ASSESSMENT OF PHENOTYPIC VARIATIONS IN WORLDWIDE ACCESSIONS OF *AMARANTHUS TRICOLOR*

Reda Helmy Sammour ✉
Department of Botany[1]
redasammour54@gmail.com

Mohammed Mosa Mira
Department of Botany[1]

[1]*Tanta University*
Medical campus, Tanta, Egypt, 31527

✉**Corresponding author**

Summary

The objective of this work was to assess the genetic diversity in *Amaranthus tricolor* accessions using quantitative morphological traits. As a result of this study, the Amaranthus *tricolor* accessions showed a wide variation in the desirable trait of higher vegetative yield.

The results of this work showed that the coefficient of variation of the following traits was high: germination percentage (38.69), seedling vigor index (48.31), plant height (61.40), leaf area (41.08), number of branches (161.29), width of shoot system (64.97), width of the seed head (46.09), and length of seed head (128.18). The Pearson correlation coefficient showed a highly significant relationship between the following traits: germination percentage and seedling vigor index (0.76); length of seed head and plant height (0.75); width of seed head and width of shoot system (0.64); leaf area and width of seed blade (0.69); and width of shoot system and plant height (0.58). The corresponding analysis identified the accessions that have the best stem diameter, leaf area, plant height, and number of branches. These accessions are a valuable resource to breed for stem diameter, leaf area, plant height, and number of branches. Cluster analysis showed that there is no link between accession diversity and geographical origin. The multiple regression analysis and path analysis data demonstrated a positive correlation between leaf area and both plant height and width of the blade.

This study provides a solid foundation for the identification of the superior *Amaranthus tricolor* accessions that can be used for designing a breeding program to improve the vegetative yield.

Keywords: *Amaranthus tricolor*, phenotypic traits, Pearson correlation coefficient, corresponding analysis (CA), cluster analysis.

DOI: 10.21303/2504-5695.2026.004188

1. Introduction

The genus *Amaranthus* L. belongs to the family Amaranthaceae, order Caryophyllales. It comprises approximately 70 species of dicotyledonous herbaceous plants [1–3].

Although *Amaranthus* originated in South America, it spread around the world in Africa, Central America, Southeast Asia, the Andean highlands in South America, and North America [4, 5]. Many *Amaranthus* L. species are cultivated as vegetables, highly nutritious pseudo-cereals (rich in seed proteins), forage, and ornamentals. However, regional preferences are the limiting factor in the utilization of amaranths as a vegetable, grain, or weed. For example, *Amaranthus hypochondriacus* L, *Amaranthus caudatus* L, and *Amaranthus cruentus* L were utilized as grain species in Asian countries and as vegetables in African countries [6]. In addition, the weedy species *Amaranthus blitum* L. and *Amaranthus dubius* Mart. ex Thell were utilized as vegetables in most of the countries in Asia and Africa [7, 8].

Amaranthus have been considered a promising grain and leafy crop due to their superior nutritional value, good adaptability to drought and disease, high pest resistance, and high production yield [9]. Moreover, *Amaranthus* has several protective and curative properties attributed majorly to strong antioxidant activity [10, 11]. Grain amaranths have received more research attention because of the potential nutritional impact of their seed consumption on human health in the temperate and tropical regions of Asia, Australia, Europe, America, and Africa [12, 13]. In contrast, leafy amaranths have received significantly less research attention, despite their importance as sources of bioactive compounds and micronutrients and as an affordable protein source [14, 15].

The leafy amaranth, *Amaranthus tricolor,* is characterized by a wide genetic diversity and polymorphism and a tremendous adaptability to different eco-geographic conditions [15, 16], which was attributed to the out-crossing and frequent inter-varietal hybridization [17]. This wide genetic diversity was identified as an area for prospects for research and development [14, 18, 19]. However, it did not receive much attention. Therefore, evaluating the genetic diversity and polymorphism of *Amaranthus tricolor* is important for breeders who are concerned with producing new cultivars best adapted to the local environmental conditions and that have high vegetative yield.

Morphological traits have an important role in the evaluation of genetic variability in plants, especially when assessing genetic resources for choosing the best-suited accessions to be integrated into a breeding program [20–22]. However, growing plants under controlled conditions can overcome the severe influence of the environmental and developmental changes on the morphological traits [23].

This research, therefore, was devoted to evaluating the morphological variations in 30 accessions of *Amaranthus tricolor,* collected from different sub-geographical regions, and identifying the best-suited accessions that can be used as starting material for developing a new cultivar with high vegetative yield.

2. Materials and methods

2. 1. Seed materials

30 *Amaranthus tricolor* accessions were evaluated in this research. The *accessions* were collected from the United States Department of Agriculture, Agricultural Research Service (USDA/ARS) on the basis of their subgeographic region distribution (**Table 1**).

