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GENETIC VARIATION IN MINERAL PROFILES, YIELD CONTRIBUTING AGRONOMIC TRAITS, AND FOLIAGE YIELD OF STEM AMARANTH

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The study was evaluated to estimate mineral profiles and find out selection criteria for high foliage yielding cultivars by assessing the magnitude of genetic variability, heritability, genetic advance, association, and contribution of characters of sixteen stem amaranth genotypes in a randomized block design with three replications. Based on high heritability and high GA and GAPM and close values between Vg vs. Vp and GCV vs. PCV, all the traits could be selected to improve the foliage yield of stem amaranth. A significant and desirable positive correlation was observed for Fe, Ca, Mn, K, and leaves plant^{-1} both at genotypic and phenotypic levels. These five traits could be selected for improving the foliage yield of stem amaranth as these traits exhibited less influence on the environment. The insignificant genotypic correlation values were observed between mineral *vs*. mineral and mineral *vs*. foliage yield and yield contributing agronomic traits, which indicate that selection for high mineral content might be possible without compromising yield loss. A high to moderate direct effect along with a significant correlation was found in Fe, K, Ca, and Mn. Fe, K, Ca, and Mn had the most significant contribution to foliage yield of stem amaranth as these traits exhibited considerable positive direct effects and significant correlation coefficients on foliage yield. The accessions AS7, AS4, AS5, AS14, and AS16 had high foliage yields containing moderate to high mineral profiles. These five accessions could be selected as high-yielding cultivars. Selection could be made based on Fe, K, Ca, and Mn content to improve stem amaranth. The accessions AS7, AS4, AS5, AS14, and AS16 could be used as high foliage yielding and mineral profiles enrich cultivars.
Keywords: mean, genotypic and phenotypic variances, genotypic and phenotypic coefficient of variations, heritability, genetic advance, correlation, and path coefficients.

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Abbreviations
CV (coefficient of variation); CD (critical difference); GA (genetic advance); GAMP (genetic advance in percent of mean); GCV (genotypic coefficient of variation); PCV (phenotypic coefficient of variation); RCBD (randomized complete block design); Vg (genotypic variance); Vp (phenotypic variance); h^2_b (heritability in broad sense); Fe (iron); Zn (zinc); Ca (calcium); Mn (manganese); Mg (Magnesium); K (Potassium); Ni (nickel)

INTRODUCTION

Amaranths are very fast-growing C_4 crops of extremely high-yield potential. In warm, humid tropical climates, the foliage yield exceeds 30 tons of fresh green or 4.5 tones of dry matter per hectare in 4 weeks from the direct sowing. It is an inexpensive vegetable and has abundant dietary fiber and protein with essential amino acids such as methionine and lysine (SARKER *et al*., 2016; 2017). It contains all essential macro and microelements for human nutrition (SARKER and OBA, 2019a-b), pigments, such as betacyanin, betaxanthin, chlorophyll, carotenoids, beta-carotene (SARKER *et al*., 2018a-c; 2019c; 2022; HOSSAIN, *et al*., 2022), and antioxidant phytochemicals, such as vitamin C, (SARKER *et al*., 2020a-c) phenolic compounds, flavonoids, and antioxidant capacity (SARKER and OBA, 2020a-g; 2021; SARKER *et al*., 2022a,b). In Bangladesh, amaranth is grown year-round. It could be produced in the gaps period of leafy vegetables between winter and summer in both homestead nutrition gardens and commercial cultivation (SARKER *et al*., 2015a,b). Stem amaranth is a trendy vegetable in Bangladesh, including south-east Asia, Africa, and South America, and is consumed for many culinary purposes. It is consumed both as a leafy vegetable in the early stages and vegetables (stem only) in the later stage. In the earlier stage, around 30 days old, the whole plant, including leaves and tender, succulent stems, is used as leafy vegetables. The large barreled fleshy stalk of this amaranth is succulent and juicy and becomes edible as vegetables up to flowering initiation.

The existence of wide variability and remarkable phenotypic plasticity were documented in amaranth. Plant breeding revolves around selection, which can be effectively practiced only in the presence of variability of desired traits (SARKER *et al*., 2002a,b). Hence the success of breeding depends entirely upon the variability (GANAPATHI *et al*., 2014). However, some improved cultivars have been developed in different countries, including India, Bangladesh, and elsewhere but many suitable local types are often found in different regions. Critical evaluation of the available germplasm and selecting the improved types with high yield potential and good quality is always a good promise. The variability arises due to genotypic and environmental effects. Variability has two components, such as additive and non-additive. To obtain a clear understanding of the pattern of variations, the phenotypic variance has been partitioned into genotypic and environmental variance. The extent of variability for any character is significant for the improvement of a crop through breeding. Correlation coefficient analysis measures the mutual relationship between various plant characters and determines the component characters on which selection can be based on genetic improvement (KARIM *et al*., 2007, 2014). Mass selection has been used to improve foliage yield through an indirect choice of highly heritable characters that are associated with foliage yield. Therefore, it is necessary to know the correlation of various component characters with foliage yield and among themselves.

