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Original scientific paper

VARIABILITY IN MINERAL COMPOSITIONS, YIELD AND YIELD CONTRIBUTING TRAITS OF STEM AMARANTH (*Amaranthus lividus*)

Tonmoy CHAKRABARTY[1], Umakanta SARKER[1*], M. HASAN[1], and M. M. RAHMAN[2]

[1]Department of Genetics and Plant Breeding, Faculty of Agriculture, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur-1706, Bangladesh
[2]Department of Soil Science, Faculty of Agriculture, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur-1706, Bangladesh

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Twenty stem amaranth genotypes collected previously from different eco-geographic regions of Bangladesh were assessed to evaluate variations in mineral compositions, yield and yield components, their interrelationships and direct and indirect effects on biological yield. Analysis of variance revealed significant difference among the genotypes for all the characters studied. Considering mean, range and all genetic parameters, selection could be performed on the basis of leaves per plant, leaf area, shoot weight, root weight, stem weight, Zn, Mn, Cu, Fe and biological yield for significant improvement of stem amaranth genotypes. Correlation revealed that stem base diameter, shoot weight, root weight, stem weight and leaves plant^{-1} could significantly improve the biological yield of stem amaranth. Insignificant associations amongst mineral compositions indicated that improvement of mineral compositions was possible without compromising the loss of biological yield of stem amaranth. Path analysis revealed that direct selection based on shoot weight and root weight would be effective for yield improvement of stem amaranth. SA8 had higher yield along with calcium, magnesium, potassium, iron, manganese and zinc content and could be utilized as high yield potential mineral enriched variety. The genotypes SA1, SA2, SA3, SA5, SA7, SA8, SA13, SA18 and SA20 could be utilized in

Corresponding author: Umakanta Sarker, Department of Genetics and Plant Breeding, Faculty of Agriculture, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur-1706, Bangladesh, Postal Code 1706. Phone: +880-1716606098, Email address: umakanta@bsmrau.edu.bd

future breeding program for improvement of stem amaranth. The genotypes SA6 and SA11 might also be selected as a donor parent for introgression of potential genes of high minerals into other genotypes.

Keywords: Minerals, yield and yield contributing traits, variability, correlation and path coefficient, stem amaranth

Abbreviations

CD = Critical difference, GA =Genetic advance, GAMP = Genetic advance in percent of mean, GCV = Genotypic coefficient of variation, h^2_b = Heritability in broad sense, V_g = genotypic variance, V_p = phenotypic variance, PCV = phenotypic coefficient of variation, RCBD = Randomized complete block design

INTRODUCTION

Stem amaranth *(Amaranthus lividus)* belongs to the genus *Amaranthus. Amaranthus* is a core genus of the family Amaranthaceae, consists of 70 species of hardy, weedy, herbaceous, fast growing grains and vegetables, widely distributed in America, Africa, Australia, Asia, and Europe (FRANSSEN *et al*., 2001). Among them only 17 species produce edible leaves and 3 produce food grains (JANSEN, 2004). *Amaranthus* leaves and stems are rich sources of antioxidants, protein, carotenoids, vitamin C, dietary fiber, and minerals such as calcium, iron, zinc, and magnesium (SARKER *et al*., 2014; 2015a; 2015b; 2016; 2017; 2018a; 2018b; 2018c; SARKER and OBA, 2018d; 2018e; 2018f; 2018g; 2018h; SHUKLA *et al*., 2006b; OZSOY *et al*., 2009; ANITHA and PONBAVANI, 2013; LÓPEZ- MEJÍA *et al*., 2014). Member of these genera are widely used as traditional medicinal plant, especially as antiviral, antimalarial, antidiabetic, antibacterial, antihelminthic, snake antidote (KUSUMANINGTYAS *et al.*, 2006; VARDHANA, 2011; KUMAR *et al*., 2010) and tolerant to drought and salinity (SARKER and OBA, 2018i, 2018j). *Amaranthus lividus* is an inexpensive vegetable whose stem and leaves are used as human food (MARTIN and RUBERTE, 1989). Flashy succulent stems and leaves of *A. lividus* are very popular in Bangladesh including Asia, Africa and are becoming increasingly popular in the rest of the continent and elsewhere due to its attractive leaf and stem color, taste and nutritional value. It is one of the cheapest vegetables because of low production cost and high yield.

Compared to lettuce, *Amaranthus* contains 18 times more vitamin A, 13 times more vitamin C, 20 times more calcium and 7 times more iron (GUILLET, 2004). It has been rated equal or superior in taste to spinach and is considerably higher in carotenoids (90-200 mg kg-1), protein (14-30% on dry weight basis) and ascorbic acid (about 28 mg 100g-1) (WU-LEUNG *et al*., 1968; MAKUS, 1990; PRAKASH and PAL, 1991; SHUKLA *et al*., 2006b). It is an under exploited plant with promising economic value, which has been recognized by the USA National Academy of Sciences (1984).

Minerals are of critical importance in the diet, even though they comprise only 4–6% of the human body. Major minerals are those required in amounts greater than 100 mg per day and they represent 1% or less of body weight. These include calcium, phosphorus, magnesium, sulfur, potassium, chloride, and sodium. Human, as well as animal, studies showed that optimal intake of elements, such as sodium, potassium, magnesium, calcium, manganese, copper, zinc, and iodine, could reduce individual risk factors, including those related to cardiovascular disease (ANKE, 1984; MERTZ, 1982; SANCHEZ-CASTILLO, 1998). Trace minerals are essential in much smaller amounts, less than 100 mg per day, and make up less than 0.01% of body weight. Essential trace elements are zinc, iron, silicon, manganese, copper, fluoride, iodine, and

chromium. The major minerals serve as structural components of tissues and function in cellular and basal metabolism and water and acid–base balance (MACRAE, 1993; NIELSEN, 1984).