Table 1

Code, accession number and origin of 30 accessions of *Amaranthus tricolor*

Code	Accession No.	Origin	Code	Accession No.	Origin
1	PI 277267	India	16	Arries 5135	Madhya Pradesh (India)
2	PI 277268	India	17	PI 214036	Karnataka (India)
3	PI 419057	Beijing (China)	18	PI 277269	India
4	PI 419121	China	19	PI 349553	Papua (New Guinea)
5	PI 462129	India	20	PI 462126	India
6	PI 478310	China	21	PI 462127	India
7	PI 566899	Tamil Nadu (India)	22	PI 462128	India
8	PI 603896	California (USA)	23	PI 477918	Unknown
9	PI 604668	Taiwan	24	PI 490762	India
10	PI 604670	Taiwan	25	PI 527321	China
11	PI 607446	Thailand	26	PI 604669	Taiwan
12	PI 632237	Connecticut (USA)	27	PI 608761	Gujarat (India)
13	PI 633591	Unknown	28	PI 619252	Tamil Nadu (India)
14	PI 633594	Unknown	29	PI 633590	Unknown
15	PI 636179	Taiwan	30	PI 633595	Unknown

2. 2. Seed germination and plant growing

Amaranthus tricolor accessions were grown in a greenhouse at 25–30°C. The greenhouse was located at the Department of Botany, College of Science, Tanta University, Tanta, Egypt. The seeds of these accessions were subjected to cold treatment for the first 24 hours to improve germination and then germinated in plastic trays (5 × 5 holes; diameter, 5.0 cm; depth, 5.0 cm) containing "Perlite" (Carolina Perlite Company, USA) for 3 weeks. Five germinating plants per accession were transplanted into a pot containing peat moss as a biological fertilizer mixed with silt in a ratio of 1:4, respectively. The pots were arranged in a completely randomized design.

2. 3. Morphological traits evaluation

Morphological traits were assessed five times per accession. Each time, 3 tagged plants in a pot were randomly assessed. Thus, a total of 15 observations were measured for each trait. The assessed morphological traits were recorded in **Table 2**.

Table 2

List of accessions of *Amaranthus tricolor* and values of morphological characters

Code	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	50	2.7	0.7	20	4	6	4	3.7	5	0	5	0.7	4	23.85
2	80	2	0.8	12	3	1	6	4.7	14	1	1.5	0.7	3	31.65
3	40	4.5	0.5	40	3	0	5	4.7	12	3	9	1.2	4	22.67
4	50	3	1	30	5	0	6.5	6	10	2	0.5	0.5	4	35.19
5	85	1.7	1	18	3	0	5	2	12	2	0.7	1.3	3	19.25
6	85	2.5	1	21	4	0	4.8	3	3	1	0.5	0.5	2	14.41
7	100	4	1	18	4	0	4.2	2.8	15	0	0.5	0.5	5	17.83
8	100	2	1	12	2	0	4.5	1.8	15	0	0.5	0.5	3	14.17
9	100	2.5	1.2	50	3	0	6.5	4.7	20	1	10	1	4	26.69
10	90	1.8	1.2	38	3	0	5	3.5	20	1	0.5	1	3	14.31
11	15	2.5	1.2	30	1	0	2.7	2	11	0	0.5	1	3	17.65
12	65	3.2	1	7	5	0	7	5.3	10	1	0.5	0.5	3	55.97
13	75	2.5	1.7	19	3	0	6.5	5.3	16	1	0.6	1.5	3	29.99
14	65	2.5	2	12	3	5	7	6	23	0	0.7	1.5	4	53.49
15	35	2.5	1.5	10	3	5	6	3.9	15	0	0.7	1	3	26.92
16	45	2	1.5	20	4	5	5	4.4	30	2	0.6	1.3	3	20.19
17	20	2.7	1.5	30	4	10	5	4.1	19	1	4	0.8	4	17.7
18	50	3.5	1.5	17	5	0	5.3	4.7	23	1	1.5	1.5	4	25.92
19	25	2.5	1	11	2	0	4.5	4	19	2	0.6	1.5	3	41.09
20	70	2.3	0.9	19	2	0	4.7	2.5	25	0	0.5	0.5	3	16.23
21	65	2.5	1	15	2	0	4	3.3	27	1	0.6	0.5	5	21.49
22	40	2.5	1	26	3	0	6	3.3	25	2	1	1.5	3	27.63
23	45	2.5	1	4	2	0	4.5	4.5	8	1	2.5	0.6	4	32.71
24	90	2.3	1.6	39	3	12	4.5	4.5	22	2	8	2	3	17
25	95	2.2	1.3	19	3	0	7	2	3	0	0.5	1	3	16.53
26	55	3	0.9	18	3	3	4.5	4.3	19	0	0.7	1.5	5	27.34
27	95	1.9	1.8	24	3	1	4.3	3.4	21	3	1.5	1.3	4	16.47
28	85	2.5	1.4	71	5	10	6	5.4	70	1	9	2.5	4	33.47
29	90	1.8	1.6	10	3	2	5.5	5	19	0	1.5	1.5	4	23.26
30	85	2.3	1.6	40	3	5	5.3	4.2	20	1	5.5	1.5	3	31.53

Note: A – germination percentage; B – plumule length; C – radical length; D – plant height; E – stem diameter; F – number of branches; G – length of blade; H – wide of blade; I – wide of shoot system; J – anthocyanin; K – length of seed head; L – wide of seed head; M – size of seeds; N – leaf area.

The seedling vigor index was calculated by multiplying the germination percentage by seedling length (cm) [24]. The stem diameter (mm) was measured using a slide caliper from Digimatic Solar DC-S15m, Mitutoyo, Japan. The leaf area was determined with the VH-analyzer image analysis software, version 2.20, Keyence Co., Ltd., Osaka, Japan. The leaves were arranged on a white paper background and scanned with a GT-9800 F scanner, produced by EPSON, Tokyo, Japan, before leaf area measurement. A 1 cm^2 color marker was used as the standard.

2. 4. Statistical analysis

The method of [25] was used to calculate analysis of variance, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), and heritability for the analyzed traits, whereas genetic advance was estimated by the method of [26].