The correlation between foliage yield and component characters may sometimes be misleading due to an overestimation or underestimation of its association with other characters. Thus, yield components have influenced ultimate foliage yield both directly and indirectly. Therefore, correlation in combination with path coefficient analysis could be an essential tool to determine the association between direct and indirect and quantify the direct and indirect influence of one character upon another.

Although amaranths are drought (SARKER and OBA, 2018a-d) and salinity (SARKER and OBA, 2018e; 2019; SARKER *et al*., 2018) tolerant and inexpensive sources of minerals, there is scarce information on this species. To our knowledge, there are scarce information on mineral profiles, yield contributing agronomic traits, and foliage yield in diversified stem amaranth germplasms available in Bangladesh and elsewhere. Therefore, to fill these gaps, the present investigation was undertaken to evaluate mineral profiles of stem amaranth genotypes and to find out selection criteria for high foliage yielding cultivars by assessing the magnitude of genetic variability, heritability, genetic advance, association, and contribution of characters to foliage yield in selected genotypes.

MATERIALS AND METHODS

Experimental site and soil condition

The experiment was carried out at the experimental farm of Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur (AEZ28, 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).

Experimental design, layout, cultural practices

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The plot size was 1 m^2 to estimate yield contributing agronomic traits and mineral content and 4 m^2 for estimation of foliage yield. The spacing was maintained at 25 cm × 5 cm from row to row and plant to plant, respectively. The experiment was conducted using 16 promising genotypes of stem amaranth collected from the Department of Genetics and Plant Breeding. There are red and green colors in both stem and leaves. The stems are succulent solid and juicy. Tender leaves and stems are used as a salad or consumed just after boiling. Mature stems are used as vegetables for different culinary purposes. The total required compost (10 tons/ha) was applied during land preparation. Urea, triple superphosphate, murate of potash, and gypsum were applied at 200, 100, 150, and 30 kg/ha, respectively. Appropriate production technology was also maintained. Thinning was done to maintain appropriate plant density within rows. Weeding and hoeing were done at 7 days intervals. The average day temperature during the experimental period ranged from 21.5 to 28.5 °C (Table 1). Irrigation (by narrow hose pipe from underground water) was provided at 5-7 days intervals.

Table 1. Weather data of experimental cite during cropping period in 2017

March 2017	Air temperature (ºC)**			Soil temperature (ºC)**	Humidity**	Rainfall	Evapoation
Date	Maximu	Minimum	Average	30 cm depth	(%)	mm	mm
1	31	14	22.5	20	82	0.00	3.63
2	31	15	23.0	20	75	0.00	3.54
3	32	17	24.5	22	75	0.00	3.89
4	33	19	26.0	23	76	0.00	4.07
5	30	20	25.0	23	91	0.65	3.04
6	31	18	24.5	23	91	19.81	4.06
7	30	18	24.0	23.5	91	0.00	3.54
8	31	20	25.5	22	91	0.00	3.27
9	29	18	23.5	22	91	0.00	2.65
10	30	19	24.5	23	91	0.00	2.48
11	29	18	23.5	22	-	16.88	3.61
12	25	19	22.0	23	83	10.06	2.28
13	28	16	22.0	23	66	0.00	3.27
14	29	15	22.0	22.5	75	0.00	3.54
15	29	14	21.5	22	66	0.00	3.63
16	30	14	22.0	21	83	0.00	3.80
17	31.5	15	23.3	22	66	0.00	4.42
18	30	17	23.5	21	91	0.65	4.28
19	29	17	23.0	21	-	0.49	3.58
20	30.5	16	23.3	23	91	5.19	1.83
21	28	18	23.0	21	75	5.84	2.22
22	28	18	23.0	22	75	0.00	3.36
23	31	19	25.0	23	84	0.00	3.63
24	31	21	26.0	22	75	0.00	3.36
25	30	22	26.0	22	92	0.00	3.98
26	26	18	22.0	21	83	17.21	3.05
27	30	23	26.5	25	92	0.00	3.36
28	31	24	27.5	25	92	3.25	2.36
29	30	25	27.5	25	-	0.00	3.10
30	29.5	25	27.3	25.5	92	0.00	2.65
31	32.0	25.0	28.5	26.0	92.0	2.60	1.36
Total/Aver	29.85	18.61	24.23	22.56	83.11	82.63	100.85

**Daily Average

Data collection

Data were collected 30 days after sowing of seed on ten randomly selected plants in each replication for two agronomic traits, such as plant height (cm), and the number of leaves plant^{-1}. Foliage yield plot^{-1} was recorded on 4 square meters of land. Besides, seven minerals, such as Fe, Zn, Mn, Ni, K, Ca, and Mg were estimated.

Estimation of mineral elements

Stem amaranth leaf samples were dried for 24 hours at 70 °C in an oven. We ground the dried leaves in a mill finely. Calcium, potassium, magnesium, iron, manganese, nickel, and zinc were determined following the nitric-perchloric acid digestion method (SARKER and OBA, 2018d). Exactly 0.5 g dried leaf sample was digested with 40 ml $HClO_4$ (70%), 400 ml HNO_3 (65%), and 10 ml H_2SO_4 (96%) in the presence of carborundum beads. The absorbance was read by atomic absorption spectrophotometry (ASS) (Hitachi, Tokyo, Japan) at a wavelength of 285.2 nm (magnesium), 766.5 nm (potassium), 248.3 nm (iron), 422.7 nm (calcium), 279.5 nm (manganese), 213.9 nm (zinc), 232 nm (nickel).