Although genetic variability and interrelationship studies among morpho-nutritional traits are available in other crops (SUKHCHAIN *et al*., 1997; LOPEZ *et al*., 1998; FINNE *et al*., 2000), such reports on vegetable amaranth are rare. The nutritional composition of *A. tricolor* has been previously studied (SARKER *et al*., 2014; 2015a; 2015b; 2016; 2017a; 2017b; 2018a; 2018b; SHUKLA *et al*., 2006a). To our knowledge, there is no information on mineral compositions in huge number of diversified *A. lividus* germplasms available in Bangladesh and elsewhere.

Therefore, to fill these gaps, the present investigation was undertaken with the following objectives.

1) To evaluate mineral compositions, yield and yield related traits of stem amaranth (*A. lividus*) genotypes.
2) To determine the variability of these traits in stem amaranth (*A. lividus*) genotypes.

MATERIALS AND METHODS

The experiment was conducted by using 20 distinct and promising genotypes of stem amaranth (*A. lividus*) which were collected from different eco-geographic region of Bangladesh. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The plot size was 1 m × 1 m. Spacing was maintained by 20 cm × 5 cm from row to row and plant to plant, respectively. Recommended fertilizer and compost doses (Urea, Triple super phosphate, muriate of potash and gypsum were applied at 200, 100, 150 and 30 kg/ha, respectively) and appropriate growing practices was maintained. Thinning was performed to maintain appropriate plant density within rows. Weeding and hoeing were performed at 7-day intervals. Day-time temperatures during the experimental period ranged from 21 to 33 °C. Irrigation was provided at 5 to 7 day intervals. For biological yield, the plants were uprooted completely from the ground.

Data collection of biological yield and yield related traits

The seed were sown in the experimental field on 18th February, 2015. Data were collected at 60 days after sowing (DAS) of seeds. The data were recorded on 10 randomly selected plants in each replication for plant height (cm), stem base diameter (cm), leaves plant^{-1}, leaf area plant^{-1} (cm^2), shoot weight (g), root weight (g), stem weight (g). For biological yield (kg), all plants of whole plot were harvested.

Estimation of mineral content

Leaves and stem of stem amaranth were dried at 70 °C in a well-ventilated drying oven for 24 hours. Dried leaf and stem of stem amaranth (*A. lividus*) was ground finely in a mill and passed through 841 microns' screen, then portions of the dried tissues were analyzed for the following macronutrients (Ca, Mg, K) and microelements (Fe, Mn, Cu, Zn). All macronutrients and microelements were extracted after dissolution of the *A. lividus* samples by nitric-perchloric acid digestion. According to SARKER and OBA (2018d) nitric-perchloric acid digestion was performed by adding 0.5 g of the dried samples to 400 ml of nitric acid (65%) with 40 ml of perchloric acid (70%) and 10 ml of sulphuric acid (96%) in the presence of carborundum beads. After nitric-perchloric acid digestion, the solution was appropriately diluted and P analysis was

performed in triplicate according to the Ascorbic Acid Method (JHON, 1970). In acidic medium, orthophosphates formed a yellow-colored complex with molybdate ions and, after addition of ascorbic acid and Sb, a blue-colored phosphomolybdenum complex was formed. Absorbance was taken according to the method described by SARKER and OBA (2018d) in triplicate at wave length 766.5 nm (K), 422.7 nm (Ca), 285.2 nm (Mg), 248.3 nm (Fe), 279.5 nm (Mn), 324.8 nm (Cu), 213.9 nm (Zn), by atomic absorption spectrophotometry (AAS) (Hitachi, Tokyo, Japan). For calibration, AAS standard solutions (1000 mg l^{-1} in 5% HNO_3) were purchased from Merck, Germany. Finally, interferences were controlled by the addition of lanthanum and caesium chloride (0.1%) to samples and standards.

Statistical analysis

The raw data were compiled by taking the means of all the plants taken for each treatment and replication for different traits. Mean, range and standard deviation (SD) for each character were also estimated. The mean sum of square (MS), genotypic and phenotypic variances was estimated followed by JOHNSON *et al*. (1955). Genotypic and phenotypic coefficients of variation were calculated by the formula suggested by BURTON (1952). Broad sense heritability was estimated (defined by LUSH 1949) by the formula suggested by JOHNSON *et al*. (1955). The expected genetic advance for different characters under selection was estimated using the formula suggested by LUSH (1949) and JOHNSON *et al*. (1955). Genetic advance in percentage of mean was calculated from the formula given by COMSTOCK and ROBINSON (1952). The genotypic and phenotypic correlation coefficients were calculated in all possible combinations through the formula suggested by HANSON *et al*. (1956), JOHNSON *et al*. (1955). Correlation coefficients were further partitioned into components of direct and indirect effects by path coefficient analysis originally developed by WRIGHT (1921, 1923 and 1992) and later described by DEWEY and LU (1959).

RESULTS AND DISCUSSION

Mean performance

Mean performance, standard deviation (SD), standard error (SE), coefficient of variation (CV, %) and critical difference (CD) for yield and yield contributing traits and minerals content of 20 genotypes of *Amaranthus lividus* are shown in the Table 1 and Table 2. Analysis of variance showed wide range of variations for all the traits studied.