Pearson correlation and boxplot were performed using the software package PAST, Version 4.02, Natural History Museum, University of Oslo, 1999–2020.

The association between accessions and traits was determined using correspondence analysis with R instat software version 0.8.2.97.

The accessions were grouped based on the morphological traits using Ward's method of cluster analysis, whereas the genetic distance between accessions was estimated by the Euclidean measure of distance using MYSTAT version 12.2.

Multiple regression analysis and path analysis were determined using the following website: https://www.statskingdom.com/410multi_linear_regression.html.

3. Results and discussion

The results of the genetic parameter of variability for quantitative traits are presented in **Table 3**. They showed a wide range of variation in the morphological traits of *Amaranthus tricolor* accessions. This wide range of variability was attributed to:

1) the absence of selection pressure, as the existing variations are natural;
2) *Amaranthus tricolor* is inbred and outbred (4 to 34%) by winds;
3) the process of natural introgression;
4) the wide geographic and ecological ranges of the investigated accessions.

Table 3

Genetic parameter of variability for 14 quantitative characters of 30 accessions of *Amaranthus tricolor*

Code	Character	Mean ± Standard Error	Range		Coefficient of variation	Coefficient of variation (%)		Heritability (H^2)	Genetic Advance
			Minimum	Maximum		(PCV)*	(GCV)**		
A	Germination Percentage	66.33±4.69	15.00	100.00	38.69	41.22	41.08	99.33	74.75
B	Plumule Length	2.55±0.11	1.70	4.50	24.40	24.41	22.51	85.00	36.52
C	Radical length	1.21±0.06	0.50	2.00	29.10	29.41	29.34	99.49	51.50
D	Plant height	23.33±2.62	4.00	71.00	61.40	54.05	54.05	100.00	95.12
E	Stem diameter	3.20±0.18	1.00	5.00	31.14	34.34	32.09	87.35	52.79
F	Number of branches	2.17±0.64	0.00	12.00	161.29	199.85	197.54	97.70	343.64
G	Length of blade	5.23±0.19	2.70	7.00	19.92	20.76	20.76	100.00	36.54
H	Wide of blade	3.97±0.22	1.80	6.00	29.71	31.01	30.98	99.77	54.46
I	Wide of shoot system	18.37±2.18	3.00	70.00	64.97	43.38	43.37	99.96	76.32
J	Anthocyanin	1.00±0.17	0.00	3.00	90.97	85.28	85.28	100.00	150.09
K	Length of seed head	2.32±0.54	0.50	10.00	128.18	142.71	142.56	99.78	250.63
L	Wide of seed head	1.10±0.09	0.50	2.50	46.09	42.61	42.52	99.58	74.67
M	Size of seeds	3.53±0.13	2.00	5.00	20.67	21.10	20.54	94.83	35.21
N	Leaf Area	25.75±1.93	14.17	55.97	41.08	42.05	40.92	94.71	70.10

Note: PCV – phenotypic coefficient of variation; GCV** – genotypic coefficient of variation.*

The germination percentage of *Amaranthus tricolor* accessions was highly variable, ranging from 15 to 100%. This highly variable germination behavior might be affected by a wide geographic and ecological range of *Amaranthus tricolor* [27], reflecting adaptations to the site conditions, the environmental conditions experienced by the mother plants, and seed traits [28, 29].

There was a wide variation in the number of branches, ranging from 0 to 12 in accession PI490762 from India and 10 in accession PI214036 from Karnataka (India) and PI619252 from Tamil Nadu (India). However, most accessions had a few branches. Since the number of branches is a heritable trait [30], the accessions that had the highest number of branches were a valuable resource for breeding for this trait. The presence of fewer branches on the main stem in most accessions of *Amaranthus tricolor*, compared to other *Amaranthus* species, was consistent with the results obtained by [7]. However, [7] found that the shortest genotypes were characterized by the highest number of branches and vice versa. Our results were inconsistent with this finding, since accession PI490762 from India had 12 branches and a 39 cm height, whereas accession PI604668

from Taiwan had no branches and a 50 cm height. The discrepancy between our results and those of [7] could be attributed to the fact that they analyzed several *Amaranthus* species, including *Amaranthus tricolor* L.

The plant height exhibited a wide variation. It extends from 4 cm for PI477918 to 71 cm for PI61925 (Tamil Nadu, India). This wide variation reflects the capacity of these accessions to adapt to various environmental conditions.

A large variation in leaf area was observed in the present study, ranging between 14.17 and 55.97 cm^2. The accessions with a large leaf area could be considered a good reservoir of genetic diversity for this trait, which might play an important role in *Amaranthus tricolor* breeding programs. A similar range of variation in leaf area was reported by [31].

The results of the genetic parameter of variability for quantitative traits displayed that the germination percentage, plant height, width of the shoot system, and leaf area were characterized by considerable genetic diversity. It suggested that the accessions characterized by considerable variation in these traits can be used in breeding programs to develop new cultivars with high vegetative growth. Additionally, these traits can be useful in differentiating among *Amaranthus tricolor* accessions.

Analysis of variance for the studied traits showed highly significant variation for the following traits: the germination percentage, plant height, width of the shoot system, and leaf area (**Table 4**). This finding was inconsistent with the results of [32]. The variation between our results and [32] could be due to the difference in the characteristic traits used in the two studies and the sub-geographic area of the investigated accessions.

