugation, and then the sample was dried in vacuum to evaporate the acetone. The pellet was digested with 1 mL of 0.5 N NaOH at 80 °C for 10 min

in a water bath. Further, 4 mL of distilled water was added and the sample was centrifuged at 7500 rpm. An aliquot of 0.5 mL was taken and 5 mL of B.C. reagent (prepared by adding 50 mg of $CuSO_4.5H_2O$ in 10 mL of 2% sodium tartarate; 1 mL of this solution was added to 50 mL of 2% sodium carbonate prepared in 0.1 N NaOH) was added. After 10 min the colour was developed by the addition of 0.5 mL 1 N Folin Ciocalteu's reagent in the sample. The absorbance values were taken at 640 nm. The standard graph was plotted against concentration of protein and absorbance values, using BSA at concentrations 0.2, 0.4, 0.6, 0.8 and 1 µg/mL. The amount of protein in the sample was calculated by comparison (interpolation) with the standard graph and expressed as percentage of the fresh sample weight initially taken.

Dietary fibre

Fibre content was estimated using the method proposed by Watson (1994). Dried leaves (500 mg) were boiled for 30 min in 50 mL of 5% H_2SO_4 and 75 mL of distilled water. After 1 h, the sample was filtered through linen cloth with the addition of cold distilled water and residue was washed twice with distilled water. Again 50 mL of 5% KOH and 75 mL of distilled water was added to the residue and the solution was further boiled for 30 min. After adding 5 mL of cold distilled water the solution was allowed to stand for 15 min and filtered through linen cloth. The residue was again washed with hot distilled water followed by a mixture of 5 mL HCl: H_2O (1:2) and 5 mL ethanol. The residue was finally dried in a crucible at 80-100 °C, and the dried weight was measured and represented as percentage of initial material taken.

Minerals

For determination of mineral nutrient, the leaves were first oven dried and then digested in a mixture of $HClO_3$:HNO_3 (1:4). Potassium, calcium and magnesium were determined by flame photometry (Hitachi, Tokyo, Japan).

Statistical analysis

The raw data of the three years (2012 to 2014) were compiled by taking the means of all the plants taken for each treatment and replication for different traits. The data of consecutive three years were averaged and the averages were statistically and biometrically analyzed. Analysis of variance was done according to Panse & Sukhatme (1978) for each character. Genotypic and phenotypic variances, genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV), heritability (h^2_b) in broad sense and genetic advance in percent of mean (GAMP) were estimated according to Singh & Chaudhary (1985). Correlation among the traits was analyzed following Johnson *et al*. (1955a).

Results

Mean performance, coefficient of variation (CV, %) and critical difference (CD) for mineral content, quality and agronomic traits and biological yield for 43 vegetable amaranth genotypes are presented in Table 1. The analysis of variance revealed significant differences among the genotypes for the ten traits studied, indicating the validity of further statistical analysis.

Mineral composition

Potassium. Accession VA6 had the highest K content (1.60%), followed by VA16 (1.24%) and VA1 (1.12%). The lowest amount of K was found in VA36 (0.84%). The mean K content was 1.014%. The estimated CV for K was the highest among all minerals (0.71%).

Calcium. The average Ca content was 2.476%. The highest amount of Ca was found in VA31 (3.47%) followed by VA1 (3.25%) and VA28 (3.18%), while the lowest amount was found in the leaves of VA9 (1.49%). The CV for Ca (0.51%) was less than for K. Twenty genotypes showed above-average mean values for Ca content.

Magnesium. The average Mg content was 2.984%. The highest Mg content was observed in VA6 (3.53%), followed by VA16 (3.24%), and VA1, VA5 and VA19 (3.10% the three of them), whereas the lowest Mg content was observed in VA24 (2.84%). The CV (0.22%) was the least among all the minerals analyzed. Out of 43 genotypes, 18 showed above-average values for Mg content.