Among 20 genotypes, pronounced variation was observed in biological yield per m^{-2}, shoot weight, root weight and stem weight and ranged from (6.33 kg to 18.48 kg), (53.95 g to 149.44 g), (9.63 g to 30.24 g) and (38.88 g to 143.03 g), respectively. This results were agreed to the findings of SHANKAR *et al*. (2012) who found that shoot weight, root weight and stem weight of different amaranth species ranged from (11.8 g - 128.7 g), (2. 1 g - 13.3 g) and (5.3 g to 98.3 g). Moderate variability was observed in leaf area and leaves per plant that ranged from (105.01 cm^2 to 183.15 cm^2) and (25.96 to 52.53. PAMELA *et al*. (2016) found that leaf area and leaf per plant ranged from (10.40 cm^2-113.50 cm^2) and (32-185.50) in different accessions of *A. caudatus, A. hypochondriacus, A. cruentus, A. hybrids* and *Amaranthus* hybrid. SHANKAR *et al*. (2012) showed that leaves per plant of different accessions of *A. tricolor, A. dubius, A. cruentus* and *A. hybridus* ranged from 10.3 to 272.6 cm. Plant height and stem base diameter ranged from (64.97 cm to 95.45 cm) and (10.52 cm to 20.43 cm). Similarly, HASAN *et al*. (2013) reported that

plant height and stem base diameter in *Amaranthus tricolor* ranged from (77.5 cm to 143.9 cm) and (11.80 cm to 33.20 cm).

Within the 20 genotypes investigated, the highest variation was observed for iron, copper, calcium, manganese content which were ranged from (106.80 µg g^{-1} to 2140.30 µg g^{-1}), (8.25 µg g^{-1} to 35.28 µg g^{-1}), (12.70 mg g^{-1} to 48.53 mg g^{-1}) and (61.34 µg g^{-1} to 117.04 µg g^{-1}), respectively. These results were full agreement with the results of SARKER *et al*. (2016) who found high variation in *A. tricolor* accessions for iron, calcium, manganese content that were ranged from (595.72-2355.45 µg g^{-1}), (7.6-21.5 mg g^{-1}) and (71.80-165.55 µg g^{-1}), respectively. Zinc content exhibited moderate variation which ranged from 40.53 µg g^{-1} to 77.16 µg g^{-1}. SARKER *et al*. (2015a) found 449.68-1235.01 µg g^{-1} zinc in *A. tricolor* accessions. In contrast, potassium and magnesium content had low variation which ranged from (17.44 mg g^{-1} to 18.24 mg g^{-1}) and (2.60 mg g^{-1} to 5.80 mg g^{-1}). SARKER *et al*. (2015b) found low variation in magnesium content (28.4-35.3 mg g^{-1}) in *A. tricolor* accessions, while they found moderate variation for potassium content (17-65 mg g^{-1}) in *A. tricolor* accessions.

Table 1. Mean performance for yield and yield contributing traits of 20 genotypes of stem amaranth (Amaranthus lividus)

Genotypes	Plant height(cm)	Stem base diameter(mm)	Leaves $Plant^{-1}$	Leaf area (cm^2)	Shoot weight(g)	Root weight(g)	Stem weight(g)	Biological yield m^{-2}(kg)
SA1	95.45	14.87	48.50	144.19	119.08	16.46	99.25	13.91
SA2	79.86	20.09	43.16	156.39	121.37	28.56	97.50	14.00
SA3	70.67	18.58	43.66	141.98	149.44	29.77	106.14	18.49
SA4	75.64	15.20	52.53	122.91	60.55	16.37	45.87	7.04
SA5	76.18	17.78	45.33	143.47	137.3	30.24	96.65	16.52
SA6	73.80	17.41	35.20	156.91	85.14	15.94	109.36	9.91
SA7	75.40	20.43	46.70	132.51	148.26	25.63	143.03	17.82
SA8	80.80	16.05	35.64	156.15	96.77	14.93	91.39	12.33
SA9	82.88	13.11	43.86	131.23	77.58	10.34	63.64	8.79
SA10	67.35	10.52	36.17	183.15	55.76	9.63	38.88	6.60
SA11	69.20	17.20	28.43	125.41	77.80	13.77	77.01	10.55
SA12	64.97	14.09	26.30	126.11	53.95	9.96	45.42	6.33
SA13	75.21	17.79	33.06	152.22	112.44	13.61	84.28	11.47
SA14	79.73	14.87	36.11	109.95	72.97	11.41	74.11	9.96
SA15	81.00	13.82	33.53	116.88	65.09	10.39	74.12	9.66
SA16	73.74	14.69	27.26	147.88	64.46	12.67	52.19	8.05
SA17	85.03	14.07	37.90	108.65	73.03	11.55	52.98	10.46
SA18	75.91	16.98	29.90	130.01	102.15	16.50	73.81	11.80
SA19	75.82	13.66	25.96	105.01	63.66	10.56	89.94	7.27
SA20	78.90	17.57	35.26	166.32	140.62	24.93	92.98	13.82
Grand Mean	76.87	15.94	37.22	137.86	93.87	16.66	80.42	11.24
SD	6.73	2.48	7.81	20.65	32.58	7.07	25.98	3.61
SE	1.51	0.55	1.75	4.62	7.29	1.58	5.81	0.81
CV (%)	8.95	12.85	6.16	3.08	3.91	4.64	4.72	5.03
CD (5%)	11.37	3.38	3.79	7.01	6.06	1.27	6.28	1265.8
CD (1%)	15.23	4.53	5.07	9.39	8.11	1.71	8.41	1577.2

