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Research Article

Heritability Analysis and Phenotypic Characterization of Spider Plant (*Cleome gynandra* L.) for Yield

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Knowledge on phenotypic diversity among existing spider plant accessions is a milestone in the improvement of spider plant, which is a highly nutritious indigenous vegetable in Kenya. A study involving agronomic and morphological characterization of 49 spider plant accessions assembled from East and South Africa was carried out at the University of Nairobi Field Station for two seasons in a randomized complete block design with three replications. Phenotypic data was collected on growth habit, flower, petiole, leaf and stem colour, petiole, leaf and stem hairiness, number of leaves per plant, plant height, number of primary branches, leaf length and width, single leaf area, and chlorophyll content according to FAO descriptors with modifications. Data was analyzed using both DARwin software V6 and Genstat Version 14. We observed significant differences among the traits implying great genetic variability among the evaluated spider plant accessions. The high genetic variation was further validated using the Unweighted Pair Group Method with Arithmetic mean (UPGMA) clustering method with stem and flower colour as key traits. The 49-spider plant accessions were clustered into 2 major groups, each consisting of Kenyan and South African accessions. Stepwise regression revealed that plant height had the most influence on yield in terms of number of leaves per plant. We also observed high heritability for several traits including days to flowering (91%), number of leaves per plant (99%), plant height (99%), number of primary branches (94%), chlorophyll content (94%), and single leaf area (87%). Our results reveal the high genetic variation between different spider plant accessions, especially from different regions of Africa that could be further exploited to improve productivity in the plant. The high heritability of most of the yield related traits is promising for improving yield in the crop through direct selection.

1. Introduction

Cleome gynandra, also known as "African spider plant", is among the most important traditional leafy vegetables widely used in Africa [1]. It belongs to the family of Capparaceae. It is also an erect herbaceous annual herb that is mainly self-pollinated [2]. The plant is highly nutritive and contains health promoting bioactive compounds important in combating malnutrition and reducing human degenerative diseases. Spider plant is native to the Southern Africa, Western Africa, Central Africa, Eastern Africa, and South East Asia [3]. In South Africa, spider plant has been found to grow in the wild in KwaZulu-Natal, Free State, Northern Cape, Limpopo, and North West provinces [3]. In Kenya, the plants are mainly found in Western, Rift Valley, Eastern, and Coastal regions. The key counties producing the crop include Kisii, Nyamira, Kericho, Migori, and Siaya [4]. Despite this wide adaptation and continued increase in production and consumption, there have been limited efforts towards its improvement. There is lack of critical information on the extent and structure of phenotypic variation crucial for the breeding and conservation of spider plant [2, 5]. Genetic diversity is particularly useful in characterizing individual accessions and cultivars, in detecting genetic materials with novel genes and thereby rescuing them from genetic erosion, and as a general guide, in selecting appropriate parents in breeding programs. Most of the genetic diversity observed in spider plant in Kenya and South Africa has traditionally been maintained by farmers *in situ.* This poses the risk of species extinction due to loss of natural habitat as humans continue

to exploit and develop land, divert water flow, and change the environment. Secondly, as human population continues to increase, there is pressure on natural land being cleared by human activity. The need for cultivation, conservation, and characterization of spider plant remains imperative in maintaining the integrity of the genetic information and diversity.

Mendelian analysis of discrete morphological traits can be used to estimate genetic diversity in plants [6] and has been successfully used in spider plant [5]. Some of the key traits that have been used as a guide in selection for good genotypes in previous studies included high heritability traits such as days to flowering, plant height, and number of leaves per plant [7]. Omondi [7] observed that higher leaf yield, plant uniformity, longer vegetative phase, late flowering, and drought tolerance could form the best criterion in selection of good performing spider plant accessions. However, for an efficient crop improvement program, information on estimates of heritability for these desirable traits must be established [8]. Due to limited knowledge on the genetic variability, more research remains of the essence to elucidate the genetic and phenotypic diversity of existing spider plant accessions. Thus, the main thrust of this study was to understand the extent of phenotypic diversity and heritability of qualitative traits among 49 spider plant accessions assembled from Kenya and South Africa. Promising spider plant accessions can be utilized in various breeding programs and have the potential of enhancing its utilization while aiding to fight hidden hunger in Kenya.

2. Materials and Methods

2.1. Plant Materials. The study used 49 spider plant accessions, mainly local landraces assembled from 3 sources: Gene bank of Kenya (25), Gene bank of South Africa (9), and Kenyan farmers' landraces (15) (Table 1).

2.2. Experimental Design and Study Site. The experiments were carried out at the University of Nairobi's Kabete Field station (Nairobi, Kenya) for two seasons from March 2014 to May 2014 and October 2014 to January 2015. The experiments were laid out in a randomized complete block design with three replications. Kabete Field station lies at 36°41′E and 01°15'S with an altitude of 1737 m above sea level. It receives an average temperature of 23°C with a bimodal rainfall pattern and an annual precipitation of 600 mm to 1800 mm. The soil type is well drained very dark reddish, brown to dark red friable clay locally known as Kikuyu red clay loam with an average pH of 6.2 [9].

2.3. Crop Husbandry. Pregermination for each accession was done for 72 hours under treatment with 0.2% gibberellic acid to break seed dormancy and enhance germination [10]. Each individual accession was planted by hand in two rows comprising ten seeding holes per row (20 plants in a plot). Row plots were 3 m in length with inter-row spacing of 30 cm and intra-row spacing of 30 cm. Farmyard manure was applied to rows at the rate of 10.5 g/accession and mixed with soil at planting. Hand weeding was done throughout the

Table 1: List of Kenyan and South African spider plant accessions evaluated in the study.