Quality traits

Protein content. The average protein content was 1.258%. VA32 showed the highest protein content (1.88%) followed by VA34 (1.69%), VA39 (1.62%), VA28 (1.59%) and VA33 (1.56%). On the other hand, the lowest protein content was observed in VA31 (1.01%). The CV for protein (0.84%) was the highest

Table 1. Mean performance, coefficient of variation (CV) and critical difference (CD) values for mineral, quality and agronomic traits in 43 vegetable amaranth genotypes. Years 2012-2014

Genotype	K (%)	Ca (%)	Mg (%)	Protein (%)	Dietary fibre (%)	Leaf area (cm^2)	Shoot weight (g)	Shoot/root weight	Stem base diameter (cm)	Biological yield (g/m^2)
VA1	1.12	3.25	3.10	1.24	7.31	56.08	12.92	13.11	2.77	1163.57
VA2	1.08	2.78	2.97	1.19	8.81	48.05	14.51	15.09	4.17	1322.60
VA3	1.03	2.05	3.04	1.27	9.51	60.29	15.53	26.39	4.83	1386.81
VA4	1.09	2.69	2.89	1.07	8.85	134.74	18.63	12.08	5.06	1666.19
VA5	1.07	2.05	3.10	1.08	7.31	86.62	11.53	15.43	6.47	1067.05
VA6	1.60	2.22	3.53	1.03	7.35	155.08	16.78	10.19	5.04	1516.08
VA7	1.05	2.39	3.04	1.06	8.08	114.93	18.42	10.17	5.73	1658.88
VA8	1.00	2.62	2.97	1.12	7.82	140.79	21.12	13.58	7.99	1900.01
VA9	0.97	1.49	2.85	1.29	7.74	58.45	15.42	14.90	4.88	1387.92
VA10	0.94	1.59	3.04	1.22	8.51	217.78	21.27	26.24	9.74	1914.98
VA11	0.97	2.45	3.04	1.42	8.31	206.43	11.09	10.75	6.51	997.09
VA12	0.97	2.39	3.00	1.11	7.75	130.38	18.81	8.36	6.27	1697.58
VA13	0.99	1.65	2.85	1.18	9.09	272.54	23.59	13.19	10.79	2131.40
VA14	0.97	1.90	2.91	1.28	6.74	294.59	25.49	10.41	11.45	2295.29
VA15	0.98	1.90	2.97	1.15	7.43	222.82	21.56	12.26	6.98	1946.94
VA16	1.24	1.76	3.24	1.13	7.82	187.84	28.98	18.28	8.61	2628.43
VA17	0.97	2.29	3.00	1.03	9.33	102.83	12.22	10.63	5.83	1098.52
VA18	0.97	3.09	3.00	1.04	8.21	299.67	24.82	14.80	5.08	2238.83
VA19	0.98	2.70	3.10	1.47	9.75	33.89	18.72	13.45	6.09	1687.90
VA20	1.00	2.39	3.04	1.41	7.71	120.80	12.45	14.85	6.40	1121.35
VA21	1.00	3.02	3.07	1.30	7.91	71.34	13.46	15.36	2.99	1242.66
VA22	0.95	3.01	3.04	1.23	6.65	123.63	18.12	13.68	6.30	1631.26
VA23	1.00	2.14	2.91	1.06	8.21	139.31	13.58	30.69	3.25	1232.58
VA24	1.03	1.89	2.84	1.03	9.55	136.30	10.20	12.34	5.84	918.04
VA25	1.03	2.53	2.97	1.14	8.37	197.76	17.07	10.62	8.23	1577.22
VA26	1.02	2.29	2.85	1.49	5.97	131.17	26.33	70.29	4.14	2372.89
VA27	1.01	2.79	2.85	1.17	6.02	90.72	27.58	44.09	4.60	2485.66
VA28	0.97	3.18	3.04	1.59	6.98	150.86	14.09	4.26	6.36	1278.67
VA29	0.98	2.85	2.97	1.29	7.25	69.85	14.47	14.14	4.56	1373.83
VA30	0.96	2.53	2.91	1.08	8.25	110.41	16.02	10.58	5.81	1435.89
VA31	1.00	3.47	3.04	1.01	8.74	99.87	17.32	10.38	5.55	1561.74
VA32	1.00	3.09	2.94	1.88	6.95	220.42	11.57	9.69	2.68	1051.46
VA33	1.00	2.39	2.94	1.56	7.77	127.01	10.16	12.29	5.47	954.37
VA34	0.95	2.29	2.84	1.69	7.20	156.98	12.25	8.68	7.10	1154.05
VA35	0.96	2.62	2.91	1.41	6.51	119.26	11.33	9.47	6.61	1042.90
VA36	0.84	2.38	2.94	1.23	6.68	159.98	10.17	9.78	6.43	936.51
VA37	1.03	2.79	3.01	1.38	6.20	210.38	15.76	8.81	7.32	1436.01
VA38	0.97	2.47	2.97	1.33	8.51	178.92	13.22	8.53	6.95	1182.90
VA39	0.98	2.39	2.91	1.62	7.85	114.59	18.26	8.13	5.97	1664.55
VA40	1.00	2.62	2.91	1.36	9.15	234.54	13.14	9.88	6.98	1187.71
VA41	0.97	2.69	2.97	1.18	6.84	117.52	17.06	15.73	6.10	1552.88
VA42	0.98	2.45	2.91	1.13	7.64	60.67	13.82	12.96	4.84	1256.58
VA43	0.98	2.94	2.90	1.15	7.35	109.92	17.52	9.57	5.49	1566.22
Mean	1.014	2.476	2.984	1.258	7.81	141.30	16.66	14.98	6.05	1509.86
Mean squares	0.036	0.638	0.044	0.122	2.812	12976.85	73.22	364.15	10.44	583375.75
SE	0.417	0.734	0.382	0.606	0.727	0.214	0.605	0.409	0.537	2.205
CV%	0.71	0.51	0.22	0.84	0.16	3.24	1.16	1.57	0.98	5.28
CD	0.203	0.357	0.186	0.295	0.3542	0.1043	0.294	0.199	0.2614	10.74