SD = Standard deviation, SE = Standard error, CV = Coefficient of Variation, CD = Critical difference

Table 2. Mean performance for mineral composition of 20 genotypes of stem amaranth (Amaranthus lividus)

Genotypes	Ca (mg g^{-1})	Mg (mg g^{-1})	K (mg g^{-1})	Fe (µg g^{-1})	Mn (µg g^{-1})	Cu (µg g^{-1})	Zn (µg g^{-1})
SA1	13.55	3.51	18.05	266.75	59.97	11.70	54.70
SA2	16.02	3.60	18.22	882.32	109.87	9.90	51.23
SA3	14.05	3.32	18.10	267.07	75.73	19.60	47.73
SA4	15.22	2.60	18.26	187.40	85.32	24.06	49.50
SA5	15.95	3.59	18.24	587.82	104.39	13.66	43.03
SA6	17.31	3.58	17.84	2140.30	117.04	15.80	46.73
SA7	15.86	4.28	18.14	280.08	82.21	16.61	53.23
SA8	48.53	5.80	18.12	830.06	108.55	11.35	60.66
SA9	15.22	3.75	18.11	106.80	101.20	8.25	43.80
SA10	16.94	4.04	18.11	347.57	89.40	23.71	57.33
SA11	17.31	3.81	18.12	507.07	80.63	35.28	77.16
SA12	16.04	3.42	18.09	186.42	74.93	23.41	57.10
SA13	15.25	3.35	17.75	240.70	73.47	21.01	58.46
SA14	15.54	3.21	18.17	186.89	81.85	8.79	42.86
SA15	14.76	3.26	18.03	399.84	65.19	15.48	40.53
SA16	16.72	3.95	17.96	937.08	61.34	14.68	39.26
SA17	16.08	3.73	17.57	401.50	61.43	12.65	62.93
SA19	12.72	2.71	17.44	360.68	72.10	19.43	46.10
SA20	12.70	3.10	17.52	775.40	92.00	18.33	57.13
Grand	16.84	3.59	17.98	514.56	83.06	17.58	52.50
SD	7.64	0.66	0.23	456.62	17.64	6.91	9.29
SE	1.71	0.15	0.05	102.10	3.94	1.55	2.08
CV (%)	2.40	6.07	1.43	0.23	7.11	2.22	1.43
CD (5%)	0.91	0.49	0.37	1.91	9.75	0.64	1.24
CD (1%)	1.13	0.61	0.46	2.56	13.06	0.86	1.66

SD = Standard deviation, SE = Standard error, CV = Coefficient of Variation, CD = Critical difference

The present investigation revealed that the stem amaranth (*Amaranthus lividus*) is a good source of potassium (17.98 mg g^{-1}), calcium (16.84 mg g^{-1}), magnesium (3.59 mg g^{-1}), iron (514.56 µg g^{-1}), zinc (52.50 µg g^{-1}), manganese (83.06 (µg g^{-1}) and copper (17.58 µg g^{-1}). Nine genotypes such as, SA1, SA2, SA3, SA5, SA7, SA8, SA13, SA18 and SA20 are out yielded over the mean and could be utilized in future breeding program for improvement of stem amaranth. One, seven, thirteen, six, eight, nine and ten genotypes had more calcium, magnesium, potassium, iron, manganese, copper and zinc content, respectively than their corresponding mean value. SA8 had higher yield along with calcium, magnesium, potassium, iron, manganese and zinc content could be utilized as high yield potential mineral enriched variety. The genotypes SA6 and SA11 had low biological yield along with the highest content of iron, manganese, zinc, and copper. These two genotypes might also be selected as a donor parent for introgression of

potential genes of high minerals into other genotypes. The genotypes SA4, SA6, SA9, SA10, SA11, SA12, SA14, SA15 SA16, SA17 and SA19 had low amount of minerals having below average biological yield and would be of little contribution in breeding programs.

Variability studies

The genotypic and phenotypic variance (Vg, Vp) and coefficient of variation (GCV, PCV), h^2_b, GA and GA in percent of mean are presented in Table 3. The highest genotypic and phenotypic variances were observed for iron content. Similarly, high genotypic and phenotypic variances was noted for shoot weight, stem weight, leaf area, manganese, Zn, plant height, leaves per plant, Ca, root weight and Cu content. All the traits except plant height, stem base diameter and K content had close differences in genotypic and phenotypic variances. The heritability was high for all the traits except plant height, stem base diameter and K content. High heritability coupled with high GA in percent of mean was observed for all the traits except plant height, stem diameter and K content. The highest heritability value was observed for Fe (100%) and the lowest value for K (33.52%) and plant height (38.36%). The heritability values were high for Ca (99.72%), Cu (99.68%), Zn (99.35%), root weight (98.81%), shoot weight (98.74%), stem weight (97.89%), biological yield (97.60%), leaf area (95.90%) and leaves plant^{-1} (91.85%). In vegetable amaranth including *Amranthus tricolor,* SARKER *et al*. (2014; 2015a; 2015b; 2016; 2018a) reported high heritability for Ca, Mg, K, Fe, Mn, Zn, leaves plant^{-1}, leaf area, shoot weight, root/shoot weight, foliage yield. The highest genetic advance in percent of mean was observed for Fe (140.21%), followed by Ca (71.49%), whereas the lowest genetic advance in percent of mean was recorded for K (0.93%). SARKER *et al*. (2016) also observed the highest genetic advance for Fe and lowest genetic advance for Ca in vegetable amaranth. Moderate genetic advance in percent of mean was observed for Cu (61.67%), root weight (66.46%), shoot weight (54.37%), stem weight (50.31%), and biological yield (50.05%). SARKER *et al*. (2014; 2015a; 2016) also noticed moderate genetic advance for Mn and Zn in vegetable amaranth. Zn (99.35%) showed high heritability but low genetic advance in percent of mean (27.84%).