Entry	Accession no.	Country of origin	Region
1	1^{ke}	Kenya	Siaya
2	2^{ke}	Kenya	Bungoma
3	3^{ke}	Kenya	Kakamega
4	4^{ke}	Kenya	Kitale
5	5^{ke}	Kenya	Mbale
6	6^{ke}	Kenya	Bomet
7	7^{ke}	Kenya	Busia
8	9^{ke}	Kenya	Marakwet
9	10^{ke}	Kenya	Kisumu
10	11^{ke}	Kenya	Homabay
11	12^{ke}	Kenya	Nandi
12	13^{ke}	Kenya	Kakamega
13	14^{ke}	Kenya	Kisii
14	15^{ke}	Kenya	Mbale
15	16^{ke}	Kenya	Meru
16	1959^{sa}	South Africa	Mpumalanga
17	1988^{sa}	South Africa	Mpumalanga
18	2000^{sa}	South Africa	Mpumalanga
19	2232^{sa}	South Africa	Northern province
20	2241^{sa}	South Africa	Northern province
21	2249^{sa}	South Africa	Northern province
22	2279^{sa}	South Africa	Northern province
23	2289^{sa}	South Africa	Mpumalanga
24	2299^{sa}	South Africa	Mpumalanga
25	30316^{ke}	Kenya	Western
26	31990^{ke}	Kenya	Western
27	31992^{ke}	Kenya	Western
28	45426^{ke}	Kenya	Western
29	45446^{ke}	Kenya	Central
30	45451^{ke}	Kenya	Central
31	50259^{ke}	Kenya	Kisii
32	50264^{ke}	Kenya	Nyamira
33	50265^{ke}	Kenya	Nyamira
34	50273^{ke}	Kenya	Nyamira
35	50290^{ke}	Kenya	Nyamira
36	50296^{ke}	Kenya	Nyamira
37	50298^{ke}	Kenya	Nyamira
38	50299^{ke}	Kenya	Nyamira
39	50307^{ke}	Kenya	Kisii
40	50319^{ke}	Kenya	Nyamira
41	50325^{ke}	Kenya	Kisii
42	50326^{ke}	Kenya	Nyamira
43	50328^{ke}	Kenya	Nyamira
44	50330^{ke}	Kenya	Nyamira
45	50332^{ke}	Kenya	Kisii
46	50339^{ke}	Kenya	Nyamira
47	50353^{ke}	Kenya	Nyamira
48	50584^{ke}	Kenya	Nyamira
49	50600^{ke}	Kenya	Kisii

^{ke}=originated from Kenya; ^{sa}=originated from South Africa.

Table 2: Character, descriptor, and codes used for characterization of qualitative traits in spider plant accessions.

S/No.	Character	Descriptor and code
1	Growth habit	Erect (2), semi-erect (4) and prostrate (6)
2	Flower colour	White (1), purple (2) and pink (3)
3	Stem colour	Green (1), pink (2), violet (3) and purple (4)
4	Stem hairiness	Glabrous (1), weak/sparse (3), medium (5) and profuse (7)
5	Petiole colour	Green (1), pink (2), violet (3) and purple (4),
6	Petiole hairiness	Glabrous (1), weak/sparse (3), medium (5) and profuse (7)
7	Leaf colour	Dark green (1) and light green (2),
8	Leaf hairiness	Glabrous (1), weak/sparse (3), medium (5) and profuse (7)

Source: Food and Agriculture Organization of the United Nations (FAO, 1995); numbers in brackets on the right-hand side are the corresponding descriptor codes listed in the FAO publication with modifications during the development of the list.

experimental period. The experiment was conducted under rain-fed conditions with supplemental overhead irrigation when required.

2.4. Data Collection and Analysis. There were two sets of data collected in the study, namely, qualitative (morphological) and quantitative (agronomic).

2.5. Qualitative Traits. Spider plant traits that were considered qualitative included growth habit, flower colour, stem colour, stem hairiness, petiole colour, petiole hairiness, leaf colour, and leaf pubescence based on the list of modified spider plant descriptors [11] (Table 2). Three randomly selected plants were tagged per accession per replicate during crop growth, before flowering. The data was subjected to DARwin 5.0 software as described by Perrier and Jacquemoud-Collet [12]. Euclidean distance matrix and hierarchical clustering analyses of Unweighted Pair Group Method of Arithmetic averaging were used to estimate dissimilarities among the accessions and results displayed in a dendrogram. This was followed by the identification of the most significant descriptors contributing to most phenotypic variation among the spider plant accessions through a stepwise regression analysis.

2.6. Quantitative Traits. All the yield and yield related traits were considered quantitative, including days to 50% flowering, SPAD values, plant height, number of primary branches, leaf length, leaf width, single leaf area, and number of leaves per plant. Using Genstat version 14 software as described by [13], the data was subjected to Analysis of Variance to establish any significance differences among the traits and to obtain genotype means which were then separated using the Fishers protected least significant differences (LSD) at $P < 0.05$.

To establish the relationship among the traits collected, a two-tail correlation analysis was performed to estimate quantitative relationships among the traits and also to identify those traits that could be of great significance in a spider plant breeding program.

Heritability in the broad sense was estimated as a ratio of genotypic variance to the phenotypic variance and expressed in percentage [14] as per the following equation.

$$\text{Heritability } \left(H^2\right) = \left(\frac{Vg}{Vp} \times 100\right) \quad (1)$$

where V_g is the genotypic variance and V_p is the phenotypic variance.

Genotypic variance ($\sigma^2 g$) was derived by subtracting error mean sum of squares (EMS) from the genotypic mean sum of squares (GMS) and divided by the number of replications as given by the following equation.

$$\sigma^2 g = GMS - \frac{EMS}{r} \quad (2)$$

where

GMS is the genotype mean sum of squares, EMS is the error mean sum of squares, and r is the number of replications.