Table 4

Analysis of variance for 14 quantitative characters of 30 accessions of *Amaranthus tricolor*

Code	Character	Count	Sum	Average	Variance
A	Germination percentage	30	1990	66.33333	**658.5057**
D	Plumule length	30	76.4	2.546667	0.386023
C	Radical length	30	36.4	1.213333	0.124644
D	Plant height	30	700	23.33333	**205.2644**
E	Stem diameter	30	96	3.2	0.993103
F	Number of branches	30	65	2.166667	12.21264
G	Length of blade	30	156.8	5.226667	1.084092
H	Wide of blade	30	119	3.966667	1.389195
I	Wide of shoot system	30	551	18.36667	**142.3782**
J	Anthocyanin	30	30	1	0.827586
K	Length of seed head	30	69.7	2.323333	8.869437
L	Wide of seed head	30	32.9	1.096667	0.255506
M	Size of seeds	30	106	3.533333	0.533333
N	Leaf area	30	772.6	25.75333	**111.9102**

Genotypic and phenotypic coefficients of variation are commonly used for the assessment of variability, giving an idea about their magnitude in the investigated accessions. The phenotypic coefficient of variation (PCV) for the following morphological traits, germination percentage, plumule length, radical length, stem diameter, wide of seed head, size of seeds, leaf area, wide of blade, wide of shoot system, was higher than the genotypic coefficient of variation (GCV) (**Table 3**). It means that variation in trait is significantly influenced by environmental factors, indicating lower scope for improvement through simple selection and suggesting that environment plays a crucial role in how the trait is expressed. However, the phenotypic and genotypic coefficients of variations were equal for the following morphological traits, anthocyanin, length of blade, plant height, which means the trait's variation is almost entirely due to genetic factors, with minimal influence from the environment, indicating high heritability and making selection for that trait very effective in breeding programs. The phenotypic and genotypic coefficients of variation for length of seed head and number of branches are very high. It means that the substantial variations in these traits are

due to phenotypic and genetic factors, suggesting good potential for crop improvement, pointing to additive gene action, and making selection successful.

Plant height, length of blade, and anthocyanin were found to have 100% heritability (**Table 3**). This suggested the important role of genetic constitution in the expression of these traits, which are considered independent from a breeding point of view. These traits are less influenced by environmental factors and controlled by additive genes.

Heritability plus genetic advance are more useful for choosing the best accessions for a breeding program than heritability alone. Our results showed that the values of heritability and genetic advance were high for the following traits: leaf area, wide of shoot system, anthocyanin, length of seed head, wide of seed head, number of branches, plant height, germination percentage. This data indicated that the heritability is most likely due to additive gene effects, and the selection may be effective for these traits (**Table 3**).

Pearson correlation coefficients were evaluated for 14 morphological traits in 30 *Amaranthus tricolor* accessions (**Table 5**). The data showed no correlation between germination percentage and seed size, indicating that seed size did not influence germination percentage. This finding was consistent with the results reported by [29] and contradicted the data obtained by [33]. This variation in data could be attributed to the adaptive response of the plant to a particular niche, and/or seed size might be significantly influenced by accessions [34].

Table 5

Pearson correlation coefficient among 14 morphological characters of *Amaranthus tricolor*

Code	A	B	C	D	E	F	G	H	I	J	K	L	M	N
A	1	0.10	0.39	0.35	0.63	0.67	0.24	0.48	0.64	0.59	0.52	0.84	0.87	0.23
B	–0.31	1	0.05	0.68	0.06	0.57	0.96	0.18	0.57	0.68	0.21	0.50	0.01	0.29
C	0.16	–0.36	1	0.65	0.64	0.02	0.15	0.12	0.09	0.82	0.92	0.00	0.77	0.55
D	0.18	0.08	0.09	1	0.21	0.02	0.81	0.39	0.00	0.14	0.00	0.01	0.79	0.37
E	0.09	0.35	0.09	0.24	1	0.14	0.01	0.01	0.27	0.42	0.39	0.56	0.48	0.16
F	–0.08	–0.11	0.42	0.41	0.28	1	0.98	0.10	0.01	0.91	0.01	0.00	0.71	0.91
G	0.22	–0.01	0.27	0.05	0.45	0	1	0.00	0.67	1.00	0.78	0.43	0.41	0.00
H	–0.13	0.25	0.29	0.16	0.5	0.31	0.53	1	0.13	0.28	0.08	0.07	0.16	0.00
I	0.09	–0.11	0.31	0.58	0.21	0.46	0.08	0.29	1	0.57	0.05	0.00	0.25	0.57
J	–0.1	0.08	–0.04	0.28	0.15	–0.02	0.0	0.21	0.11	1	0.15	0.17	0.59	0.98
K	0.12	0.24	–0.02	0.75	0.16	0.5	0.05	0.32	0.35	0.27	1	0.02	0.35	0.95
L	0.04	–0.13	0.51	0.49	0.11	0.51	0.15	0.34	0.64	0.25	0.41	1	0.98	0.43
M	–0.03	0.44	–0.06	0.05	0.13	0.07	–0.16	0.26	0.22	–0.1	0.18	0	1	0.67
N	–0.23	0.2	0.11	–0.17	0.26	0.02	0.56	0.69	0.11	0	–0.01	0.15	0.08	1

Note: Correlation is significant at $p > 0.05$.

A significant correlation was found between plant height and number of branches. This finding was not in agreement with the work [7], which reported a significant correlation between stem diameter and blade ratio of amaranths. They also reported that there is no correlation between plant height, stem diameter, and branches.

The present results show a correlation between leaf area and width of blade. This correlation is important in defining leaf form and other traits. It is also decisive for the improvement of leaf area, the favorable traits that are preferred in the Amaranthus fried chip industry.

