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GENETIC VARIATION AND HERITABILITY FOR FOLIAGE YIELD AND YIELD COMPONENT TRAITS IN EDIBLE *Amaranthus cruentus* [L.] GENOTYPES

O. T ADENIJI[1]

Abstract

The field experiment with nine *Amaranthus cruentus* genotype was conducted, to estimate the magnitude of genetic variability, heritability and genetic advance for leaf yield and contributing traits of amaranth genotypes during 2013 and 2017 cropping seasons. Field experiment was carried out in a randomized complete block design with three replications between 2013 and 2014 cropping season in Jalingo Taraba state. Data were collected on branches/plant, leaves/plant, leaf length, lead width, leaf fresh weight, leaf dry weight, marketable foliage yield, non- marketable foliage yield and plant height. Analysis of variance revealed highly significant mean squares ($P < 0.01$) among the genotypes tested for all the traits investigated. Thus indicating presence of high variability for foliage yield and yield traits. The PCV value was greater than GCV for all traits; however, GCV values were near to PCV values for the traits like leaf width, plant height branches/plant indicating high contribution of genotypic effect for phenotypic expression of such characters. High heritability coupled with high genetic advance per percent of mean reflect the presence of additive gene action in the expression of these traits, and improving of these traits could be done through simple selection.For multiple traits, AM 45 outperformed other genotypes for leaves/plant, fresh weight of leaves, plant height, and branches/plant.While AM 42 performed best for foliage yield (t/ha) and branches/plant.

Keywords: *Amaranth cruentus*, Genotypic and phenotypic coefficient of variation, genetic variation, heritability, and marketable foliage yield.

Introduction

Amaranth belongs to the family Amarantheaceae, which include 650 genera and 850 species which are widely distributed in the tropical and temperate regions of the world. The genus Amaranthus, is a native to different parts of North, Central, and South America. It is mostly monoecious inflorescences bearing both male and female flowers (Trucco and Tranel, 2011). *A. cruentus* [L.] is diploids with chromosome number 2n = 32, but occasionally it can be 34 (Chan and Sun, 1997). Amaranth is an important high value indigenous vegetable in sub Saharan Africa, particularly important crop for developing countries (Smith and

[1]Department of Crop Science and Horticulture, Federal University, Oye Ekiti, Nigeria.

Eyzaguirre 2007). It is characterized by a high protein content of 12.5%–18% with a well-balanced amino acid composition and high lysine and methionine contents (Pospišil *et al.,* 2006). One cup of amaranth leaves that are cooked, boiled, and drained contains 90 % vitamin C daily value requirement, 73 % vitamin A, 28 % calcium and 17 % iron (Smith and Eyzaguirre 2007). The vitamin composition of the plant is higher than those reported for *Aspilia africana*, *Bryophyllum pinnatum* (Lam.) Oken, *Vernonia amygdalina, Eucalyptus globulus* L. and *Ocimum gratissimum* L. (Alabi *et al*., 2005). Amaranths leaves and stems are used as food in Southeast Asia and Equatorial Africa and can compete with spinach leaves in terms of protein content (van Le *et al.,* 1998). The particularity of amino acid profile of *A. cruentus* leaves is its methionine and lysine levels, which are the limiting amino acids in most plant proteins (Fasuyi 2007). Amaranth exhibit C_4 photosynthetic pathway, great amount of genetic diversity and phenotypic plasticity. It is a quantitative short-day plant, which is an advantage in the subtropics, where the generative stage is delayed during summer. Amaranths performed best on fertile, well-drained alkaline soils (pH 6) with a loose structure. Vegetable amaranth is cultivated anytime provided water is not limiting. Its cultivation for leaf is profitable during dry season compared to rain fed conditions. Vegetable amaranths grow well at day temperatures above 25 ^{0}C and night temperatures not lower than 15 ^{0}C. Shade is disadvantageous except in cases of drought stress. The mineral uptake in*Amaranthus cruentus* is very high (Grubben, 2004).