Variability plays a vital role in the selection of superior genotypes in crop improvement program. Pronounced variation in the breeding materials is a prerequisite for development of varieties to fulfill the existing demand. Economically important traits are generally quantitative in nature that interacts with the environment where it is grown. This is why; breeder should calculate the variability by partitioning into genotypic, phenotypic, and environmental effects. Creation of variability is prerequisite for crop breeders. Agronomic traits are quantitative in nature, and interact with the 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. The genotypic and phenotypic variance (Vg, Vp) and coefficient of variation (GCV, PCV), h^2_b, GA and GA in percent of mean are presented in Table 3. The highest genotypic and phenotypic variances were observed for iron content. Similarly, high genotypic and phenotypic variances was noted for shoot weight, stem weight, leaf area, manganese, Zn, plant height, leaves per plant, Ca, root weight and Cu content indicating the presence of the wide range of variability for the traits under studied and had greater scope of selection for the improvement of stem amaranth. All the traits except plant height, stem base diameter and K content had close differences in genotypic and phenotypic variances along with genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) values, which indicate preponderance of

additive gene effects for these traits i. e., less environmental influence in the expression of these traits or the major portion of the phenotypic variance was genetic in nature and greater scope of improvement of stem amaranth through selection.

Table 3. Phenotypic variance (V_p), genotypic variance (V_g), genotypic and phenotypic coefficient of variation (GCV and PCV), heritability (h^2_b), genetic advance (GA), genetic advance in percent of mean GAMP) of 20 genotypes of stem amaranth (Amaranthus lividus)

Traits	V_p	V_g	PCV	GCV	h^2_b	GA (5%)	GAPM
PH (cm)	76.78	29.45	11.40	7.06	38.36	5.31	6.91
SBD (mm)	8.95	4.76	18.77	13.69	53.20	2.52	15.78
Leaves plant^{-1}	64.47	59.21	21.57	20.67	91.85	11.65	31.30
LA (cm^2)	438.25	420.26	15.18	14.87	95.90	31.72	23.01
Shoot weight (g)	1070.20	1056.76	34.85	34.63	98.74	51.04	54.37
Root weight (g)	50.32	49.72	42.57	42.31	98.81	11.07	66.46
Stem weight (g)	684.48	670.04	32.53	32.18	97.89	40.46	50.31
BY m^{-2} (kg)	13.31	12.99	32.46	32.06	97.60	5.63	50.05
Ca (mg g^{-1})	58.41	58.24	45.38	45.31	99.72	12.04	71.49
Mg (mg g^{-1})	0.47	0.42	18.89	17.89	89.68	0.97	26.77
K (mg g^{-1})	0.07	0.04	1.49	1.17	62.28	0.26	1.46
Fe (µg g^{-1})	208504.33	208503.33	88.74	88.74	100.00	721.46	140.21
Mn (µg g^{-1})	334.22	299.39	22.01	20.83	89.58	25.87	31.15
Cu (µg g^{-1})	47.88	47.73	39.35	39.28	99.68	10.90	61.97
Zn (µg g^{-1})	86.75	86.19	17.74	17.68	99.35	14.62	27.84

PH = Plant height, SBD = Stem base diameter, LA = leaf area, Ca = Calcium, Mg = Magnesium, K = Potassium, Fe = Iron, Mn = Manganese, Cu = Copper, Zn = Zinc, BY = Biological yield, V_p = Phenotypic variance, V_g = Genotypic variance, PCV = Phenotypic coefficient of variation, GCV = Genotypic coefficient of variation, h^2_b = Heritability (Broad sense), GA = Genetic advance, GAPM = Genetic advance in percent of mean

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). High heritability alone is not enough to make sufficient improvement through selection generally in advance generations unless accompanied by a substantial amount of genetic advance (JOHNSON *et al*., 1955). 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*., 2006a). 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, if it is governed by additive gene action, heritability and genetic advance would be high, consequently substantial gain can be achieved through selection.

The heritability was high for all the traits except plant height, stem base diameter and K content indicated the preponderance of additive gene action for these traits. High heritability coupled with high GA in percent of mean was observed for all the traits except plant height, stem diameter and K content indicated that these traits were governed to a great extent by additive gene action. So, direct selection would be effective for these traits for the genetic improvement. Considering mean, range and all genetic parameters selection could be performed on the basis of leaves per plant, leaf area, shoot weight, root weight, stem weight, Zn, Mn, Cu, Fe and biological yield for significant improvement of stem amaranth genotypes.

Correlation study

The phenotypic and genotypic correlations between morpho-nutritional characters are presented in Table 4. In the present investigation, the genotypic correlation coefficients were very much close to the corresponding phenotypic values for all the traits. From Table 4 it was revealed that biological yield had a significant positive correlation with stem base diameter (0.779**), leaves plant^{-1} (0.477*), shoot weight (0.956**), root weight (0.863**) and stem weight (0.790**). Calcium, iron and copper is significantly positive correlated with magnesium (0.863**), manganese (0.536*) and zinc (0.600*), respectively. Rest of the interrelationships among traits was found insignificant.