Statistical analysis

The raw data of the three years were compiled by taking the means of all the plants taken for each treatment and replication for different traits. The data for consecutive three years were averaged, and the averages were statistically and biometrically analyzed. Statistix 8 software was used to analyze the data for analysis of variance (ANOVA) (RASHAD and SARKER, 2020; HASAN *et al*., 2020; AZAD, *et al*., 2022). Genotypic and phenotypic coefficients of variation were calculated by the formula suggested by RAI *et al*. (2013). Broad sense heritability was estimated following the formula of HASAN *et al*. (2012a, b). The expected genetic advance for different characters under selection was estimated using the formula of RAHMAN *et al*. (2007a, b) and HASAN-UD-DAULA and SARKER (2020). Genetic advance in the percentage of mean was calculated from the formula given by AZAM *et al*. (2014). The genotypic and phenotypic correlation coefficients were calculated in all possible combinations through the formula suggested by SARKER and MIAN (2003; 2004). Correlation coefficients were further partitioned into components of direct and indirect effects by path coefficient analysis (SARKER *et al*., 2001).

RESULTS

Mineral elements

The extents of variation among the genotypes in terms of 10 traits were studied, and their grand mean values, coefficient of variation, and critical difference are presented in Table 2. In the present study, the mean sum squares of all the traits were highly significant. It indicated that genotypes differed remarkably for all the mineral elements, foliage yield, and yield contributing agronomic traits (Table 2).

The accession number AS3 showed the highest Fe content (2327.28 mg kg^{-1}) followed by the accession AS6 and AS12. On the other hand, the accession number AS13 exhibited the lowest Fe content (634.61 mg kg^{-1}). The recorded grand mean value of Fe was 1195.16 mg kg^{-1}. The Fe content of seven accessions was much higher than their grand mean value. The coefficient of variation of Fe content was 1.18%.

Table 2. Mean performance, coefficient of variation (CV), and critical difference (CD) values for mineral composition, yield, and yield contributing traits in stem amaranth.

Genotype	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Ca (g 100 g^{-1})	Mn (mg kg^{-1})	Mg (g 100 g^{-1})	K (g 100 g^{-1})	Ni (mg kg^{-1})	Plant height (cm)	Leaves plant^{-1}	Foliage yield plot^{-1} (kg)
AS1	777.	847.2	2.21	158.82	3.21	5.54	181.73	23.72	14.37	5.62
AS2	1235	950.8	2.05	133.22	3.12	4.04	201.09	27.75	10.32	5.51
AS3	2327	1125.	1.95	144.23	3.33	2.64	290.59	17.88	7.76	6.02
AS4	1155	924.2	2.09	88.98	3.31	3.04	278.59	31.77	14.75	6.54
AS5	953.	625.4	2.12	161.99	3.27	4.53	227.29	28.74	12.35	6.52
AS6	1844	712.3	2.52	124.08	3.21	2.94	328.99	12.89	8.66	5.53
AS7	1752	867.3	2.17	134.78	3.31	6.94	158.69	25.84	22.55	6.98
AS8	679.	924.7	2.32	128.91	3.62	2.14	244.39	11.92	10.66	5.59
AS9	1255	777.3	1.74	82.23	3.21	6.54	251.79	33.44	17.36	5.83
AS10	1065	1239.	2.24	117.22	3.31	5.53	171.29	21.44	12.35	5.82
AS11	783.	454.5	1.16	69.23	3.21	2.94	178.79	43.44	18.21	5.13
AS12	1428	720.6	2.18	79.01	3.21	3.14	250.79	33.86	16.44	5.71
AS13	634.	687.1	2.29	108.99	3.64	3.24	258.79	23.48	9.36	5.18
AS14	1124	754.3	2.13	104.96	3.25	5.84	167.72	30.75	11.55	6.88
AS15	827.	855.3	2.32	83.13	3.33	6.54	287.68	14.7	8.69	5.88
AS16	1277	637.2	2.33	152.17	3.61	5.44	187.09	26.64	13.75	6.82
Mean	1195	819.0	2.11	117.00	3.32	4.44	229.08	25.52	13.07	5.97
CV (%)	1.18	1.51	0.12	1.16	0.24	0.54	1.21	0.85	0.97	1.32
CD	4.32	2.547	0.012	2.124	0.025	0.016	1.212	0.124	0.284	0.198
MSS	**	**	**	**	**	**	**	**	**	**

Fe = Iron, Zn = Zinc, Ca = Calcium, Mn = Manganese, Mg = Magnesium, K = Potassium, Ni = Nickel.

The pronounced variations were recorded in the Zn content of stem amaranth (454.54 to 1239.82 mg kg^{-1}). The highest Zn content was detected in the accession number AS10 (1239.82 mg kg^{-1}) followed by AS3. In contrast, the lowest Zn content was noted in the accession number AS11 (454.54 mg kg^{-1}) with a grand mean value of 819.01. The coefficient of variation of Zn content was 1.51%. The Zn content of eight accessions was much higher than their grand mean value.