In *Amaranthus cruentus* there is an urgent need for genetic improvement to enhance foliage leaf yield and quality characters. Improvement in foliage yield requires knowledge of the magnitude of variation in available germplasm, interdependence of quantitative traits on leaf yield, extent of environmental influences, heritability and genetic gain. Genetic variability is important for selection of parents with transgressive segregation (Patro and Ravisankar, 2004). Information on genetic variability and availability of commercial varieties of *Amaranthus cruentus* genotypes is limited. Therefore, there is a need to generate information on genetic variability, heritability, and genetic advance to estimate the progress of breeding program in future. Progress and gain from selection in any breeding programme depend upon the magnitude of useful variability present in the population and the degree to which the desired traits are heritable. Heritability estimate of a character is important for plant breeder, because it provides information on the extent to which a particular character can be transmitted from the parent to the progeny (Allard, 1960; Poehlman and Sleper, 1995; Syukur *et al.,* 2012). Similarly, genetic advance is important because it shows the degree of the gain obtained in a character from one cycle of selection. High genetic advance coupled with high heritability estimates offers the most suitable condition to decide the criteria of selection (Allard, 1960; Poehlman and

Sleper, 1995; Syukur *et al.,* 2012). Efficiency of selection in breeding programme relies upon association between traits. Correlation between leaf yield and its related traits could improve the efficiency of selection in amaranth breeding. Leaf yield is a complex quantitative character and controlled by several genes interacting with the environment. The extent of genetic variation and genotypes agronomic performance of *Amaranthus cruentus* remains largely rudimentary indicating untapped potential for research. Currently, there are few commercial varieties of *Amaranth cruentus* released into the cropping systems in Nigeria.

The objectives of this study are to evaluate the magnitude of variation for leaf yield and yield component traits under short cycle harvest, estimate genetic variation and heritability for leaf yield and yield component traits and determine association between leaf yield and yield component characters.

Materials and Methods

Location, Site characteristics and Germplasm

This research was conducted at the research farm, National Open University of Nigeria, Jalingo, Nigeria (Lat $8^{o}47$'S and Lon 11^{0} 09'E,altitude of masl) in May, 2013 and 2014. Jalingo is characterized by monomodal rainfall regime. The rainfall season starts in April/May, thereafter the cold and dry season (November to January). The hottest month is between February to March/April. The soil type is clay loam with pH between 6.0 and 6.5. Eight amaranth genotypes (AM 42, AM 38-2, AMTZ 01, AM 40, AM 50, Ex-Zimbabwe, AM 25, AM 45 and a popular local cultivar (AM local) received from the gene bank of The World Vegetable Center were used for field investigations.The entries are homogeneous for phenotypic traits.

Experimental design and Data collection

Field experiments were established in July, 2013 and 2014. Nine amaranth genotypes were grown in a randomized complete blocks design with three replications. Sunken beds were made at 1 m x 2 m, each bed was separated by alley of 1m. A total of 9 beds constituted a replicates. Each bed was treated with 4 Kg of matured farmyard manure. Prior to field establishment seeds were tested for viability. Thereafter 10 g of viable seeds was uniformly spread on each vegetable bed. The experiment was rain fed with occasional manual irrigation. Weeding was carried out manually and frequently to maintain a weed free plots. Harvesting was done by uprooting at 4 weeks after sowing. Amaranth plants in each net plot (1 m x 1 m) were used to determine leaf yield and yield contributing traits. Branches/plant, leaves/plant was estimated by counting branches or leaves on ten randomly picked amaranth plants. The leaf length and width were measured with a meter rule on five randomly picked leaves per plant. Plant height (cm) was measured with a meter rule on ten randomly picked plants per entry. Foliage yield was separated into marketable foliage yield and non-marketable yield. The non-marketable foliage yield comprised weak and yellowish green plants, and portion of the lower stem and roots. The marketable foliage yield (t/ha) and non-marketable yield (t/ha) were estimated from marketable foliage yield/plot and non-marketable foliage yield/plot measured on weigh balance (Kg). At harvest three plants were randomly picked per plot, thereafter all leaves/plant were excised, counted and weighed on electronic weigh balance to obtain the fresh weight of leaves. The fresh leaves were oven dried at 32^0C, until a constant weight was obtained. Dried leaves were weighed on sensitive electronic weight balance to obtain leaf dry weight.