Phenotypic variance ($\sigma^2 p$) was derived by adding genotypic variance with error variance as per the following equation.

$$\sigma^2 p = \sigma^2 e + \sigma^2 g \quad (3)$$

3. Results and Discussions

3.1. Qualitative Traits. There were three distinct flower colours displayed by the spider plant accessions: purple, pink, and white. Among these, the purple flower colour was the most dominant among the Kenyan accessions at 49% (Table 3) while the most dominant flower colour among the South African accessions was white. Most of the South African accessions displayed a green stem with a green petiole as opposed to the Kenyans accessions, which displayed purple stems and pubescence. Previous study by Masuka and Mazarura [15] reported that purple-stemmed plants tended to be more hairy (trichomes) than the green-stemmed plants. Anthocyanins have been implicated as responsible for the

Table 3: Morphological descriptors recorded for the 49 field grown spider plant accessions for the combined season.

Entry	Accession no.	Origin	Flower colour	Stem colour	Petiole colour	Stem hairiness	Petiole hairiness	Leaf colour	Leaf hairiness	Growth habit
1	1	Kenya	Purple	Purple	Green	Profuse	Medium	dark green	Medium	Erect
2	2	Kenya	White	Purple	Pink	Profuse	Medium	light green	Sparse	Erect
3	3	Kenya	Pink	Purple	Pink	Profuse	Medium	dark green	Sparse	Erect
4	4	Kenya	Pink	Purple	Pink	Profuse	Medium	light green	Medium	Erect
5	5	Kenya	White	Purple	Purple	Profuse	Profuse	light green	Profuse	Erect
6	6	Kenya	Pink	Purple	Pink	Profuse	Profuse	dark green	Medium	Erect
7	7	Kenya	Pink	Purple	Purple	Profuse	Medium	dark green	Medium	Erect
8	9	Kenya	White	Purple	Purple	Profuse	Profuse	dark green	Sparse	Erect
9	10	Kenya	Purple	Purple	Purple	Medium	Medium	light green	Sparse	Erect
10	11	Kenya	Pink	Purple	Purple	Medium	Medium	dark green	Medium	Erect
11	12	Kenya	Pink	Purple	Purple	Profuse	Medium	light green	Sparse	Erect
12	13	Kenya	Purple	Purple	Purple	Medium	Medium	light green	Sparse	Erect
13	14	Kenya	Purple	Green	Purple	Profuse	Profuse	dark green	Medium	Erect
14	15	Kenya	Pink	Purple	Purple	Medium	Sparse	dark green	Sparse	Erect
15	16	Kenya	Pink	Purple	Pink	Medium	Sparse	light green	Sparse	Erect
16	1959	S. Africa	Pink	Purple	Pink	Profuse	Medium	light green	Medium	Erect
17	1988	S. Africa	White	Green	Green	Sparse	Sparse	light green	Sparse	Semi erect
18	2000	S. Africa	White	Green	Green	Glabrous	Glabrous	light green	Glabrous	semi erect
19	2232	S. Africa	White	Green	Green	Glabrous	Glabrous	dark green	Glabrous	Erect
20	2241	S. Africa	White	Green	Pink	Sparse	Sparse	light green	Sparse	Erect
21	2249	S. Africa	White	Green	Pink	Glabrous	Glabrous	light green	Glabrous	Erect
22	2279	S. Africa	White	Green	Green	Glabrous	Glabrous	light green	Glabrous	Semi erect
23	2289	S. Africa	White	Green	Pink	Medium	Sparse	dark green	Sparse	Erect
24	2299	S.Africa	White	Green	Green	Glabrous	Sparse	light green	Glabrous	Erect
25	30316	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Sparse	Erect

Table 3: Continued.

Entry	Accession no.	Origin	Flower colour	Stem colour	Petiole colour	Stem hairiness	Petiole hairiness	Leaf colour	Leaf hairiness	Growth habit
26	31990	Kenya	Purple	green	Green	Medium	Sparse	light green	Sparse	Erect
27	31992	Kenya	Pink	purple	Green	Profuse	Medium	dark green	Medium	Erect
28	45426	Kenya	Purple	Purple	Green	Profuse	Sparse	dark green	Sparse	Erect
29	45446	Kenya	White	Purple	Purple	Profuse	Medium	dark green	Sparse	Erect
30	45451	Kenya	Pink	Purple	Purple	Profuse	Profuse	dark green	Medium	Erect
31	50259	Kenya	Pink	Purple	Purple	Profuse	Medium	dark green	Sparse	Erect
32	50264	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Sparse	Erect
33	50265	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Medium	Erect
34	50273	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Sparse	Erect
35	50290	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Medium	Semi erect
36	50296	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Medium	Erect
37	50298	Kenya	Purple	Purple	Purple	Medium	Sparse	light green	Sparse	Semi erect
38	50299	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Sparse	Erect
39	50307	Kenya	Purple	Purple	Purple	Medium	Medium	dark green	Sparse	Erect
40	50319	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Medium	erect
41	50325	Kenya	Pink	Purple	Purple	Medium	Medium	dark green	Sparse	erect
42	50326	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Sparse	erect
43	50328	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Sparse	erect
44	50330	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Sparse	erect
45	50332	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Medium	erect
46	50339	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Sparse	erect
47	50353	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Medium	erect
48	50584	Kenya	Purple	Purple	Purple	Medium	Medium	dark green	Sparse	erect
49	50600	Kenya	Purple	Purple	Purple	Profuse	Medium	dark green	Sparse	erect

stem pigmentation in most herbaceous plants [16] and have also been widely studied for their potential medicinal value [17]. Although spider plants have been traditionally used for medicinal purposes [18], the obvious contrast between South African and Kenyan accessions in their anthocyanin content calls for more studies in order to elucidate the benefits of the variations observed. Presence of trichomes, on the other hand, has been associated with insect resistance in several studies including soybean [19], pigeonpea [20], and Brassicaceae [21]. Trichomes are considered a domestication trait and are often more abundant in unadapted landraces than in improved germplasm. The absence of trichomes in South African accessions may suggest that they have undergone much more intense selection cycles than the Kenyan accessions, although more studies would need to be done to confirm this fact.