The leaf area was positively correlated with the length and width of the leaf blade, which is considered an indirect parameter of vegetative yield in *Amaranthus tricolor* [7, 31].

The corresponding analysis (CA) was performed to assess the variation patterns and the degree of association between morphological traits and *Amaranthus tricolor* accessions (**Fig. 1**).

The first two principal components accounted for 44.7%: PC1 accounted for 16.7% of the total morphological variation, and PC2 accounted for 28%. The corresponding analysis (CA) showed that PI 277268 from India, PI 419057 from Beijing (China), PI 632237 from Connecticut (USA),

PI 633591, and PI 214036 from Karnataka (India) were associated with stem diameter and leaf area. Therefore, these accessions are a good resource for breeding for these traits. Additionally, it was found that PI 603896 from California (USA), PI 636179 from Taiwan, Arries5135 from Madhya Pradesh (India), PI 477918 and PI 604669 from Taiwan, PI 608761 from Gujarat (India), and PI 633595 and PI 619252 from Tamil Nadu (India) were associated with germination percentage, number of branches, plant height, and width of shoot system. So, this accession is suited for breeding for these traits.

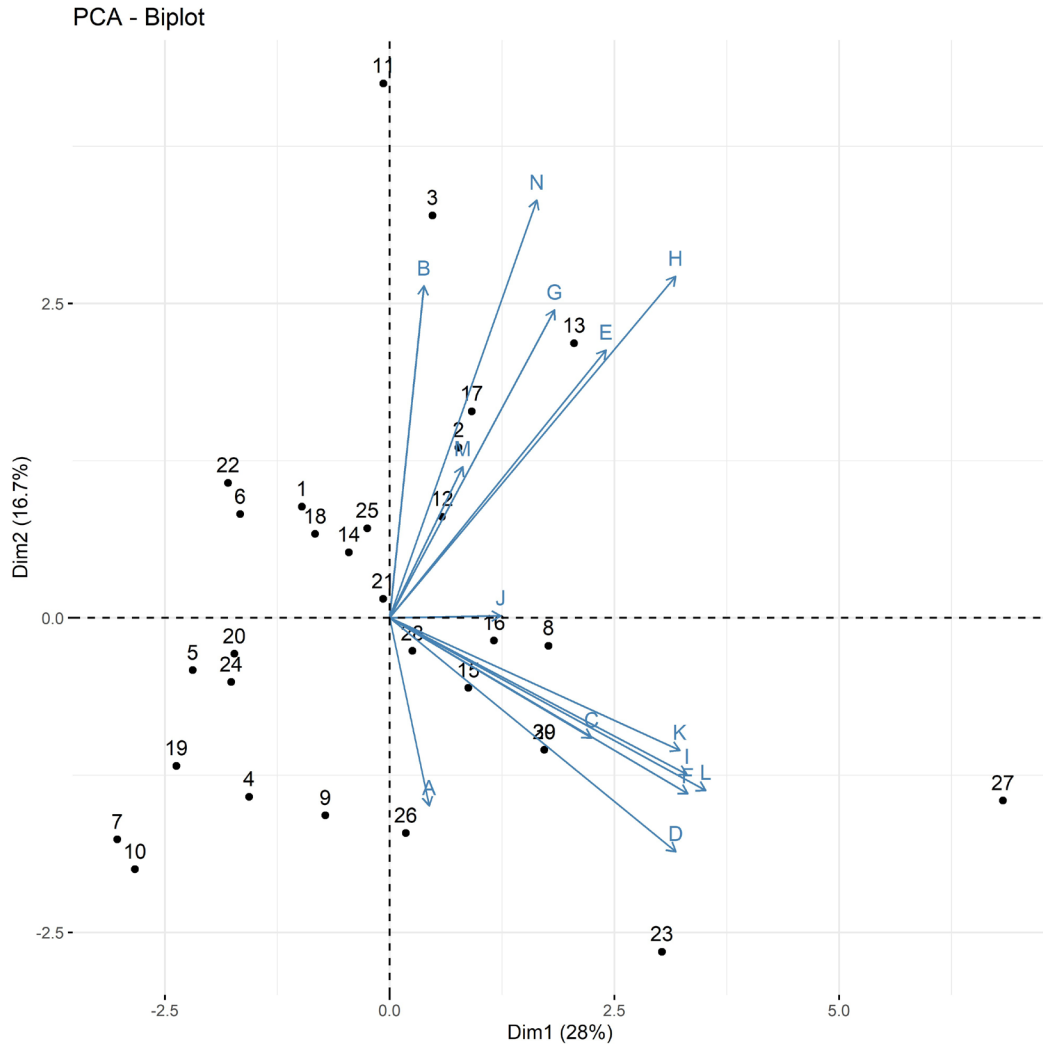


Fig. 1. Corresponding analysis of 30 accessions of Amaranthus tricolor based on 19 morphological characters explained by X and Y-axes

The results also showed that accessions from the same subgeographic region can be varied morphologically and genetically; for example, the accessions from India were distributed in more than one cluster, indicating no link between accession diversity and geographical origin (**Fig. 2**). This finding was not consistent with the strong relationship between the diversity of *Amaranthus tricolor* accessions and their geographical origin reported by [31]. This discrepancy in results could be attributed to the difference in the collection sites and the investigated traits [31] carried out their study on accessions collected from the Indo-Gangetic Plains and the Himalayan region and used morphological and nutritional quality traits, whereas our accessions were collected from different subgeographic regions and used morphological traits. The results of the cluster analysis

revealed its usefulness as a good tool in defining the distinct patterns of variation in the studied accessions.