In the present investigation, the genotypic correlation coefficients were very much close to the corresponding phenotypic values for all the traits indicating additive type of gene action i.e., less environmental influence on the expression of the traits. From Table 4 it was revealed that biological yield had a significant positive correlation with stem base diameter (0.779**), leaves plant^{-1} (0.477*), shoot weight (0.956**), root weight (0.863**) and stem weight (0.790**) indicating selection of stem amaranth based on stem base diameter, leaves plant^{-1}, shoot weight, root weight, and stem weight would be highly effective as these traits were closely associated with high biological yield. SARKER *et al*. (2014) found leaves/plant and stem base diameter positively significant with foliage yield in *A. tricolor*. SARKER *et al*. (2015b) found shoot weight is positively significant with foliage yield in *A. tricolor*. Calcium, iron and copper is significantly positive correlated with magnesium (0.863**), manganese (0.536*) and zinc (0.600*), respectively. SARKER *et al*. (2015b) reported that calcium positively correlated with magnesium in *A. tricolor*. Iron, zinc, manganese, magnesium and potassium positively correlated with biological yield. SARKER *et al*. (2015a) reported that iron, zinc, manganese, magnesium and potassium positively correlated with foliage yield *A. tricolor*. Rest of the interrelationships among traits was found insignificant. Correlation values of biological yield with stem diameter, shoot weight, root weight, stem weight and leaves per plant revealed that selection based on this trait could significantly improve the biological yield of stem amaranth. In contrast, mineral compositions showed insignificant associations among them along with biological yield except

Zn versus Cu, Mg versus Ca, and Mn versus Fe. It indicated that improvement of mineral compositions was possible without compromising the loss of biological yield of stem amaranth.

Table 4. Phenotypic (r_p) and genotypic correlation coefficient (r_g) among yield, yield contributing traits and minerals of 20 genotypes of stem amaranth (Amaranthus lividus)

Characters		Stem base diameter (mm)	Leaves plant^{-1}	Leaf area (cm^2)	Shoot weight (g)	Root weight (g)	Stem weight (g)	Ca (mg g^{-1})	Mg (mg g^{-1})	K (mg g^{-1})	Fe (µg g^{-1})	Mn (µg g^{-1})	Cu (µg g^{-1})	Zn (µg g^{-1})	Biological yield m^{-2} (kg)
Plant height (cm)	r_g	-0.261	0.559*	-0.200	0.243	0.017	0.236	0.071	0.075	-0.204	-0.091	-0.171	-0.792	-0.175	0.233
	r_p	0.178	0.314	-0.112	0.180	0.012	0.198	0.055	0.035	-0.072	-0.057	-0.078	-0.499	-0.109	0.194
Stem base diameter (mm)	r_g		0.298	0.175	0.892**	0.911**	0.855**	-0.009	0.063	0.082	0.315	0.318	0.022	0.139	0.779**
	r_p		0.214	0.111	0.681**	0.674**	0.656**	0.006	0.057	-0.055	0.229	0.248	0.009	0.111	0.652*
Leaves plant^{-1}	r_g			0.112	0.467*	0.527*	0.304	-0.023	-0.008	0.566	-0.209	0.338	-0.353	-0.172	0.477*
	r_p			0.123	0.436*	0.502*	0.278	-0.017	0.006	0.334	-0.191	0.265	-0.327	-0.157	0.457*
Leaf area (cm^2)	r_g				0.342	0.321	0.123	0.231	0.389	0.135	0.378	0.463	0.005	0.125	0.200
	r_p				0.328	0.310	0.115	0.228	0.368	0.101	0.376	0.435	0.004	0.123	0.195
Shoot weight (g)	r_g					0.883**	0.794**	0.022	0.138	-0.029	0.274	0.308	-0.214	-0.082	0.956**
	r_p					0.876**	0.791**	0.023	0.127	-0.025	0.271	0.289	-0.213	-0.083	0.947**
Root weight (g)	r_g						0.660**	-0.094	0.001	0.151	0.147	0.347	-0.117	-0.083	0.863**
	r_p						0.652**	-0.091	-0.0005	0.125	0.146	0.336	-0.117	-0.082	0.857**
Stem weight (g)	r_g							0.052	0.165	-0.076	0.287	0.273	-0.224	-0.075	0.800**
	r_p							0.052	0.151	-0.064	0.284	0.253	-0.222	-0.077	0.790**
Ca (mg g^{-1})	r_g								0.863**	0.235	0.227	0.416	-0.221	0.207	0.024
	r_p								0.819**	0.174	0.227	0.400	-0.220	0.206	0.024
Mg (mg g^{-1})	r_g									0.300	0.208	0.357	-0.253	0.264	0.209
	r_p									0.218	0.196	0.344	-0.239	0.253	0.184
K (mg g^{-1})	r_g										-0.173	0.280	-0.041	-0.183	0.141
	r_p										-0.134	0.181	-0.028	-0.156	0.110
Fe (µg g^{-1})	r_g											0.536*	-0.132	-0.100	0.026
	r_p											0.507*	-0.132	-0.100	0.026
Mn (µg g^{-1})	r_g												-0.270	-0.095	0.145
	r_p												-0.256	-0.082	0.138
Cu (µg g^{-1})	r_g													0.600*	-0.207
	r_p													0.597*	-0.204
Zn (µg g^{-1})	r_g														0.030
	r_p														0.029