Erect growth habit was more dominant and was observed in 90% of the accessions as opposed to the semi-erect growth habit observed among 10% of the accessions. This observation agrees with earlier findings [22], which reported over 80% erect growth in the studied spider plant accessions. Other past research has also shown that majority of the spider plant morphotypes present an erect type of growth [5]. Growth habit is crucial in vegetable breeding as reported in other indigenous vegetables [23]. Bushy growth habit results in many small leaves arising from numerous shoots that are not a preference trait to producers while the erect growth habit with only primary and secondary branches maximizes the leaf area. This implies that yield improvement in spider plant could be exploited through selection of genotypes exhibiting erect growth habit and therefore large leaf size. Further reports have suggested that, in mixed cropping, farmers could adopt the semi-erect type whereas the erect types are ideal for intercrop adaptability [14].

3.2. Cluster Analysis. Sufficient phenotypic variation was observed among the accessions as revealed by the cluster analysis (Figure 1). Two major clusters, namely, clusters 1 and 2, were distinguished using the eight morphological descriptors. Cluster 1 included 9 accessions of South African origin with an exception of one Kenyan accession 1959 while cluster 2 is comprised of 40 Kenyan accessions inclusive of one South African origin. Stem and petiole colour were the major traits that contributed to the Kenyan accession 31990 grouping together with the South African accessions that were mainly green stemmed with green petiole. The exceptional South African accession grouped together with the Kenyan accessions due to the purple stem colour and profuse pubescence that were predominant among the Kenyan accessions. This clearly revealed the differences in the genetic makeup of the accessions from the two regions. However, the South African accessions 2279 and 2000, which were collected from the Northern Province, showed similarity in their phenotypic traits. Most of the Kenyan gene bank accessions, namely, 50339, 50330, 50328, 50326, 50299, and 50273, from Nyamira region clustered closely together with accession 30316 from Western region despite being collected from different regions. Additionally, Kenyan accession 45451 from central region and Kenyan accession 14 collected from Kisii region grouped together suggesting some degree of similarity in their morphological traits. Most of the Kenyan farmers' landraces clustered together based on their origin. There were major overlaps with the accessions assembled from the gene bank implying that they could have same genetic makeup. A study by K'opondo [5] has demonstrated a close relationship among spider plant genotypes following the evaluation of the variability in seed proteins among them. In addition, this uniformity could also arise from the self-pollination status of spider plant. However, more characterization needs to be done to validate such findings. The cluster analysis, which clearly grouped the accessions according to their geographical origin, suggests that crop improvement of spider plant could be achieved through exploiting the variation revealed. However, the current cluster analysis was done using morphological traits, which can be influenced by several environmental factors. There will be need to undertake a more detailed genetic analysis using molecular markers to confirm the existence of genetic variation across the different geographical regions. There is need for specific regional breeding efforts to target preferred traits [24, 25].

3.3. Quantitative Traits

3.3.1. Analysis of Variance. Spider plant accessions showed significant differences ($P<0.05$) with no seasonal effect for all the traits, namely, days to 50% flowering, single leaf area, leaf length and width, chlorophyll content, number of leaves per plant, number of primary branches, and plant height (Table 4), implying the existence of variability for the respective traits among spider plant accessions. Accessions that exhibited longer days to 50% flowering also yielded more leaf count. Late flowering enables a plant to have a longer vegetative phase during growth period [7]. Past research has associated late flowering with increased leaf yield and consequently early flowering as a limit to leaf yield in other indigenous vegetables [23]. This suggests that late flowering would be a good selection criterion for yield improvement in spider plant.

Other traits that contributed to increased leaf count were plant height and number of primary branches. Kenyan accessions were taller than the South African accessions with plant height varying from 21 cm for accession 2249 to 113 cm for accession 50296. The Kenyan accessions performed better than South African genotypes for the number of leaves per plant, number of primary branches, leaf length, leaf width, plant height, single leaf area, and chlorophyll content conforming to past research by Wasonga [22]. The best 5 outstanding accessions with regard to yield related traits like 50% flowering, single leaf area, and number of leaves per plant included Kenyan accessions: 3, 7, 45451, 50296, and South African accession 2241 (Table 5).

3.3.2. Correlation among the Traits. Knowledge of the correlations among yield and the yield related traits is of considerable importance in crop improvement because it aids in indirect selection [26]. There was positive and significant correlation between leaf length, leaf width, and leaf area with number of days to 50% flowering Table 6. This agrees