The Ca content of stem amaranth was observed the lowest compared to any other mineral contents. The highest Ca content was detected in the accession number AS6 (2.52 g 100 g^{-1}) followed by AS8, AS15, and AS16. The lowest Ca content was recorded in the accession number AS11 (1.16 g 100 g^{-1}). The grand mean value and the coefficient of variation of Ca content were 2.11 g 100 g^{-1} and 0.12%, respectively. The Zn content of eleven accessions was much higher than their grand mean value.

The Mn content had prominent variations among the stem amaranth accessions studied. The highest Mn content was noticed in accession number AS5 (161.99 mg kg^{-1}) followed by

AS1 and AS16. Alternatively, the lowest Mn content was noted in the accession number AS11 (69.23 mg kg^{-1}). The obtained grand mean value of Mn was 117.00 mg $kg^{-1,}$ and the coefficient of variation was 1.16%. The Mn content of nine accessions was much higher than their grand mean value.

The Mg content of stem amaranth differed significantly with a range of 3.12 to 3.64 g 100 g^{-1}. The highest Mg content was observed in the accession number AS13 (3.64 g 100 g^{-1}) followed by AS8 and AS16. Conversely, the lowest Mg content was recorded in the accession number AS2 (3.12 g 100 g^{-1}). The recorded grand mean value of Mg was 3.32 g 100 g^{-1} and the coefficient of variation of Mg content was 0.14%. The Mg content of the five accessions was much higher than their grand mean value.

K content was the highest across all mineral elements. The K content of stem amaranth differed significantly and prominently with a range of 2.14 to 6.94 g 100 g^{-1}. The highest K content was observed in the accession number AS7 (6.94 g 100 g^{-1}) followed by AS9 and AS15. The lowest K content was observed in the accession number AS8 (2.14 g 100 g^{-1}). The recorded grand mean value of K was 4.44 g 100 $g^{-1,}$ and the coefficient of variation was 0.54%. The Mg content of seven accessions was much higher than their grand mean value.

The Ni content of stem amaranth showed a significant and prominent variation among the accessions studied (158.69 to 328.99 mg kg^{-1}). The highest Ni content was observed in the accession number AS6 (328.99 mg kg^{-1}) followed by AS3, AS4, and AS15. In contrast, the lowest Ni content was reported in the accession number AS7 (158.69 mg kg^{-1}). The noted grand mean value of Ni was 229.08 mg kg^{-1}. The coefficient of variation of Ni content was 1.21%. The Ni content of eight accessions was much higher than their grand mean value.

Yield and yield contributing agronomic traits

A significant and pronounced variation was observed in stem amaranth's plant height (11.92 to 43.44 cm). The highest plant height was noted in the accession number AS11 (43.44 cm), followed by AS4, AS9, AS12, and AS14 (Table 2). Alternatively, the lowest plant height was documented for the accession number AS8 (11.92). The noted grand mean value of plant height was 25.52 cm, and the coefficient of variation of plant height was 0.85%. The plant height of nine accessions was much higher than their grand mean value.

A significant and pronounced variation was observed in the number of leaves $plant^{-1}$ of stem amaranth (7.76 to 22.55). The highest leaves $plant^{-1}$ was observed in the accession number AS7 (22.55) followed by AS9 and AS11. On the other hand, the lowest leaves $plant^{-1}$ was obtained for the accession number AS3 (7.76). The grand mean value of leaves per plant was 13.07, and the coefficient of variation was 0.97%. The leaves $plant^{-1}$ of seven accessions was much higher than their grand mean value.

The foliage yield $plot^{-1}$ was high for all the accessions of stem amaranth, and variation was significant, albeit not pronounced (5.13 to 6.98 kg). The highest foliage yield $plot^{-1}$ was detected in accession number AS7 (6.98 kg), followed by AS4, AS5, AS14, and AS16. Conversely, the lowest foliage yield $plot^{-1}$ was noted in the accession number AS11 (5.13 kg). The estimated grand mean value of foliage yield $plot^{-1}$ was 5.97, and the coefficient of variation of foliage yield $plot^{-1}$ was 1.32%. The foliage yield $plot^{-1}$ of six accessions was much higher than their grand mean value.

Variability studies

The genotypes differed significantly for all the characters studied (Table 3). The genotypic variance (V_g), phenotypic variance (V_P), genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability ($h^2{}_b$), genetic advance (GA), and genetic advance in percent of the mean (GAMP%) are presented in Table 2. The genotypic variance was the highest for Zn (34585.16), followed by Fe (21444.71), Ni (2641.65), and Mn (922.58). Plant height (72.95), leaves plant^{-1} (14.12), and K (3.56) exhibited moderate genotypic variances (Table 2). On the other hand, the lowest genotypic variance was noticed in Mn (0.22), foliage yield plot^{-1} (0.37), and Ca (1.09). The phenotypic variances for all the traits were a little higher but close to the genotypic variances. PCV and GCV values were moderate for all the traits studied. The highest genotypic and phenotypic coefficient of variation was recorded in Ca (49.45 and 51.89), followed by K (24.51 and 42.63), while the lowest GCV and PCV were recorded in foliage yield plot^{-1} (1019 & 10.46). The values of PCV were a little higher but close to the corresponding GCV values for all the traits (Table 2). The heritability estimates were high for all the traits studied with a range of 87.43 (leaves plant^{-1}) to 99.99 (Fe). The highest expected genetic advance was exhibited for Zn (401.66%), followed by Fe (316.31) and Ni (111.00), while the lowest GA was reported for Mg (0.97). GAPM values were moderate for all the traits studied with a range of 21.44% (foliage yield plot^{-1}) to 101.80% (Ca).