Data analysis

Homogeneity of residual variances was tested prior to a combined analysis over years using Bartlet's test (Bartlett, 1937). The data collected were homogenous and showed normal distribution. The Genotype (G) and Year (Y) were considered to be fixed-effects, while replications was considered as random effect. The combined analysis of variance was performed using a mixed model on plot means combined across years for all traits using PROC - GLM procedure of Statistical Analysis System (SAS) software version 9.2 (SAS, 2008). Thereafter treatment means were tested with Duncan multiple range testing (DMRT) at 5% probability levels (SAS, 2008). Correlation coefficients between traits was computed using PROC CORR procedure of SAS (2008).

Estimates of variance components

The variability present in genotypes on *A. cruentus* was estimated by phenotypic and genotypic variance and coefficient of variation. The phenotypic and genotypic variance, genotypic and phenotypic coefficients of variation were estimated based on formula Syukur *et al.* (2012) as follow:

$\sigma^2G = [(MSG) – (MSE)]/r$

$\sigma^2P = [\sigma^2G + (\sigma^2E/r)]$,

Where: σ^2G = Genotypic variance; σ^2P = Phenotypic variance; σ^2E = environmental variance (error mean square from the analysis of variance); MSG = mean square of genotypes; MSE = error mean square; r = number of replications.

Genotypic coefficient of variation (GCV) was calculated as = $[(\sigma^2G)^{½}X] \times 100$;

While Phenotypic coefficient of variation (PCV) was computed as = $[(\sigma^2P)^{½}/X] \times 100$, Where: σ^2G = Genotypic variance; σ^2P = Phenotypic variance; is grand mean of a character.

Estimation of heritability in broad sense heritability (h^2) of the all traits were calculated according to the formula as described by Allard (1960) as follow:

$h^2_{bs}= [(\sigma^2G) / (\sigma^2P)] \times 100$

Where: h^2b = heritability in broad sense; σ^2G =Genotypic variance; σ^2P = Phenotypic variance.

Genetic advance (GA) was determined as described by Johnson *et al.* (1955): GA = K (σP) h^2, where: K = the selection differential (K = 2.06 at 5% selection intensity); σP = the phenotypic standard deviation of the character; h^2 = broad sense heritability. The genetic advance as percentage of the mean (GAM) was calculated as: GAM (%) = GM/X × 100, where: GAM = genetic advance as percentage of the mean, GA = genetic advance, and X = grand mean of a character.

Results and Discussion

The analysis of variance for foliage yield and component traits combined across years (Table 1) showed significant ($P \leq 0.05$) mean squares for branches/plant, marketable foliage yield (t/ha), non-marketable foliage yield (tha^{-1}), fresh weight of leaves/plant, leaf dry weight/plant, plant height, leaf length and leaf width. The year effect recorded statistically significant ($P \leq 0.05$) mean squares (leaves/plant, marketable foliage yield (tha^{-1}), non-marketable foliage yield (tha^{-1}), leaf fresh weight, leaf dry weight and plant height) and insignificant ($P \geq 0.05$) mean squares for branches/plant). The genotype by year interaction had significant ($P \leq 0.05$) mean squares for leaves/plant, marketable foliage yield (tha^{-1}), fresh weight of leaves/plant, dry weight of leaves/plant, plant height and leaf length, and insignificant mean squares for branches/plant, non-marketable leaf weight and leaf width.