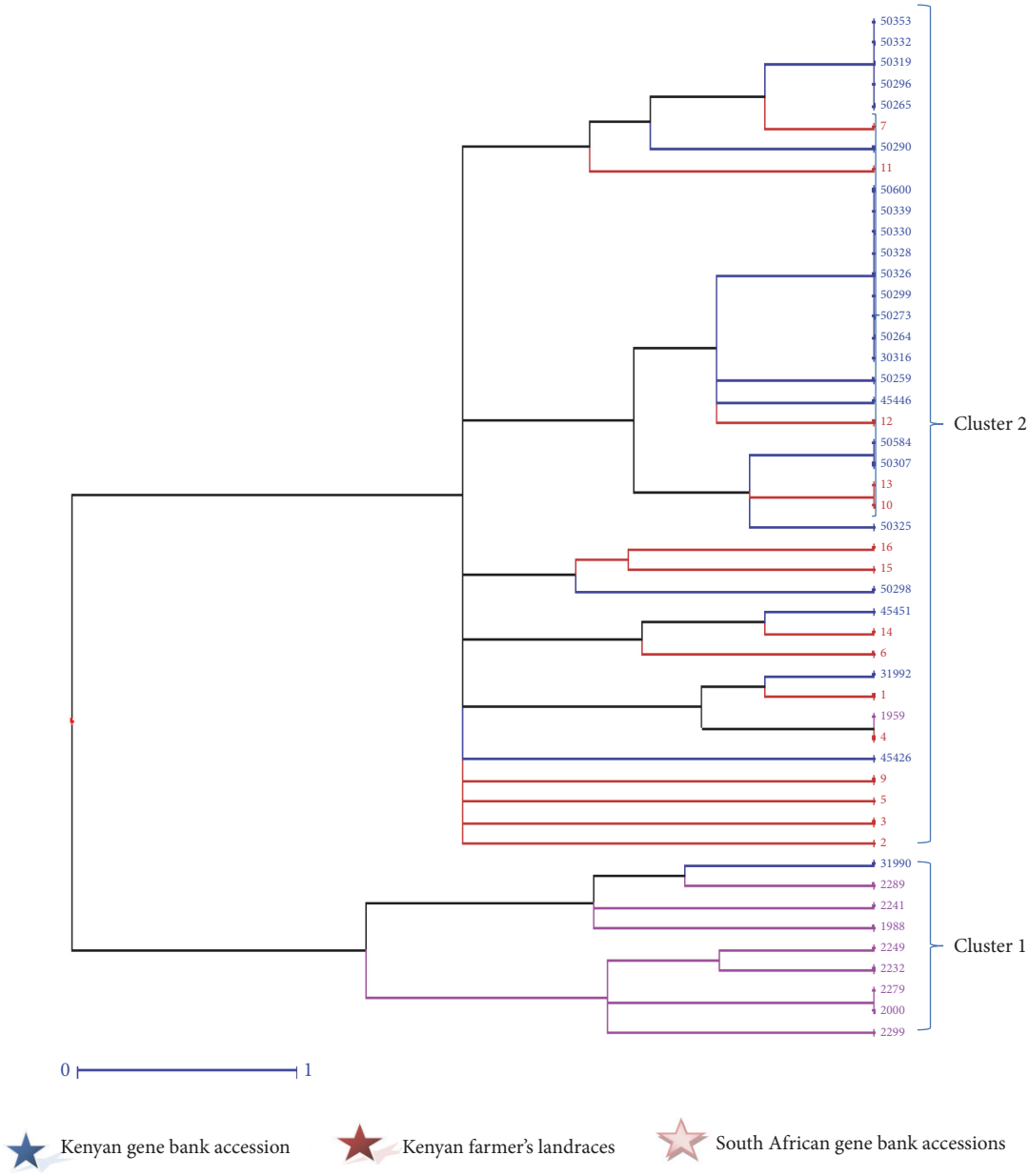

Figure 1: Phenogram showing relationship among accessions characterized using morphological traits.

with the findings of Kiebre et al. [27] who also reported a positive significant correlation between number of days to 50% flowering with leaf length and width. This further suggests that the late flowering genotypes could be selected for their big size, which is a crucial trait to the producers who regard leaf biomass as key in leafy vegetables production.

There was a significant positive correlation between plant height and number of primary branches conforming to the results of Kiebre et al. [27] indicating the taller the plant, the more the number of primary branches. This is further supported by the observed correlations, where yield in terms of number of leaves per plant had a positive and significant correlation with plant height ($r = 0.69$) and number of primary branches ($r = 0.63$) implying that the higher the number of the branches and the taller the plant, the higher the number of leaves. Single leaf area correlated positively with leaf length, width, and days to 50% flowering at $r = 0.92$, $r = 0.88$, and $r = 0.21$, respectively. As expected, the leaf area would be determined by its length and width suggesting the longer and wider the leaf, the bigger the leaf area. This suggests leaf length and width as important traits in selecting for vegetative yield in spider plant.

However, there was a nonsignificant negative correlation between leaf size and leaf yield indicating the more the number of leaves in the plant, the smaller the leaves. Yield is influenced by complex soil plant interactions in many crops. In this study, the chlorophyll content measured in SPAD value had a positive significant correlation with number of leaves

Table 4

(a) Analyses of variance showing the mean squares for the agronomic traits in Cleome gynandra season one (April-July 2014).

Source of variation	d.f.	DTF	LL	LW	NPB	NLPP	PH	SLA	SPAD
Rep	2	4.3	0.6	1.7	1.6	27.9	6.5	0.4	1
Genotype	48	34.7∗	5.2∗	16.3∗	14.7∗	6895.6∗	2734.0∗	8.1∗	165.4∗
Residual	96	1	0.2	1.4	0.3	13.4	8.2	0.4	2.1
Total	146								

(b) Analyses of variance showing the mean squares for the agronomic traits in Cleome gynandra season one (October-July 2014).

Source of variation	d.f.	DTF	LL	LW	NPB	NLPP	PH	SLA	SPAD
Rep	2	5	0.5	0.5	0.4	1.5	3.2	0.6	3.6
Genotype	48	31.1∗	5.1∗	16.5∗	11.9∗	6961.3∗	2723.8∗	7.9∗	139.5∗
Residual	96	0.8	0.1	0.5	0.5	17.6	6.4	0.2	4.3
Total	146								

(c) Analyses of variance showing the mean squares for the agronomic traits in Cleome gynandra for the combined seasons.