between the two quality traits analyzed. Out of 43 genotypes, 18 showed above-average values for protein content.

Dietary fibre content. The highest dietary fibre content was found in VA19 (9.75%), followed by VA24 (9.55%), VA3 (9.51%), VA17 (9.33%) and VA40 (9.15%). In contrast, the lowest dietary fibre content was observed in VA26 (5.97%). The average dietary fibre content was 7.81%. The CV for dietary fibre (0.16%) was the lowest among all the quality traits analyzed. Out of 43 accessions, 21 showed above-average values.

Agronomic traits

Leaf area. The highest leaf area was found in VA18 (299.67 cm^2), followed by VA14 (294.59 cm^2), VA13 (272.54 cm^2) and VA40 (234.54 cm^2), whereas, the lowest leaf area was found in VA2 (48.05 cm^2). The average leaf area was 141.30 cm^2. The CV for leaf area was 3.24%. Out of 43 accessions, 16 showed above-average values.

Shoot weight. The highest shoot weight was found in VA16 (28.98 g), followed by VA27 (27.58 g), VA26 (26.33 g), VA14 (25.49 g), VA18 (24.82 g) and VA13 (23.59 g). Conversely, the lowest shoot weight was observed in VA33 (10.16 g) followed by VA36 (10.17 g). The mean shoot weight was 16.66 g. The CV for shoot weight was 1.16%. Twenty accessions showed above-average values.

Shoot/root weight. The highest shoot/root weight was found in VA26 (70.29), and the lowest in VA39 (8.13), followed by VA12 (8.36) VA38 (8.53) VA34 (8.68) VA37 (8.81). The average was 14.98. The CV for shoot/root weight was 1.57%. Ten accessions showed above-average values.

Stem base diameter. The highest value was found in VA14 (11.45 cm), followed by VA13 (10.79 cm). The lowest value was observed in VA1 (2.77 cm), followed by VA32 (2.68 cm) and VA21 (2.99 cm). The average was 6.05 cm. The CV (0.98%) was the lowest among the agronomic traits analyzed. Twenty-one accessions showed above-average values.

Biological yield. The highest value was found in VA16 (2628.43 g/m^2) followed by VA27 (2458.66 g/m^2), VA26 (2372.89 g/m^2), VA14 (2295.29 g/m^2), VA18 (2238.83 g/m^2) and VA13 (2131.40 g/m^2). The lowest value was observed in VA24 (918.04 g/m^2) followed by VA36 (936.51 g/m^2), VA33 (954.37 g/m^2) and VA11 (997.09 g/m^2). The average was 1509.86 g/m^2. The CV (5.26%) was the highest among all the agronomic traits analyzed. Twenty accessions showed above-average values.

Variability studies

The genotypic and phenotypic variances (σ^2g, σ^2p) and coefficients of variation (GCV, PCV), h^2_b, and GAMP are presented in Table 2. The highest genotypic variance was for biological yield (194457.42), followed by leaf area (4326.36). Shoot/root weight, shoot weight and dietary fibre content exhibited moderate genotypic variances. On the other hand, the lowest genotypic variance was observed for K (0.012) followed by Mg (0.015), Ca (0.212) and protein (0.040) contents. The phenotypic variances for all the traits were slightly higher but close to the genotypic variances. GCV values ranged from 4.10% (Mg) to 73.56% (shoot/root weight). The PCV values showed similar trends as GCV values and ranged from 4.37% (Mg) to 74.75% (shoot/root weight). The heritability estimates were high for all the traits and ranged from 85.71% (K) to 99.99% (biological yield). The highest expected genetic advance was exhibited for shoot/root weight (149.10%) followed by leaf area (95.83%), stem base diameter (63.40%), shoot weight (61.01%), and biological yield (60.16%). Moderate GAMP was found in Ca (38.13%), protein content (32.78%), dietary fibre content (25.43%) and K (20.60%).