The number of branches/plant ranged from 5 to 7, AM 25and AMTZ 01 outperformed other genotypes for this trait (Table 2). Leaves/plant was low (5) in AM 38-2, but high (8.60-8.68) in AM 25 andAM 45 respectively. Other genotypes recorded values intermediate between the two extremes. Over years marketable foliage yield (t/ha) ranged from 11.50 t/ha and 22.67 tha^{-1}(Table 2). AM 42, AMTZ 01 performed best (22.67 tha^{-1} and 22.37 t/ha) followed by AMLOC. High and consistent leaf yield over years indicated that these genotypes are promising for leaf yield and further testing in other locations. Non-marketable foliage yield was high in AM 42 followed by AMTZ 01 and AM 45. High proportion of non-marketable foliage yield may be associated overcrowding associated with broadcasting of seeds, competition for available nutrients and insect pests attack. Marketable foliage yield recorded in this study was low compared to those reported for vegetable amaranth accessions harvested by uprooting in East Africa (AVRDC, 2002, 2008; Oluoch *et al.* 2009). The weight of fresh leaves/plant was high (38.2 g) in AM 45, while AMTZ 01 recorded 36.33 g, and 36.1 g in AM 25. In contrast, entries with high estimates for fresh weight of leaves recorded low values for leaf dry weight. This suggests high proportion of water compared to dry matter. Best genotypes for leaf dry weight are AM 25, AM 38-2 and AM LOC. Plant height is short (10.33 cm) in AM 38-2, on the other hand AM 45 and AM 42 are tall (28 cm and 25 cm at 4 weeks, respectively). The leaves of AM 42 are long (9.00 cm), followed by AM 45 (8.37 cm) and AMLOC (7.70 cm)(Table 2). The leaves of Ex-Zimbabwe are narrow (1.55 cm).In contrast AM 42, AM 45 and AMTZ 01 had wider leaves (range from 6.16 cm to 6.83 cm). AM 42 recorded high leaf yield, and also exhibited highest mean performance for leaf length and width (Table 2). For multiple traits, AM 45 was best for leaves/plant, fresh weight of leaves, plant height. While AM 42 performed best for leaf yield (t/ha) and branches/plant (Table 2).

Variability played an important role in crop breeding program, it is prerequisite to understand variability in the population and partitioning into genotypic, phenotypic and environmental effects. Variability is also important 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. The estimates of genetic components and heritability are presented in Table 3. For all leaf yield and yield components traits estimates of genotypic variance are low in magnitude compared to their corresponding phenotypic variance. Similarly the estimates of phenotypic coefficient of variation (referred hereafter as PCV) were in most cases greater than their respective genotypic coefficient of variation (referred hereafter as GCV) for all the traits indicating the impact of the environmental factors towards expression of traits. Similar results were also reported by Syukur and Rosidah (2014) in pepper. Moderate estimate of PCV was recorded for plant height, fresh weight of leaves, leaf length, leaf width and non-marketable foliage yield, and moderate GCV was recorded for leaf dry weight. This implies that improvement in this trait under selection may be achieved up to a reasonable extent. Low PCV (branches/plant, leaves/plant and leaf length) and GCV (branches/plant, marketable foliage yield, fresh weight of leaves, leaves/plant) for traits implies that chances of getting substantial gain under selection are likely to be less for these traits. Environmental coefficient of variation ranged between from 0.10 (leaf dry weight) and 0.21 (non-marketable leaf weight t/ha). High PCV (marketable foliage yield, non-marketable foliage yield and dry leaf weight and leaf width) indicates the magnitude of improvement in these traits through selection to enhance the potentiality of leaf yield. Similar result were also observed in *Amaranth tricolor* (Shukla and Singh, 2000). However, GCV was

Table 1. Mean squares for foliage yield and yield component traits in *Amaranthus cruentus* [L] harvested at 4 weeks after sowing during 2013 and 2014 seasons

Source of variation	Df	Br/Pl	Lvs/Pl	Nmkt FY(t/ha	Mkt FY (t ha^{-1})	Lv Fwt (g)	Lv Dwt (g)	Plt Ht	Lvl (cm)	Lvw (cm)
Genotypes	8	17.70**	90.74***	2.13***	21.17***	5460.17***	0.21	44.46*	0.11	0.15
Year	1	3.93	8.20***	2.87***	133.28***	246.65***	4.09**	173.54***	11.19***	15.04**
Replications	2	2.79	0.50	0.14	42.39**	36.35	0.02	14.35	0.82	0.81
Genotypes x Year	8	1.37	5.03***	0.82	118.42**	195.67***	2.04***	21.12*	2.91**	0.98
Error	34	1.65	0.93	0.07	6.37	16.02	0.13	9.54	0.55	0.52
CV (%)		20	13	21.73	14.61	13.39	19.35	15.78	10.84	17.42
Mean		6.35	7.55	1.27	17.27	29.87	1.88	19.57	6.89	4.16

***= Significant at 0.1% level of probability

**= Significant at 1% level of probability

*= Significant at 5% level of probability

Br/plt= Branches/plant, Lvs/pl = leaves/plant, Nmkt FY (t/ha) = non marketable foliage yield, Nmkt FY= Non marketable foliage yield, Lv Fwt = Leaf fresh weight, Lv Dwt = Leaf fresh weight, Pht= Plant height, Lvl= Leaf length, Lvw= Leaf width.