Table 3. Mean, range, phenotypic variance (Vp), genotypic variance (Vg), genotypic and phenotypic coefficient of variation (GCV and PCV), heritability ($h^2{}_b$), genetic advance (GA), genetic advance in percent of the mean (GAMP) for mineral composition, yield, and yield contributing traits in stem amaranth.

Genetic parameters	Vp	Vg	PCV	GCV	h^2b	GA	GAMP
Fe (mg kg^{-1})	21445.08	21444.71	12.25	12.25	99.99	316.31	26.47
Zn (mg kg^{-1})	34592.13	34585.16	22.71	22.71	99.98	401.66	49.04
Ca (g 100 g^{-1})	1.20	1.09	51.89	49.45	90.83	2.15	101.80
Mn (mg kg^{-1})	925.61	922.58	26.00	25.96	99.67	65.50	55.98
Mg (g 100 g^{-1})	0.24	0.22	14.75	14.12	91.67	0.97	29.20
K (g 100 g^{-1})	3.58	3.56	42.63	42.51	99.44	4.06	91.56
Ni (mg kg^{-1})	2642.68	2641.65	22.44	22.44	99.96	111.00	48.45
Plant height	74.97	72.95	33.94	33.48	97.31	18.20	71.33
Leaves plant^{-1}	16.15	14.12	30.78	28.78	87.43	7.59	58.12
Foliage yield	0.39	0.37	10.46	10.19	94.87	1.28	21.44

Fe = Iron, Zn = Zinc, Ca = Calcium, Mn = Manganese, Mg = Magnesium, K = Potassium, Ni = Nickel

Correlation studies

The coefficient of genotypic and phenotypic **c**orrelation of all the traits of stem amaranth is shown in Tables 4 ad 5. The coefficient of genotypic and phenotypic **c**orrelation of all the traits of stem amaranth shown in Table 3 had interesting results.

Table 4. Genotypic correlation coefficient among mineral composition, yield, and yield contributing traits in stem amaranth.

Parameters	Zn mg kg^{-1}	Ca 1 g 100 g^{-1}	Mn mg kg^{-1}	Mg g 100 g^{-1}	K g 100 g^{-1}	Ni mg kg^{-1}	Plant height cm	Leaves $plant^{-1}$	Foliage yield $plot^{-1}$ kg
Fe (mg kg^{-1})	0.351*	0.241*	0.245*	-0.338*	-0.066	0.278*	-0.172	0.003	0.312*
Zn (mg kg^{-1})		0.338*	0.232*	-0.043	0.069	0.062	-	-0.276*	0.069
Ca (g 100 g^{-1})			0.466**	0.485**	0.087	0.278*	-	-	0.238*
Mn (mg kg^{-1})				0.242*	0.064	-0.225	-	-0.217	0.307*
Mg (g 100 g^{-1})					-0.225*	0.084	-	-0.284*	0.076
K (g 100 g^{-1})						-0.477**	0.075	0.365*	0.488**
Ni (mg kg^{-1})							-	-	-0.296*
Plant height								0.648**	0.075
Leaves $plant^{-1}$									0.284*

*P < 0.05, **P <0.01, Fe = Iron, Zn = Zinc, Ca = Calcium, Mn = Manganese, Mg = Magnesium, K = Potassium, Ni = Nickel, r_g = genotypic correlation coefficient, r_p = phenotypic correlation coefficient

Table 5. Phenotypic correlation coefficient among mineral composition, yield, and yield contributing traits in stem amaranth.

Parameters	Zn mg kg^{-1}	Ca g 100 g^{-1}	Mn mg kg^{-1}	Mg g 100 g^{-1}	K g 100 g^{-1}	Ni mg kg^{-1}	Plant height cm	Leaves $plant^{-1}$	Foliage yield $plot^{-1}$ kg
Fe (mg kg^{-1})	0.348*	0.237*	0.242*	-0.336*	-0.063	0.277*	-0.171	0.002	0.311*
Zn (mg kg^{-1})		0.334*	0.228*	-0.038	0.068	0.060	-	-0.274*	0.066
Ca (g 100 g^{-1})			0.462**	0.483**	0.086	0.275*	-	-	0.232*
Mn (mg kg^{-1})				0.238*	0.063	-0.223	-	-0.215	0.302*
Mg (g 100 g^{-1})					-0.224*	0.085	-	-0.283*	0.064
K (g 100 g^{-1})						-	0.074	0.363*	0.486**
Ni (mg kg^{-1})							-	-	-0.295*
Plant height								0.646**	0.072
Leaves $plant^{-1}$									0.282*