Correlation studies

Table 3 shows the phenotypic and genotypic correlations among the characters studied. The r_g (genotypic correlation coefficients) were very much close to the corresponding phenotypic values for all the traits. The biological yield had significant positive correlation with leaf area (0.326), shoot weight (0.999), shoot/root weight (0.454) and stem base diameter (0.368). Stem base diameter had a significant positive association with leaf area (0.597) and shoot weight (0.365), whereas this trait showed significant negative association with Ca (–0.491). Shoot/root weight exhibited significant positive

Table 2. Genetic parameters for mineral, quality and agronomic traits in 43 vegetable amaranth genotypes. Years 2012-2014

Genetic parameter	K (%)	Ca (%)	Mg (%)	Protein (%)	Dietary fibre (%)	Leaf area (cm^2)	Shoot weight (g)	Shoot/root weight	Stem base diameter (cm)	Biological yield (g/m^2)
σ^2g	0.012	0.212	0.015	0.040	0.936	4326.36	24.41	121.40	3.48	194457.42
σ^2p	0.014	0.214	0.017	0.044	0.940	4332.27	24.48	125.38	3.49	194468.25
GCV	10.80	18.60	4.10	16.29	12.38	46.55	29.66	73.56	30.82	29.21
PCV	11.67	18.68	4.37	16.67	12.42	46.58	29.70	74.75	30.87	29.21
h^2_b	85.71	99.07	88.24	95.45	99.36	99.86	99.71	96.83	99.71	99.99
GAMP	20.60	38.13	7.94	32.78	25.43	95.83	61.01	149.10	63.40	60.16

σ^2g = genotypic variance, σ^2p = phenotypic variance, GCV = genotypic coefficient of variation, PCV = phenotypic coefficient of variation, h^2_b = heritability in broad sense, GAMP = genetic advance in percent of mean.

Table 3. Genotypic (r_g) and phenotypic (r_p) correlation coefficients for mineral, quality and agronomic traits in 43 vegetable amaranth genotypes

Traits		Ca (%)	Mg (%)	Protein (%)	Dietary fibre (%)	Leaf area (cm^2)	Shoot weight (g)	Shoot/root weight	Stem base diameter (cm)	Biological yield (g/m^2)
K (%)	r_g	–0.091	0.753**	–0.256	0.012	–0.038	0.154	0.019	–0.124	0.153
	r_p	–0.093	0.755**	–0.258	0.013	–0.039	0.156	0.020	–0.126	0.155
Ca (%)	r_g		0.063	0.256	–0.194	–0.217	–0.183	–0.168	–0.491**	–0.182
	r_p		0.065	0.158	–0.196	–0.219	–0.184	–0.169	–0.493**	–0.184
Mg (%)	r_g			–0.214	0.042	–0.055	0.036	–0.179	–0.038	0.036
	r_p			–0.215	0.046	–0.057	0.038	–0.180	–0.039	0.037
Protein (%)	r_g				–0.295*	0.067	–0.255	–0.010	–0.084	–0.246
	r_p				–0.297*	0.069	–0.257	–0.013	–0.086	–0.248
Dietary fibre (%)	r_g					–0.065	–0.152	–0.246	0.074	–0.163
	r_p					–0.067	–0.155	–0.248	0.075	–0.166
Leaf area (cm^2)	r_g						0.326*	–0.127	0.597**	0.326*
	r_p						0.328*	–0.129	0.599**	0.328*
Shoot weight (g)	r_g							0.454**	0.365**	0.999**
	r_p							0.456**	0.367**	0.999**
Shoot /root weight	r_g								–0.226	0.454**
	r_p								–0.228	0.456**
Stem base diameter (cm)	r_g									0.368**
	r_p									0.369**

* Significant at 5% level, ** Significant at 1% level.

interrelationship with shoot weight (0.454). Significant positive association was observed between shoot weight and leaf area (0.326). Among mineral content quality and agronomic traits and biological yield, only K exhibited a significant positive association with Mg (0.753); protein showed a significant negative association with dietary fibre (–0.295); and Ca had a significant negative association with stem base diameter (–0.491). The rest of the interrelationships among mineral, quality and agronomic traits were insignificant.