Table 2. Mean values for foliage and leaf quality traits in 9 genotypes of *Amaranthus cruentus* during 2013 and 2014 cropping seasons

Genotypes	Br/Pl	Lvs/Pl	Mkt LvY (t ha^{-1})	Nmkt LvY(t ha^{-1})	Lv Fwt (g)	Lv Dwt (g)	Plt Ht	Lvl (cm)	Lvw (cm)
AM 25	7.17a	8.60a	16.56b	13.17bc	36.1ab	2.65a	17.56de	6.00de	4.30b
AM 42	7.00a	8.00ab	22.30a	17.83a	23.5de	1.48d	25.67ab	9.00a	6.83a
AM TZ 01	7.03a	7.00bc	22.67a	17.83a	36.33ab	1.35d	19.17dc	7.50bc	4.33b
AM 45	7.00	8.68a	20.67a	17.67a	38.20a	2.10bc	28.0a	8.37ab	6.16a
AM 40	6.83a	8.16ab	14.83bc	13.50bc	23.50de	1.80cd	22.17bc	7.70bc	4.11b
AM local	5.83ab	7.67abc	21.00a	14.67ab	32.33bc	2.37ab	17.83de	6.83cd	3.00c
AM 50	5.83ab	6.67c	13.83bcd	14.17ab	28.17cd	1.73cd	20.67cd	4.83f	3.50bc
AM 38-2	5.50ab	5.00a	11.50d	10.00c	21.50e	2.60a	10.33e	6.33de	3.56bc
EX ZIM	5.00b	8.33a	12.17cd	11.17bc	30.16c	0.91e	14.83c	5.50ef	1.55d

Br/plt= Branches/plant, Lvs/pl = leaves/plant, Nmkt FY (t/ha) = non marketable foliage yield, Nmkt FY= Non marketable foliage yield, Lv Fwt = Leaf fresh weight, Lv Dwt = Leaf fresh weight, Pht= Plant height, Lvl= Leaf length, Lvw= Leaf width

Table 3. Estimates of Genotypic variation (σ^2G), phenotypic variation (σ^2P), Genotype by Year variation (σ^2GY) Genotypic coefficient of variation (GCV), Phenotypic coefficient of variation (PCV), Environment Coefficient of Variation (ECV), heritability in broad sense (H_2b), Genetic advance (GA), genetic advance as percentage of the mean (GAM) for 9 traits of *Amaranthus cruentus*

Genetic variation	Br/Pl	Lv/Pl	Mkt FY (t ha^{-1})	Nmkt FY (t ha^{-1})	Fr Lwt (g)	Lv Dwt (g)	Plt Ht	Lvl (cm)	Lvw (cm)
σ^2G	0.43	0.52	2.31	7.45	8.49	0.36	28.57	1.38	2.34
σ^2PH	0.74	3.52	62.51	33.94	109.0	1.38	40.72	2.93	2.92
σ^2GY	0.07	1.38	37.35	13.53	59.88	0.64	3.86	0.79	0.15
PCV	18.10	24.84	45.78	40.34	34.95	63.10	32.61	28.24	41.08
GCV	10.33	9.55	8.80	19.90	9.75	31.60	27.31	17.05	36.77
ECV	0.20	0.13	0.17	0.21	0.13	0.10	0.15	0.11	0.17
Hb	41	15	3.69	23	7	26	70	47	80
GA	1.03	0.60	0.60	0.81	2.72	0.63	9.18	1.65	1.65
GAM (%)	16.22	7.95	3.47	63.77	9.11	33.51	46.81	23.94	39.66
PCV - GCV	7.77	15.29	36.98	20.44	25.20	31.50	5.30	11.19	4.31