*P < 0.05, **P < 0.01, Fe = Iron, Zn = Zinc, Ca = Calcium, Mn = Manganese, Mg = Magnesium, K = Potassium, Ni = Nickel

Foliage yield per plot was significantly and positively correlated with Fe, K, Mn, Ca, and leaves per plant while significantly and negatively correlated with Ni at both, genotypic and phenotypic levels. Leaves $plant^{-1}$ showed a significant negative correlation with Mg, Ca, Ni, and Zn and a significant positive correlation with plant height at genotypic and phenotypic levels. Plant height exhibited a significant negative correlation with Mg, Ca, Ni, Mn, and Zn at genotypic and phenotypic levels. Ni revealed a significant negative correlation with K and a significant positive correlation with Fe and Ca at both genotypic and phenotypic levels. Mg significantly and positively correlated with Ca and Mn, while Mg significantly and negatively correlated with Fe at both genotypic and phenotypic levels. Mn showed a significant positive correlation with Fe, Zn, and Ca at both genotypic and phenotypic levels. Ca had a significant positive correlation with Zn and Zn at both levels. Zn exerted a significant positive correlation with Fe at both genotypic and phenotypic levels. The rest of the correlation values of mineral *vs*. mineral and mineral *vs*. foliage yield and yield contributing agronomic traits were insignificant.

Path coefficient studies

The results of the path coefficient analysis revealed that plant height had the highest positive direct effect (0.789) on foliage yield, followed by K (0.538), Fe (0.498), Mg (0.478) Ca (0.355) (Table 6). A high to moderate direct effect along with a significant correlation was found in Fe, K, Ca, and Mn. Plant height (0.789) showed a high positive direct effect on foliage yield, but its indirect negative effect via Ca and Mg made the total correlation insignificant. Similarly, Mg had a high positive direct effect on foliage yield, but negative indirect effects via Fe, K, and plant height made the total correlation insignificant. On the other hand, although leaves per plant showed a negligible negative direct effect, the positive indirect effect via K and plant height made the correlation significant. The residual effect was found 0.25, which indicated that 75% of the variability was accounted for 7 mineral traits and 2 yield contributing traits included in the present study. Rest, 25% variability, might be controlled by other yield contributed traits that were not included in the current investigation.

Table 6. Partitioning of genotypic correlation into direct (bold phase) and indirect components to foliage yield in stem amaranth.

parameters	Fe mg kg^{-1}	Zn mg kg^{-1}	Ca g 100 g^{-1}	Mn mg kg^{-1}	Mg g 100 g^{-1}	K g 100 g^{-1}	Ni mg kg^{-1}	Plant height cm	Leaves $plant^{-1}$	Foliage yield $plot^{-1}$ kg
Fe (mg kg^{-1})	**0.498**	0.038	0.034	0.041	-0.153	-0.035	0.012	-0.124	0.005	0.312*
Zn (mg kg^{-1})	0.149	**0.128**	0.115	0.047	-0.014	0.037	0.006	-0.387	0.004	0.069
Ca (g 100 g^{-1})	0.048	0.036	**0.355**	0.092	0.228	0.048	0.161	-0.591	0.006	0.238*
Mn (mg kg^{-1})	0.053	0.026	0.150	**0.215**	0.117	0.033	-0.018	-0.323	0.001	0.307*
Mg (g 100 g^{-1})	-0.164	-0.003	0.168	0.059	**0.478**	-0.109	0.006	-0.349	0.004	0.076
K (g 100 g^{-1})	-0.037	0.008	0.037	0.011	-0.099	**0.538**	-0.021	0.069	-0.005	0.488**
Ni (mg kg^{-1})	0.138	0.008	0.098	-0.044	0.036	-0.242	**0.066**	-0.659	0.007	-0.296*
Plant height (cm)	-0.077	-0.059	-0.269	-0.092	-0.210	0.047	-0.028	**0.789**	0.009	0.075
Leaves $plant^{-1}$	0.001	-0.035	-0.153	-0.041	-0.138	0.199	-0.034	0.508	**-0.114**	0.284*