In **Table 6,** leaf area was separated with length of seed head, wide of seed head, radical length plant height, stem diameter, number of branches, length of blade, wide of blade, wide of shoot system on the first principal component of the principal correspondence analysis (PCA). Therefore, multiple regression analysis and path analysis were conducted to better understand how these traits influence leaf area. In multiple regression analysis and path analysis, leaf area was set as the dependent variable (Y), and other traits were set as independent variables, denoted as X3, X4, X5, X6, X7, X8, X9, X11, X12, and X14, respectively (X3–X14 can be substituted with C, D, E, F, G, H, I, K, L, N the codes of the characters in **Table 3**).

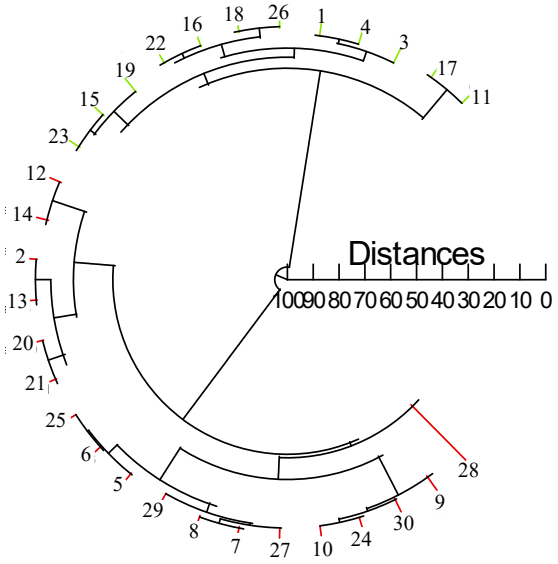


Fig. 2. Polar clustering plot of 30 *A. tricolor* accessions based on 19 morphological characters.

Table 6

First six (First five) principal components of the 14 quantitative characters in 30 *Amaranthus tricolor accessions*

Code	Character	PC1 – Principal coordinate 1	PC2 – Principal coordinate 2	PC3 – Principal coordinate 1	PC4 – Principal coordinate 4	PC5 – Principal coordinate 1
A	Germination percentage	0.07	0.32	–0.29	**0.60**	0.55
B	Plumule length	0.11	–0.55	**0.68**	0.01	0.09
C	Radical length	**0.45**	0.19	–0.63	–0.28	0.08
D	Plant height	**0.68**	0.43	0.35	0.29	0.00
E	Stem diameter	**0.52**	–0.43	0.04	0.32	0.19
F	Number of branches	**0.66**	0.29	–0.01	–0.34	0.06
G	Length of blade	**0.41**	–0.49	–0.52	0.40	0.07
H	Wide of blade	**0.70**	–0.57	–0.10	–0.07	–0.06
I	Wide of shoot system	**0.71**	0.30	0.01	–0.19	0.10
J	Anthocyanin	0.29	0.03	0.24	**0.34**	–0.68
K	Length of seed head	**0.66**	0.23	0.46	0.21	0.00
L	Wide of seed head	**0.75**	0.31	–0.15	–0.19	–0.20
M	Size of seeds	0.20	–0.24	0.49	–0.35	**0.54**
N	Leaf area	**0.36**	–0.73	–0.28	–0.15	–0.14
Variance explained by components		3.81	2.297	1.943	1.284	1.195
Percent of total variance explained		27.211	16.405	13.877	9.169	8.533

The path analysis results show the following regression equation

$$\hat{Y} = 4.491659 - 0.213158\, X_4 + 6.613956\, X_8.$$

This equation demonstrated that leaf area was positively correlated with the plant height and Wide of blade, which means that for every 1 mm increase in the plant height, the leaf area increased by 0.213159 mm. For every 1 mm increase in the Wide of blade, the leaf area increased by 6.613956 mm

R square [R^2] equals 0.557607, which means that the independent variable [*Xi*] explains 55.80% of the variance of leaf area.

The results of the regression analysis indicate that the F-statistic was 17.015865 with a P-value of less than 0.05 ($P = 0.0000165352$), suggesting that the regression model is statistically significant ($P < 0.05$).

4. Conclusions

Amaranthus tricolor accessions displayed a great variation in the morphological traits that influence the vegetable yield, such as stem diameter, leaf area, Plant height, and the number of branches. This variation can be exploited in cultivar improvement and in generating a gene pool by crossing accessions of interest. The produced hybrids can be used as a source material to develop promising *Amaranthus tricolor* cultivars. However, more research on a large number of accessions using a vast array of morphological traits is required to design successful breeding programs.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

Financing

The study was performed without financial support.

Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

Authors' contributions

Reda Sammour: Conceptualization, Software, Supervision, Validation, Visualization and Writing – review & editing; **Mohammed Mira**: Formal analysis, Investigation, Methodology, Resources, and Writing – original draft.