* significant at 5% ** significant at 1%: Ca = Calcium, Mg = Magnesium, K = Potassium, Fe = Iron, Mn = Manganese, Cu = Copper, Zn = Zinc

Path coefficient study

In the present study, shoot weight (0.9535) had the highest and positive direct effect and significant positive association with biological yield. Similarly, root weight (0.2039) and stem weight (0.0869) exhibited high and positive direct effect and significant interrelationships with biological yield (Table 5). K (0.18681), Fe (0.17468), Zn (0.14579), Mg (0.10364) also showed high and positive direct effect but insignificant correlation with biological yield (Table 5). Although stem base diameter had significant genotypic correlation with biological yield, but negative indirect effect via shoot weight, root weight, stem weight, leaf area, Fe and Mn made the direct effect of this trait negative. Similarly, leaves plant^{-1} exhibited significant genotypic correlation with biological yield, but negative indirect effect via shoot weight, root weight, plant height, stem base diameter, K, Fe, Mn and Zn made the direct effect of this trait negative. Plant height (-0.0825), leaf area (-0.2537), calcium content (-0.0053) and manganese content (-0.1671) showed negative direct effect and positive and non-significant correlation with biological yield. Copper (-0.1362) showed negative direct effect and negative and non-significant correlation with biological yield.

In the present study, shoot weight (0.9535) had the highest and positive direct effect and significant positive association with biological yield. Similarly, root weight (0.2039) and stem weight (0.0869) exhibited high and positive direct effect and significant interrelationships with biological yield (Table 5). So, direct selection of stem amaranth based on shoot weight, root weight and stem weight would remarkably be effective for improvement of stem amaranth. ANUJA (2012) reported high positive direct effect and positive genotypic correlation on yield for stem weight of amaranth. K (0.18681), Fe (0.17468), Zn (0.14579), Mg (0.10364) also showed high and positive direct effect but insignificant correlation with biological yield (Table 5). Direct selection of stem amaranth based on K, Fe, Zn and Mg would not be contributed for improvement of stem amaranth. Although stem base diameter had significant genotypic correlation with biological yield, but negative indirect effect via shoot weight, root weight, stem weight, leaf area, Fe and Mn made the direct effect of this trait negative. Similarly, leaves plant^{-1} exhibited significant genotypic correlation with biological yield, but negative indirect effect via shoot weight, root weight, plant height, stem base diameter, K, Fe, Mn and Zn made the direct effect of this trait negative. Plant height (-0.0825), leaf area (-0.2537), calcium content (-0.0053) and manganese content (-0.1671) showed negative direct effect and positive and non-significant correlation with biological yield. ISHWAR *et al*. (2017) found negative direct effect for plant height in amaranth. Copper (-0.1362) showed negative direct effect and negative and non-significant correlation with biological yield. Direct selection based on stem base diameter, leave plant^{-1}, plant height, leaf area, Ca, Mn and Cu content would not have contributed much for improvement of stem amaranth. The residual effect was found 0.01371 which indicated that 98.629% of the variability was accounted for 7 mineral traits and 7 yield contributing traits included in the present study. Rest 1.371% variability might be controlled by other yield contributing traits that were not included in the present investigation.

Table 5. Partitioning of genotypic correlation into direct (bold phase) and indirect components of 20 genotypes of stem amaranth (Amaranthus lividus)

	PH	SBD	LP	LA	SW	RW	STW	Ca	Mg	K	Fe	Mn	Cu	Zn	BY
PH	**-0.08252**	0.00612	-0.00232	0.03968	0.19923	0.00291	0.01853	-0.00033	0.00634	-0.02863	-0.01293	0.02092	0.08766	-0.02070	0.23396
SBD	0.00246	**-0.20526**	-0.00138	-0.03750	-0.75938	-0.16415	-0.06651	0.00001	0.00749	0.00670	-0.04839	-0.04797	-0.00234	0.01850	0.77914**
LP	-0.03609	-0.05350	**-0.00531**	-0.02927	-0.43488	-0.10570	-0.02565	0.00021	-0.00012	-0.09100	-0.03042	-0.04579	0.05107	-0.03043	0.47758*
LA	0.01290	-0.03032	-0.00061	**-0.25379**	0.32179	0.06469	0.01048	-0.00129	0.03874	0.02655	0.07325	-0.07882	0.00248	0.01439	0.20044
SW	-0.01724	-0.16347	-0.00242	-0.08565	**0.95354**	0.17957	0.06893	0.00023	0.01272	0.00565	0.00943	-0.03373	0.02313	0.00611	0.95681**
RW	-0.00118	-0.16523	-0.00275	-0.08051	0.83969	**0.20392**	0.05711	0.00044	0.00096	0.03818	0.02763	-0.05869	0.01629	-0.01253	0.86333**
STW	-0.01760	-0.15711	-0.00156	-0.03061	0.75633	0.13401	**0.08690**	-0.00032	0.01776	-0.01141	0.04983	-0.04720	0.03047	-0.00935	0.80014**
Ca	-0.00520	0.00045	0.00021	-0.06167	-0.04159	-0.01724	0.00529	**-0.00531**	0.08706	0.03120	0.03952	-0.06833	0.03011	0.03013	0.02463
Mg	-0.00505	-0.01484	0.000006	-0.09487	0.11707	0.00189	0.01489	-0.00446	**0.10364**	0.03966	0.03415	-0.05593	0.03271	0.04029	0.20915
K	0.01265	-0.00736	-0.00258	-0.03607	0.02886	0.04168	-0.00530	-0.00088	0.02200	**0.18681**	-0.03226	-0.04202	0.00462	-0.02896	0.14119
Fe	0.00611	-0.05690	0.00092	-0.10648	0.05151	0.03227	0.02480	-0.00120	0.02027	-0.03452	**0.17458**	-0.08787	0.01804	-0.01463	0.02690
Mn	0.01033	-0.05891	-0.00145	-0.11968	0.19243	0.07160	0.02454	-0.00217	0.03468	0.04696	0.09178	**-0.16715**	0.03614	-0.01314	0.14596
Cu	0.05309	-0.00353	0.00199	0.00462	-0.16194	-0.02438	-0.01943	0.00117	-0.02488	-0.00633	-0.02312	0.04434	**-0.13624**	0.08732	-0.20732
Zn	0.01171	-0.02605	0.00110	-0.02505	0.04001	-0.01753	-0.00557	-0.00109	0.02864	-0.03711	-0.01752	0.01507	-0.08160	**0.14579**	0.03080