Discussion

Variability plays a vital role for the selection of superior genotypes in crop improvement programs. Agronomic traits are quantitative in nature, and interact with environment under study, so partitioning the traits into genotypic, phenotypic, and environmental effects is essential to find out the additive or heritable portion of variability. In the present investigation, biological yield, leaf area, shoot/root weight, shoot weight and dietary fibre content had high to moderate genotypic and phenotypic variances along with GCV and PCV values, which indicate scope for improvement in these traits through selection due to predominance of additive gene action for these traits. Variability alone is not of much help in determining the heritable portion of variation. The amount of gain expected from a selection depends on heritability and genetic advance in a trait. Heritability has been widely used to assess the degree to which a character may be transmitted from parent to offspring. Knowledge of heritability of a character is important as it indicates the possibility and extent to which improvement is possible through selection (Robinson *et al*., 1949). However, high heritability alone is not enough to make sufficient improvement through selection generally in advance generations unless accompanied by substantial amount of genetic advance (Johnson *et al*., 1955b). The expected genetic advance is a function of selection intensity, phenotypic variance and heritability and measures the differences between the mean genotypic values of the original population from which the progeny is selected. It has been emphasized that genetic gain should be considered along with heritability in coherent selection breeding program (Shukla *et al*., 2006). It is considered that if a trait is governed by non-additive gene action it may give high heritability but low genetic advance, which limits the scope for improvement through selection, whereas if it is governed by additive gene action, heritability and genetic advance would be high, consequently substantial gain can be achieved through selection. In the present study the heritability and genetic advance values were high for all the traits, indicating preponderance of additive gene effects. The genotypic correlation coefficients were very much close

to the corresponding phenotypic values for all the traits indicating additive type of gene action for the expression of these traits. Insignificant genotypic correlation was observed among mineral, quality and agronomic traits and biological yield, except K *vs.* Mg (0.753), protein *vs.* dietary fibre (–0.295), and stem base diameter *vs.* Ca (–0.491). This indicates that selection for high mineral, protein and dietary fibre content might be possible without compromising yield loss. On the other hand, most of the interrelationships among different agronomic traits were significant. Similar trend was observed by earlier works in *A. tricolor* (Shukla *et al*., 2006; Sarker *et al.*, 2014). Biological yield had significant positive correlation with leaf area (0.326), shoot weight (0.999), shoot/root weight (0.454) and stem base diameter (0.368), indicating that biological yield of vegetable amaranth could be increased with the increase of leaf area, shoot weight, shoot/root weight and stem base diameter. Sarker *et al*. (2014) observed that foliage yield was highly associated with plant height, leaf area, leaves/plant stem base diameter and dietary fibre content. Similarly, Shukla *et al*. (2010) observed a positive association of foliage yield with beta carotene and ascorbic acid. Stem base diameter had a significant positive association with leaf area (0.597), and shoot weight (0.365), whereas these traits showed significant negative association with Ca (-0.491). Shoot/root weight exhibited significant positive interrelationship with shoot weight (0.454) indicating that plant with thick stem contained less Ca, more leaves and shoot weight. Significant positive association was observed between shoot weight and leaf area (0.326).

Considering high genotypic and phenotypic variances along with GCV and PCV values, high heritability coupled with GAMP, five traits (leaf area, shoot/root weight, shoot weight, dietary fibre content and biological yield) could be selected for the improvement of 43 vegetable amaranth genotypes under study. However, the correlation study revealed strong positive association of leaf area, shoot weight, shoot/root weight and stem base diameter with biological yield. Selection based on leaf area, shoot weight, shoot/root weight and stem base diameter could lead to increase the biological yield of vegetable amaranth genotypes. Insignificant genotypic correlation was observed among mineral, quality and agronomic traits except K *vs.* Mg (0.753), protein *vs.* dietary fibre (–0.295) and stem base diameter *vs.* Ca (–0.491) indicated that selection for high mineral, protein and dietary fibre content might be possible without compromising yield loss. Based on mean performance of the genotypes, six vegetable amaranth genotypes VA16, VA27, VA26, VA14, VA18 and, VA13 were identified as high yielding having substantial mineral, protein and dietary fibre content.

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