Source of variation	d.f.	DTF	LL	LW	NPB	NLPP	PH	SLA	SPAD
Rep	2	9.1	1	1.2	1.6	16	4.7	0.9	3.2
Genotype	48	64.6∗	10.3∗	32.6∗	26.1∗	13840.2∗	5451.1∗	15.9∗	300.8∗
Season	1	161.6∗	1.0∗	4.1∗	2.1∗	54	33.4∗	2.1∗	4.8∗
Genotype Season	48	1.2	0.1	0.2	0.4	16.7	6.7	0.1	4.1
Residual	194	0.9	0.2	0.9	0.4	15.5	7.3	0.3	3.2
Total	293								

∗Significant at $P < 0.05$, DTF: days to 50% flowering, SLA: single leaf area (cm^2), LL: leaf length (cm), LW: leaf width (cm), NLPP: number of leaves per plant, NPB: number of primary branches, PH: plant height (cm), and SPAD: soil plant analysis development.

per plant (r = 0.45), number of primary branches (r = 0.54), and plant height (r = 0.59). This contradicts the findings of [28] who reported negative correlations between chlorophyll readings with yield related traits except for plant height in beans. This positive significance correlation between SPAD values and yield related traits calls for more studies to elucidate this phenomenon. Leaf yields may be improved through selection of accessions that showed high leaf count as well as large single leaf area.

3.4. Stepwise Regression. The most important traits that have a considerable effect on the dependant variable are verified through a stepwise regression analysis. The traits selected through the regression model can then be used as a selection criterion for indirect selection in a breeding program [29]. A multiple linear regression analysis was calculated by considering the number of leaves as the dependent variable and other characters as the independent variables. Results of regression analysis showed that plant height had a significant influence on yield ($R^2 = 46.7$, P value ≤ 0.05) (Table 7). This implies that selection based on plant height will influence and increase vegetative yield in *C. gynandra*. This further agrees with other findings by Nwangburuka et al. [30] in vegetable *C. olitorius* where plant height was found to significantly increase leaf yield.

3.5. Heritability Estimates for Yield and Yield Related Traits. The estimates of heritability in broad sense for all the traits ranged from 78% to 99% (Table 8). High percentages of broad sense heritability were estimated for number of leaves per plant, plant height at 99%, and SPAD value at 96%. Leaf width exhibited a moderately lower percentage at 78% followed by single leaf area and leaf length at 86% and 89%, respectively (Table 8). High heritability plays a great role in selection for crop improvement as the traits to be improved depend immensely on their heritability and variability [27]. In this study, the genotypic variance of all traits was higher than the environmental variance implying that much of the phenotypic variation among the accessions was attributed to variation in genotype as opposed to the environment. The high estimates of heritability displayed in the study suggest that selection for yield improvement in spider plant could be based on traits like number of leaves per plant and plant height.

4. Conclusions and Recommendations

This study reported the existence of significant phenotypic variation in *Cleome gynandra* as evidenced by the morphological characterization which clearly distinguished the accessions from the two regions. The new knowledge generated on the spider plant morphological structure could offer a great potential in developing relevant genetic and genomic resources for spider plant breeding programs. It is also clear that indirect selection for improved spider plant accessions could be based on the yield related traits like number of leaves per plant, plant height, number of primary branches, and days to flowering which exhibited high heritability. This study recommends the complementation of morphological

Table 5: Mean comparison of the quantitative traits of 49 spider plant accessions from Kenya and South Africa grown in the University of Nairobi Field at Kabete, for the two combined seasons.