Br/plt= Branches/plant, Lvs/pl = leaves/plant, Nmkt FY = non marketable foliage yield, Nmkt FY= Non marketable foliage yield, Lv Fwt = Leaf fresh weight, Lv Dwt = Leaf fresh weight, Pht= Plant height, Lvl= Leaf length, Lvw= Leaf width.

not near to PCV for all traits except leaf width, plant height and branches/plant. This indicates a high contribution of environmental effects compared to genotypic effect for phenotypic expression of these traits. A large difference between GCV and PCV was observed for marketable foliage yield (t/ha) and leaf dry weight, this indicates a large contribution of environmental factors, in addition to genetic effects in the expression of these traits. Findings reported in this investigation are similar to previous reports by Sharma *et al.* (2010) in bell pepper. Preponderance of genetic variability among the tested genotypes showed that yield improvement through selection was possible in A*maranth cruentus*. The efficiency of selection depends on the magnitude of genetic variability and inherent heritability of the traits.

Singh (2001) had noted that heritability values greater than 80% were very high, values from 60–79% were moderately high, values from 40–59% were medium, and values less than 40% were low. Accordingly, heritability estimates was low for leaves/plant, marketable yield, non-marketable foliage yield, fresh weight of leaves and leaf dry weight (Table 3). High heritability estimates were recorded for leaf width (70%) and plant height (60%). Findings in this study are consistent with previous report of Sharma *et al.* (2010) in *Amaranth tricolor.*Phenotypic traits having very high heritability indicates relative small contribution of the environment factors to the phenotype, and selection for such characters could be fairly easy due to high additive effect. In addition, medium heritability estimates wererecorded for branches/plant and plant height. While leaves/plant, marketable foliage yield, non-marketable foliage yield, fresh weight of leaves and leaf dry weight had low heritability estimates. In contrast, Shukla *et al.* (2004) reported that high heritability for foliage yield, branches/plant and plant height in *Amaranthus tricolor* harvested by cutting fresh leaves at 3 weeks after planting, and at 15 days thereafter. In this investigation it was observed that some traits recorded moderate to high heritability, with low genetic advance. These traits may be governed by non-additive gene action, which limits the scope for phenotypic improvement through selection

Branches/plant recorded negative and significant correlation coefficient with leaf width (Table 4). This indicated that phenotypic improvement in the number of branches will not complement leaf width among the genotypes. The leaves/plant recorded positive and significant correlation coefficient with marketable foliage yield (t/ha), non-marketable foliage yield (t/ha) and leaf fresh weight (g). This implied interdependency among these traits as more leaves are produced per plant, a corresponding increase in marketable foliage yield is expected. Interdependency associated with non-marketable foliage yield can be reduced through uniform distribution of seeds, use of organic fertilizers and adoption of good agricultural practices designed for vegetables. The marketable foliage yield showed positive and significant correlation coefficient with non-marketable leaf yield, and positive though insignificant correlation coefficients with leaf length, leaf width and leaf dry weight. Further, weight of fresh leaves recorded positive and significant correlation coefficient with leaves/plant. These result suggest that selection and improvement of leaves/plant will enhance leaf fresh weight. Significantly negative correlation coefficient in the association between leaf dry weight and branches/plant showed that improvement in leaf dry weight will not enhance branches/plant. Considering high genotypic and phenotypic variances along with GCV and PCV values, high heritability coupled with GA five traits (branches/plant, plant height, leaf width and leaf length) could be selected.

Conclusion

The study showed considerable magnitude of variation for foliage yield and yield traits in *Amaranthus cruentus* genotypes. The magnitude of phenotypic and genotypic variation, phenotypic and genotypic coefficient of variation recorded implied the scope on which improvement can be achieved in this species. Leaf width, plant height and branches/plantare highly heritable. These traits could be used as good criteria for selection in the amaranth improvement because these traits had moderate genotypic coefficient of variation, high heritability and genetic advance as percent of the mean. AM 25, AM 42, AMTZ 01 and AM 45 performed best for individual and multiple traits and are recommended for evaluation in multiple environment.

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