Residual effect: 0.253

DISCUSSION

Variability plays a vital role in the selection of superior genotypes in crop improvement programs (CHAKRABARTY *et al*., 2018). Pronounced variation in the breeding materials is a prerequisite for the development of varieties for existing demand. Pronounced variations of these traits indicated a wide range of variations in terms of foliage yield, some contributing traits, and mineral compositions. ALI *et al*. (2014); SIDDIQUE *et al*. (2009); NATH *et al*. (2008); BISWAS *et al*. (2006); BISWAS *et al*. (2014); AZAM *et al*. (2013); TALUKDER *et al*. (2011, 2014); ASHRAF *et al*. (2020a-c) and KAYESH *et al*. (2019) reported a wide range of variability and diversity in different crops. The selection of genotypes based on their phenotypic variation (mean and range) is impractical for a breeder (SARKER *et al*., 2014). Actual genetic variation may be masked by its environmental influence. Therefore, partitioning the phenotypic variation into genotypic and environmental effects is essential for selecting desirable genotypes. The genotypic variance was the highest for Zn, followed by Fe, Ni, and Mn, while plant height, leaves plant^{-1}, and K exhibited moderate genotypic variances. The results of the genotypic variance of the above traits revealed that more variability was exhibited for these traits, exploring the greater scope of selection based on them. On the other hand, the lowest genotypic variance was noticed in Mn, foliage yield plot^{-1}, and Ca. The phenotypic variances for all the traits were slightly higher but close to the genotypic variances indicating the preponderance of additive gene effects for these traits. Genotypic coefficient of variation (GCV) considers the best relative amount of genetic variation, and it takes into account the mean value as well as the unit of measurement. In this study, PCV and GCV values were moderate for all the traits. The highest genotypic and phenotypic coefficient of variation was recorded in Ca followed by K, while the lowest GCV and PCV were recorded in foliage yield plot^{-1}. The values of PCV were slightly higher but close to the corresponding GCV values for all the traits. The small differences between PCV and GCV for all the traits indicated that the variability was predominately due to genotypic differences (SHUKLA *et al*., 2006; BHARGAVA *et al*., 2003; RASTOGI *et al*., 1995; REVANAPPA *et al*., 1998) Knowledge of heritability of a trait is important as it indicates the possibility and extent to which improvement is possible through breeding (ROBINSON *et al*., 1949). The heritability estimates were high for all the traits. The high value of heritability for all the traits suggests that all these traits are under genetic control, i. e., less environmental influence. However, it will be relevant to divulge that the total genotypic variance is made up of additive genetic variance and non-additive or non-fixable variance. High heritability alone is not enough to make sufficient improvement through selection generally in advanced generations unless it is accompanied by a substantial amount of genetic advance (JOHNSON *et al*., 1955; SARKER *et al*., 2015a). The efficacy of heritability is increased with the estimation of genetic advance, which indicates the degree of gain in a trait obtained under particular selection pressure. Thus, the genetic advance is another vital selection parameter that aids breeders in a selection program (SARKER *et al*., 2014). It has been emphasized that without genetic advances, the heritability values would not be of practical importance in a selection based on phenotypic appearance. So, the genetic advance should be considered along with heritability in coherent selection breeding programs (SARKER *et al*., 2015b). BAYE and BECKER (2005) obtained comparatively higher phenotypic variance values than the genotypic variance for most of the traits in the crop *Vernonia galamensis*, which was solely due to the involvement of high error variance. So, they narrated that due to a large difference in the phenotypic variation between different traits, the GA was not directly related to heritability. But, in our study, the magnitude of genotypic variance; and phenotypic variances were relatively closer due to the lesser role of environmental effect (Ve = Vp - Vg) therefore, all the traits were under the control of genotypic variance (additive + non-additive).

However, in general, it is considered that if a trait is governed by non-additive gene action, it may give high heritability but low genetic advance, whereas if the trait is governed by additive gene action, heritability and genetic advance both would be high. The traits, which had high heritability along with high expected genetic advance, could be substantially considered for making selections as these traits were mainly influenced by the significant effects of additive gene action (SARKER *et al*., 2014; SHUKLA *et al.*, 2000). The highest expected genetic advance was exhibited for Zn, followed by Fe and Ni, while the lowest GA was reported for Mg. GAPM values were moderate for all the traits studied. It was revealed that all the traits had the prominent role of additive gene action in the transmission of this trait from parents to offspring. All the traits also showed moderate to high coefficient of variation and high heritability values, which indicated a significant role of additive gene action in the inheritance of these traits and their amenability for improvement in the population for foliage yield and its component traits. Considering all genetic parameters, all the traits could be selected for the advancement of stem amaranth. Based on high heritability and high GA and GAPM along with close values between Vg *vs*. Vp and GCV *vs*. PCV all the traits could be selected for improving the foliage yield of stem amaranth as these traits exhibited less influence on the environment.

The genotypic correlation coefficients were high compared to phenotypic correlation coefficients. These values were very close to the corresponding phenotypic values for all the traits indicating the additive type of gene action for the expression of these traits. The higher magnitude of genotypic correlation than the respective phenotypic correlations between various characters in amaranth has also been reported (SHUKLA *et al*., 2010). Foliage yield per plot was significantly and positively correlated with Fe, K, Mn, Ca, and leaves per plant both at genotypic and phenotypic levels indicating that foliage yield of stem amaranth could be increased with the increase of Mn, Ca, and leaves per plant. SARKER *et al.* (2014) observed that foliage yield was highly associated with plant height, leaf area, and leaves/plant in vegetable amaranth. Conversely, foliage yield per plot was significantly and negatively correlated with Ni both at genotypic and phenotypic levels indicating that foliage yield of stem amaranth could be increased with the decrease in Ni content. Leaves $plant^{-1}$ showed a significant negative correlation with Mg, Ca, Ni, and Zn and a significant positive correlation with plant height at genotypic and phenotypic levels. It signifies that plants containing more leaves had low Mg, Ca, Ni, and Zn compared to the plant containing fewer leaves, while tall plants had more leaves than dwarf ones. Ni exhibited a significant negative correlation with K and a significant positive correlation with Fe and Ca at both genotypic and phenotypic levels signifying that high K content directly decreased the Ni content while high Ni content directly increased the Fe and Ca content in stem amaranth. It revealed that high Mg content directly increased the Ca and Mn content while directly decreasing the Fe content in stem amaranth. It revealed that a positive relationship was observed among Mn, Ca, Zn, and Fe content in stem amaranth. The rest of the correlation values mineral *vs*. mineral and mineral *vs*. foliage yield and yield contributing agronomic traits were insignificant, which indicates that selection for high mineral content might be possible without compromising yield loss. A similar trend was observed in earlier works on vegetable amaranth (SARKER *et al*., 2014). A significant and desirable correlation was observed for Fe, Ca, Mn, K, and leaves $plant^{-1}$ both at genotypic and phenotypic levels. These five traits could be selected for improving the foliage yield of stem amaranth as these traits exhibited less influence on the environment.