Entry	Accession No.	Origin	DTF	LL	LW	NPB	NLPP	PH	SLA	SPAD
1	1	Kenya	39.7	5.1	14.2	6.3	105	38.3	8.7	56.4
2	2	Kenya	45.7	6.4	11.5	5.7	58.8	31.5	8.8	57.6
3	3	Kenya	45.3	6.7	17	7	112.2	41	10.9	50.3
4	4	Kenya	43.8	5.2	13.8	7.5	75.8	36.7	8.7	56.9
5	5	Kenya	45.3	5	13.2	7.5	53.8	46.8	8.3	57.6
6	6	Kenya	39.7	5	11.7	7.5	57.2	47.8	7.8	56.9
7	7	Kenya	45	5.9	16	7.7	91.3	51.2	9.9	53
8	9	Kenya	45.5	6.2	14.3	6.5	94.3	39	9.6	56.6
9	10	Kenya	41.5	5.6	11.7	5.7	68	40.7	8.3	58.3
10	11	Kenya	45	3.6	10.6	5.5	100.5	40.1	6.3	56.8
11	12	Kenya	46	4.6	11.9	7.5	61	42.2	7.6	58.8
12	13	Kenya	37.8	5	13.1	6.2	64.8	38.3	8.3	55.9
13	14	Kenya	39.8	4.7	11.3	7.8	83.3	63.2	7.4	53.3
14	15	Kenya	38.7	3.7	9.3	5.7	55.7	37.8	6	46.7
15	16	Kenya	45.2	7.8	15.6	9	75.7	75.5	11.2	61.6
16	1959	S. Africa	43.8	5.8	12	6.7	89.2	34.3	8.5	54.3
17	1988	S. Africa	34.2	6.8	12.6	5.7	50.7	45.2	9.5	49.9
18	2000	S. Africa	32.8	6.5	13.6	4.2	19.7	30.8	9.6	53.1
19	2232	S. Africa	39.8	5.3	10	4.7	56	26.3	7.4	24.3
20	2241	S. Africa	45.3	7.8	15.4	7.8	41	42.3	11.2	44
21	2249	S. Africa	39.3	6.2	13.2	4.2	20.3	21.2	9.2	42.9
22	2279	S. Africa	53.2	6.3	12.3	6.7	23.2	22.1	9	39.6
23	2289	S. Africa	44	7.2	13.9	6.3	31.3	41.7	10.2	43
24	2299	S. Africa	40	5.1	9.8	7.3	78	30.3	7.2	43.7
25	30316	Kenya	37.7	5.9	10.3	10	146	83	8	57.1
26	31990	Kenya	41	5.7	13.2	8.5	109.3	91.3	8.8	55.4
27	31992	Kenya	42	8	11	9.2	201	91.7	9.9	59.5
28	45426	Kenya	43	7.4	11.5	10	97	97	9.5	58.4
29	45446	Kenya	42.3	8.8	13	8.3	68	111.7	11.1	57.3
30	45451	Kenya	47.7	7.2	16.1	9.2	247.5	109.3	10.9	53.9
31	50259	Kenya	44	5.7	10.6	9.2	182	101.3	7.9	58.1
32	50264	Kenya	40.2	4.4	10.5	11.7	172.2	108.8	6.9	60.8
33	50265	Kenya	44.3	5.5	11.6	10.3	78.7	92.2	8.2	60.1
34	50273	Kenya	40.3	5.1	9.5	8.7	92.8	89.7	7.1	57.5
35	50290	Kenya	40.3	4.8	10.4	9.3	105.2	93.2	7.1	62.2
36	50296	Kenya	40	10.5	18.3	10.7	109.5	113	14.2	57.9
37	50298	Kenya	40	4.4	7.9	11.5	140	82.7	6.1	59.5
38	50299	Kenya	41.7	4.8	9.4	10.5	101.3	99.8	6.9	58.9
39	50307	Kenya	40	6	12	8.3	140.7	93.8	8.7	58.4
40	50319	Kenya	40.3	6.2	12.5	9.5	101	77.8	9	62.5
41	50325	Kenya	40	6.8	12.1	10	94.8	95	9.3	57.9
42	50326	Kenya	44.3	5.6	11.1	12.5	165.8	101.2	8.1	57.5
43	50328	Kenya	40.2	5.4	8.6	8.7	96.5	75.7	7.1	58.6
44	50330	Kenya	39.8	5.7	10.4	9.8	172	104.3	7.8	60.8
45	50332	Kenya	40.5	4.2	8.8	9.2	115.8	110.5	6.2	62.5
46	50339	Kenya	42.7	5.2	12.8	12.5	149.8	101.7	8.3	61.6
47	50353	Kenya	42.3	4.5	8.4	11	146.8	86	6.3	57.8
48	50584	Kenya	39.7	4.8	9.8	9.7	88.8	78.7	7	57.9
49	50600	Kenya	38.8	5.9	8.8	9.5	78.8	98.8	7.5	56.2
	Mean		**41.8**	**5.8**	**12**	**8**	**97**	**68.4**	**8.5**	**55.1**
	LSD ($p<0.05$)		**1.5**	**0.7**	**1.6**	**1**	**6.3**	**4.4**	**0.9**	**2.9**
	CV %		**2.2**	**7.4**	**8.1**	**7.8**	**4**	**4**	**6.5**	**3.3**

DTF: days to 50% flowering, SLA: single leaf area (cm^2), LL: leaf length (cm), LW: leaf width (cm), NLPP: number of leaves per plant, NPB: number of primary branches, PH: plant height (cm), and SPAD: soil plant analysis development.

Table 6: Correlation in combined seasons.

	DTF	LL	LW	NPB	NLPP	PH	SLA	SPAD
DTF	-							
LL	0.12∗	-						
LW	0.28∗∗	0.62∗∗	-					
NPB	0.09	0.02	-0.20∗∗	-				
NLPP	0.1	-0.01	-0.11	0.63∗∗	-			
PH	-0.07	0.16∗	-0.19∗	0.82∗∗	0.69∗∗	-		
SLA	0.21∗∗	0.92∗∗	0.88∗∗	-0.08	-0.06	0.01	-	
SPAD	-0.04	-0.07	-0.11	0.54∗∗	0.45∗∗	0.59∗∗	-0.1	-

∗ implies significance difference at P<0.05; ∗∗ implies significance difference at p<0.001 (2-tailed), DTF- days to 50% flowering, SLA- single leaf area (cm^2), LL- leaf length (cm), LW- leaf width (cm), NLPP- number of leaves per plant, NPB- number of primary branches, PH- plant height (cm), SPAD- soil plant analysis development.

Table 7: Stepwise regression analysis of the 7 evaluated traits.

Step	Variable	Partial R square	Adjusted R square	F-test
1	Plant height	0.48	0.47	43.00∗

∗Significant at p≤ 0.05 y = 1.102x + 21.947, y = number of leaves per plant, and x = plant height.

Table 8: Estimates of yield and yield related components of 49 spider plant accessions.