Residual effect = 0.01371, * significant at 5% and ** significant at 1%., PH = Plant height, SBD = Stem base diameter, LP = Leaves plant^{-1}, LA = Leaf area, SW = Shoot weight, RW = Root weight, STW = stem weight, Ca = Calcium, Mg = Magnesium, K = Potassium, Fe = Iron, Mn = Manganese, Cu = Copper, Zn = Zinc and BY = Biological yield m^{-2} (kg)

CONCLUSIONS

Variance analysis was highly significant that expressed wide range of variability among 20 genotypes of stem amaranth. Considering mean, range and all genetic parameters selection could be performed on the basis of leaves per plant, leaf area, shoot weight, root weight, stem weight, Zn, Mn, Cu, Fe and biological yield for significant improvement of stem amaranth genotypes. Biological yield was significantly and positively correlated with stem base diameter, shoot weight, root weight, stem weight and leaves plant^{-1} both at genotypic and phenotypic levels. It revealed that selection based on this trait could significantly improve the biological yield of stem amaranth. Mineral compositions showed insignificant associations among them along with biological yield except Zn versus Cu, Mg versus Ca, and Mn versus Fe. It indicated that improvement of mineral compositions was possible without compromising the loss of biological yield of stem amaranth. Path coefficient analysis revealed that shoot weight and root weight had high positive direct effect indicated that direct selection based on these characters would be effective for yield improvement of stem amaranth. The genotypes SA1, SA2, SA3, SA5, SA7, SA8, SA13, SA18 and SA20 were out-yielded over their corresponding means could be utilized in future breeding program for improvement of stem amaranth. SA8 had higher yield along with calcium, magnesium, potassium, iron, manganese and zinc content could be utilized as high yield potential mineral enriched variety. The genotypes SA6 and SA11 had low biological yield along with the highest content of iron, manganese, zinc, and copper. These two genotypes might also be selected as a donor parent for introgression of potential genes of high minerals into other genotypes.

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VARIABILITNOST U MINERALNOM SASTAVU, PRINOSU I KOMPONENTAMA PRINOSA STABLA AMARANTUSA (*Amaranthus lividus*)

Tonmoy CHAKRABARTY[1], Umakanta SARKER[1*], M. HASAN[1], and M. M. RAHMAN[2]

[1]Departman za genetiku i oplemenjivanje biljaka, Poljoprivredni fakultet, Bangabandhu Sheikh Mujibur Rahman Poljoprivredni univerzitet, Gazipur-1706, Bangladeš
[2]Departman za zemljište, Poljoprivredni fakultet, Bangabandhu Sheikh Mujibur Rahman Poljoprivredni univerzitet, Gazipur-1706, Bangladeš

Izvod

Dvadeset genotipova amarantusa je sakupljeno iz različitih eko-geografskih regiona Bangladeša kako bi se procenile varijacije u mineralnom sastavu, prinosu i komponentama prinosa, njihova međuzavisnost i direktni i indirektni efekat na biološki prinos. Analiza varijanse otkrila je značajnu razliku između genotipova za sve proučavane osobine. Uzimajući u obzir sredinu, opseg i sve genetske parametre, selekcija bi se mogla vršiti na osnovu listova po biljci, površini listova, težine izdanka, težine korena, težine stabljike, Zn, Mn, Cu, Fe i biološkog prinosa za značajno poboljšane genotipova amaranta. Korelacija je pokazala da prečnik osnove stabljike, težina izdanka, težina korena, težina stabljika i listovi po biljci mogu znatno poboljšati biološki prinos. Nesignifikantna veza između mineralne kompozicije pokazala je da je poboljšanje mineralnog sastava moguće bez gubitka biološkog prinosa. *Path* analiza otkrila je da bi direktna selekcija zasnovana na težini izdanka i težini korena bila efikasna za poboljšanje prinosa stabljike amarantusa. SA8 je imao viši prinos, kao i povećan sadržaj kalcijuma, magnezijuma, kalijuma, gvožđa, mangana i cinka i mogao bi se iskoristiti kao varijetet sa potencijalom za povećan sadržaj mineral i prinosa. Genotipovi SA1, SA2, SA3, SA5, SA7, SA8, SA13, SA18 i SA20 mogu se koristiti u budućem programu oplemenjivanja za poboljšanje stabla amaranta. Genotipovi SA6 i SA11 mogu takođe biti izabrani kao roditelji donatori za introgresiju potencijalnih gena za visok sadržaj minerala u druge genotipove.

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