A high to moderate direct effect along with a significant correlation was found in Fe, K, Ca, and Mn. Fe, K, Ca, and Mn had the most significant contribution to foliage yield of stem amaranth as these traits exhibited considerable positive direct effects and significant correlation coefficients on foliage yield. On the other hand, a high negative direct effect was observed in Ni content. SHUKLA *et al.* (2010) also found similar results. Due to high direct effects and significant correlations, direct selection through Zn, Mg, plant height, and leaves plant^{-1} would not be effective for the improvement of stem amaranth. The residual effect was found 0.25, which indicated that 75% of the variability was accounted for 7 mineral traits and 2 yield contributing traits included in the present study. Rest, 25% variability, might be controlled by other yield contributing traits that were not included in the current investigation.

CONCLUSIONS

Based on high heritability and high GA and GAPM, along with close values between Vg *vs*. Vp and GCV *vs*. PCV, all the traits could be selected for improving the foliage yield of stem amaranth. However, a significant and desirable correlation was observed for Fe, Ca, Mn, K, and leaves plant^{-1} both at genotypic and phenotypic levels. These five traits could be selected for improving the foliage yield along with these five mineral elements of stem amaranth as these traits exhibited less influence on the environment. The insignificant genotypic correlation values were observed between mineral *vs*. mineral and mineral *vs*. foliage yield and yield contributing agronomic traits, which indicate that selection for high mineral content might be possible without compromising yield loss. A high to moderate direct effect along with a significant correlation was found in Fe, K, Ca, and Mn. Fe, K, Ca, and Mn had the most significant contribution to foliage yield of stem amaranth as these traits exhibited considerable positive direct effects and significant correlation coefficients on foliage yield. The accessions AS7, AS4, AS5, AS14, and AS16 had high foliage yields containing moderate to high mineral concentration. These five accessions could be selected as high-yielding cultivars, with an enhanced concentration of mineral elements.

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GENETIČKA VARIJACIJA U PROFILIMA MINERALA, AGRONOMSKIM OSOBINAMA KOJE DOPRINOSE PRINOSU, I PRINOSU LISTA AMARANTUSA

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Izvod

Studija je obavljena radi procene mineralnih profila i pronalaženja kriterijuma selekcije za sorte sa visokim prinosom lišća procenom veličine genetske varijabilnosti, naslednosti, genetskog napretka, povezanosti i doprinosa osobina šesnaest genotipova amarantusa sa stabljikom u randomizovanom blok dizajnu sa tri ponavljanja. Na osnovu visoke heritabilnosti i visokih GA i GAPM i bliskih vrednosti između Vg naspram Vp i GCV naspram PCV, sve osobine su mogle biti odabrane da bi se poboljšao prinos lišća amarantusa na stabljici. Uočena je značajna i poželjna pozitivna korelacija za Fe, Ca, Mn, K i listove po biljci i na genotipskom i na fenotipskom nivou. Ovih pet osobina moglo bi se odabrati za poboljšanje prinosa lišća amarantusa na stabljici jer su ove osobine pokazale manji uticaj na životnu sredinu. Uočene su beznačajne vrednosti genotipske korelacije između prinosa minerala i minerala i prinosa minerala u odnosu na lišće i agronomskih osobina koje doprinose prinosu, što ukazuje da bi selekcija za visok sadržaj minerala mogla biti moguća bez ugrožavanja gubitka prinosa. Visok do umeren direktan efekat zajedno sa značajnom korelacijom je pronađen u Fe, K, Ca i Mn. Fe, K, Ca i Mn su imali najznačajniji doprinos prinosu lišća stabljike amarantusa, jer su ispoljili značajne pozitivne direktne efekte i značajne koeficijente korelacije na prinos lišća. Uzorci AS7, AS4, AS5, AS14 i AS16 su imali visoke prinose lišća sa umerenim do visokim mineralnim profilima. Ovih pet uzoraka bi se moglo odabrati kao sorte visokog prinosa. Izbor bi se mogao izvršiti na osnovu sadržaja Fe, K, Ca i Mn da bi se poboljšao amarantus. Uzorci AS7, AS4, AS5, AS14 i AS16 mogu se koristiti kao visokoprinosne sorte i kao izvor poboljšanog mineralnog profila.

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