References

[1] Trucco, F., Tranel, P. J. (2011). Amaranthus. Wild Crop Relatives: Genomic and Breeding Resources, 11–21. https://doi.org/10.1007/978-3-642-20450-0_2

[2] Bagheri, A., Eghbali, L., Sadrabadi Haghighi, R. (2019). Seed classification of three species of amaranth (*Amaranthus* spp.) using artificial neural network and canonical discriminant analysis. The Journal of Agricultural Science, 157 (04), 333–341. https://doi.org/10.1017/s0021859619000649

[3] Iamonico, D., Hussain, A. N., Sindhu, A., Saradamma Anil Kumar, V. nair, Shaheen, S., Munir, M., Fortini, P. (2023). Trying to Understand the Complicated Taxonomy in Amaranthus (*Amaranthaceae*): Insights on Seeds Micromorphology. Plants, 12 (5), 987. https://doi.org/10.3390/plants12050987

[4] Tony-Odigi, A. E., Adekoya, K. O., Makinde, S. C. O., Oboh, B. O., Ogunkanmi, L. A., Fowora, M. A. (2012). Assessment of Genetic Interspecies Relationships among Five Selected Amaranthus Species Using Phenotypic and RAPD Markers. International Journal of Botany, 8 (3), 145–152. https://doi.org/10.3923/ijb.2012.145.152

[5] Vidal Torres, E., Valencia, E., Simsek, S., Ramírez, A. M. L. (2024). Amaranth: Multipurpose Agroindustrial Crop. Agronomy, 14 (10), 2323. https://doi.org/10.3390/agronomy14102323

[6] Santra, D. K., Schoenlechner, R., Brenner, D. M. (2024). Sustainability, Processing, Applications, and International Trade of Amaranth Grain. Sustainable Protein Sources, 399–412. https://doi.org/10.1016/b978-0-323-91652-3.00022-8

[7] Andini, R., Yoshida, S., Yoshida, Y., Ohsawa, R. (2013). Amaranthus genetic resources in Indonesia: morphological and protein content assessment in comparison with worldwide amaranths. Genetic Resources and Crop Evolution, 60 (7), 2115–2128. https://doi.org/10.1007/s10722-013-9979-y

[8] Priyadarsini, S., Acharya, G. C., Tripathy, P., Mishra, N., Singh, S., Choudhari, P. et al. (2025). Insights into genomic resources and molecular breeding strategies of Amaranth (*Amaranthus* spp.): a new millennium crop with versatile potential. South African Journal of Botany, 184, 1085–1100. https://doi.org/10.1016/j.sajb.2025.07.015

[9] Achigan-Dako, E. G., Sogbohossou, O. E. D., Maundu, P. (2014). Current knowledge on *Amaranthus* spp.: research avenues for improved nutritional value and yield in leafy amaranths in sub-Saharan Africa. Euphytica, 197 (3), 303–317. https://doi.org/10.1007/s10681-014-1081-9

[10] Peter, K., Gandhi, P. (2017). Rediscovering the therapeutic potential of Amaranthus species: A review. Egyptian Journal of Basic and Applied Sciences, 4 (3), 196–205. https://doi.org/10.1016/j.ejbas.2017.05.001

[11] Sattar, M., Saeed, F., Afzaal, M., Rasheed, A., Asif, A., Sharif, S. et al. (2024). An overview of the nutritional and therapeutic properties of amaranth. International Journal of Food Properties, 27 (1), 263–272. https://doi.org/10.1080/10942912.2024.2304266

[12] Akin-Idowu, P., Gbadegesin, M., Orkpeh, U., Ibitoye, D., Odunola, O. (2016). Characterization of Grain Amaranth (*Amaranthus* spp.) Germplasm in South West Nigeria Using Morphological, Nutritional, and Random Amplified Polymorphic DNA (RAPD) Analysis. Resources, 5 (1), 6. https://doi.org/10.3390/resources5010006

[13] Thapa, R., Blair, M. W. (2018). Morphological Assessment of Cultivated and Wild Amaranth Species Diversity. Agronomy, 8 (11), 272. https://doi.org/10.3390/agronomy8110272

[14] Omondi, E. O., Debener, T., Linde, M., Abukutsa-Onyango, M., Dinssa, F. F., Winkelmann, T. (2016). Molecular Markers for Genetic Diversity Studies in African Leafy Vegetables. Advances in Bioscience and Biotechnology, 07 (03), 188–197. https://doi.org/10.4236/abb.2016.73017

[15] Nguyen, D. C., Tran, D. S., Tran, T. T. H., Ohsawa, R., Yoshioka, Y. (2019). Genetic diversity of leafy amaranth (*Amaranthus tricolor* L.) resources in Vietnam. Breeding Science, 69 (4), 640–650. https://doi.org/10.1270/jsbbs.19050

[16] Hoshikawa, K., Lin, Y.-P., Schafleitner, R., Shirasawa, K., Isobe, S., Nguyen, D. C. et al. (2023). Genetic diversity analysis and core collection construction for *Amaranthus tricolor* germplasm based on genome-wide single-nucleotide polymorphisms. Scientia Horticulturae, 307, 111428. https://doi.org/10.1016/j.scienta.2022.111428

[17] Ray, T., Roy, S. C. (2009). Genetic Diversity of Amaranthus Species from the Indo-Gangetic Plains Revealed by RAPD Analysis Leading to the Development of Ecotype-Specific SCAR Marker. Journal of Heredity, 100 (3), 338–347. https://doi.org/10.1093/jhered/esn102

[18] Thakur, S. S., Asati, B. S., Chandrakar, S. M. K. (2021). Genetic diversity study in red amaranths (*Amaranthus tricolor* L.). The Pharma Innovation Journal, 10 (11), 660–663. Available at: https://www.thepharmajournal.com/archives/?year=2021&vol=10&issue=11&ArticleId=8768

[19] Yeshitila, M., Gedebo, A., Tesfaye, B., Degu, H. D. (2024). Agro-morphological genetic diversity assessment of Amaranthus genotypes from Ethiopia based on qualitative traits. CABI Agriculture and Bioscience. https://doi.org/10.1186/s43170-024-00288-1

[20] Saqib, M., Khalid, M. F., Ahmad, R., Anjum, M. A., Hussain, S. (2019). Evaluation of Genetic Diversity through Morphological Characteristics of Olive (*Olea europea* L.) Germplasm in Pakistan. Science, Technology and Development, 38, 7–12. Available at: https://docsdrive.com/pdfs/std/std/2019/7-12.pdf

[21] Lebkiri, N., Abbas, Y., Iraqi, D., Gaboun, F., Saghir, K., Fokar, M. et al. (2024). Morphological characterization and genetic diversity of mini core collection of Rosa damascena from Morocco. Journal of Genetic Engineering and Biotechnology, 22 (4), 100423. https://doi.org/10.1016/j.jgeb.2024.100423

[22] Belmahi, Z., Bakhy, K., Gaboun, F., Abdelwahd, R., Saghir, K., Ouedrhiri, S. et al. (2025). Morphological and genetic diversity assessment of cultivated Thymus satureioides (endemic species) of Morocco. Journal of Genetic Engineering and Biotechnology, 23 (1), 100467. https://doi.org/10.1016/j.jgeb.2025.100467

[23] Khan, M. K. U., Muhammad, N., Uddin, N., Ali, N., Khan, I., Ullah, R. (2019). Genetic polymorphism within the wild population of Rhynchosia himalensis Benth. ex Baker. International Journal of Biosciences (IJB), 14 (3), 54–64. https://doi.org/10.12692/ijb/14.3.54-64

[24] Das, M., Sharma, M., Sivan, P. (2017). Seed Germination and Seedling Vigor Index in *Bixa orellana* and *Clitoria ternatea*. International Journal of Pure & Applied Bioscience, 5 (5), 15–19. https://doi.org/10.18782/2320-7051.2869

[25] Hill, W. G., Singh, R. K., Chaudhary, B. D. (1978). Biometrical Methods in Quantitative Genetic Analysis. Biometrics, 34 (4), 723. https://doi.org/10.2307/2530404

[26] Johnson, H. W., Robinson, H. F., Comstock, R. E. (1955). Estimates of Genetic and Environmental Variability in Soybeans. Agronomy Journal, 47 (7), 314–318. https://doi.org/10.2134/agronj1955.00021962004700070009x

[27] Santelices Moya, R., Espinoza Meza, S., Magni Díaz, C., Cabrera Ariza, A., Donoso Calderón, S., Peña-Rojas, K. (2017). Variability in seed germination and seedling growth at the intra- and inter-provenance levels of Nothofagus glauca *(Lophozonia glauca*), an endemic species of Central Chile. New Zealand Journal of Forestry Science, 47 (1). https://doi.org/10.1186/s40490-017-0091-5

[28] Sales, N. M., Pérez-García, F., Silveira, F. A. O. (2013). Consistent variation in seed germination across an environmental gradient in a Neotropical savanna. South African Journal of Botany, 87, 129–133. https://doi.org/10.1016/j.sajb.2013.04.001

[29] Veloso, A. C. R., Silva, P. S., Siqueira, W. K., Duarte, K. L. R., Gomes, I. L. V., Santos, H. T., Fagundes, M. (2017). Intraspecific variation in seed size and light intensity affect seed germination and initial seedling growth of a tropical shrub. Acta Botanica Brasilica, 31 (4), 736–741. https://doi.org/10.1590/0102-33062017abb0032

[30] Gerrano, A. S., van Rensburg, W. S. J., Adebola, P. O. (2015). Genetic diversity of Amaranthus species in South Africa. South African Journal of Plant and Soil, 32 (1), 39–46. https://doi.org/10.1080/02571862.2014.973069

[31] Shukla, S., Bhargava, A., Chatterjee, A., Pandey, A. C., Mishra, B. K. (2010). Diversity in phenotypic and nutritional traits in vegetable amaranth (*Amaranthus tricolor*), a nutritionally underutilised crop. Journal of the Science of Food and Agriculture, 90 (1), 139–144. https://doi.org/10.1002/jsfa.3797

[32] Agadi, A., Kolakar, S., Lakshmana, D., Nadukeri, S., Hanumanthappa, M. (2021). Genetic variability studies in amaranthus (*Amaranthus* spp.). Journal of Horticultural Sciences, 16 (1), 36–44. https://doi.org/10.24154/jhs.2021.v16i01.004

[33] Gupta, K., Mohan Mandal, S., Chakraborty, D. (2008). Seed Size Variation: Influence on Germination and Subsequent Seedling Performance in Hyptis suaveolens (*Lamiaceae*). Research Journal of Seed Science, 1 (1), 26–33. https://doi.org/10.3923/rjss.2008.26.33

[34] Pradeep, P. (2018). Seed quality parameters (Germination percentage and seedling vigor index) of rabi sorghum seeds influenced by rice weevil infestationa. MOJ Toxicology, 4 (6). https://doi.org/10.15406/mojt.2018.04.00135

Received 22.12.2025
Received it revised form 19.01.2026
Accepted 23.02.2026
Published 24.04.2026

© The Author(s) 2026
This is an open access article
under the Creative Commons CC BY license
https://creativecommons.org/licenses/by/4.0/

How to cite: *Sammour, R. H., Mira, M. M. (2026). Assessment of phenotypic variations in worldwide accessions of Amaranthus tricolor. EUREKA: Life Sciences, 1, 50–60. https://doi.org/10.21303/2504-5695.2026.004188*