Traits		VE	VG	VP	HBS (%)
DTF	Season 1	1.0	11.2	12.2	91.8
	Season 2	1.0	10.1	11.1	91.0
LL	Season 1	0.2	1.7	1.9	89.3
	Season 2	0.2	1.7	1.9	89.3
LW	Season 1	1.4	5.0	6.4	78.0
	Season 2	1.4	5.3	6.7	79.2
NPB	Season 1	0.3	4.8	5.1	94.1
	Season 2	0.3	3.8	4.1	92.7
NLPP	Season 1	13.4	2294.1	2307.5	99.4
	Season 2	13.4	2314.6	2328.0	99.4
PH	Season 1	8.2	908.6	916.8	99.1
	Season 2	8.2	905.8	914.0	99.1
SLA	Season 1	0.4	2.6	3.0	86.5
	Season 2	0.4	2.6	3.0	86.5
SPAD	Season 1	2.1	54.4	56.5	96.3
	Season 2	2.1	45.1	47.2	95.5

VE = environmental variance, VG = genotypic variance, VP = phenotypic variance, HBS = broad sense heritability, NLLP = number of leaves per plant, NPB = number of primary branches, LL = leaf length, LW = leaf width, PH = plant height, SLA = single leaf area, and SPAD = soil plant analysis development.

characterization with the use of molecular markers for germplasm characterization and genetic diversity since they are under little influence from the environment.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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References

[1] R. R. Schippers, "African indigenous vegetables: an overview of the cultivated species," 2000.

[2] J. A. Chweya and N. A. Mnzava, *Cat's whiskers. gynandra L.: Promoting the conservation and use of underutilized and neglected crops*, vol. 11, 1997.

[3] Department of Agriculture Forestry and Fisheries (DAFF), *Cleome*, Resource Centre, Pretoria, South Africa.

[4] HCDA, *Horticulture Data 2011-2013 Validation Report*, Horticultural Crops Development authority.

[5] F. B. K'opondo, "Morphological characterization of selected spider plant (Cleome gynandraL.) types from western Kenya," *Annals of Biological Research*, vol. 2, no. 2, pp. 54–64, 2011.

[6] S. A. Mohammadi and B. M. Prasanna, "Analysis of genetic diversity in crop plants—salient statistical tools and considerations," *Crop Science*, vol. 43, no. 4, pp. 1235–1248, 2003.

[7] C. O. Omondi, *Variation and Yield Prediction Analyses of Some Morphological Traits in Six Kenyan Landraces Population of Spider flower (Gynandropsis gynandra (L.) Briq) [PhD. thesis]*, Univ. Nairobi, Nairobi, Kenya.

[8] S. Shukla, A. Bhargava, A. Chatterjee, A. Srivastava, and S. P. Singh, "Genotypic variability in vegetable amaranth (Amaranthus tricolor L.) for foliage yield and its contributing traits over successive cuttings and years," *Euphytica*, vol. 151, no. 1, pp. 103–110, 2006.

[9] R. Jaetzold, "Natural conditions and farm management information of Central Kenya. Farm management handbook of Kenya," 2004.

[10] F. Koyuncu, "Breaking seed dormancy in black mulberry (Morus nigra L.) by cold stratification and exogenous application of gibberellic acid," *Acta Biologica Cracoviensia Series Botanica*, vol. 47, no. 2, pp. 23–26, 2005.

[11] Food and Agricultural Organisation (FAO), *Production year book*, vol. 49, Food and Agricultural Organisation (FAO), Rome, Italy, 1995.

[12] X. Perrier and J. P. Jacquemoud-Collet, "DARwin software".

[13] R.W Payne, D. A. Murray, S. A. Harding, D. B. Baird, and D. Soutar, "An introduction to GenStat for Windows," vol. 2011, VSN International, Hemel Hempstead, UK.

[14] C. H. Hanson, H. F. Robinson, and R. E. Comstock, "Biometrical Studies of Yield in Segregating Populations of Korean Lespedeza 1," *Agronomy journal*, vol. 48, no. 6, pp. 268–272, 1956.

[15] A. Masuka, M. Goss, and U. Mazarura, "Morphological characterization of four selected spider plant (Cleome gynandra L.) morphs from Zimbabwe and Kenya," *Asian Journal of Agriculture and Rural Development*, vol. 2, no. 4, p. 646, 2012.

[16] K. S. Gould, D. A. Dudle, and H. S. Neufeld, "Why some stems are red: Cauline anthocyanins shield photosystem II against high light stress," *Journal of Experimental Botany*, vol. 61, no. 10, pp. 2707–2717, 2010.

[17] H. E. Khoo, A. Azlan, S. T. Tang, and S. M. Lim, "Anthocyanidins and anthocyanins: colored pigments as food, pharmaceutical ingredients, and the potential health benefits," in *Food & Nutrition Research*, vol. 61, 2017.

[18] S. Venter, W. S. Jansen van Rensburg, H. J. Vorster, E. Van den Heever, and J. J. B. Zijl, "Promotion of African leafy vegetables within the Agricultural Research Council-Vegetable and Ornamental Plant Institute: The impact of the project".

[19] H.-X. Chang, A. E. Lipka, L. L. Domier, and G. L. Hartman, "Characterization of disease resistance loci in the USDA soybean germplasm collection using genome-wide association studies," *Journal of Phytopathology*, vol. 106, no. 10, pp. 1139–1151, 2016.

[20] R. Aruna, D. M. Rao, L. J. Reddy, H. D. Upadhyaya, and H. C. Sharma, "Inheritance of trichomes and resistance to pod borer (Helicoverpa armigera) and their association in interspecific crosses between cultivated pigeonpea (Cajanus cajan) and its wild relative C. scarabaeoides," *Euphytica*, vol. 145, no. 3, pp. 247–257, 2005.

[21] U. Alahakoon, J. Adamson, L. Grenkow, J. Soroka, P. Bonham-Smith, and M. Gruber, "Field growth traits and insect-host plant interactions of two transgenic canola (Brassicaceae) lines with elevated trichome numbers," *The Canadian Entomologist*, vol. 148, no. 5, pp. 603–615, 2016.

[22] D. O. Wasonga, J. L. Ambuko, G. N. Cheminingwa, D. A. Odeny, and B. G. Crampton, "Morphological Characterization and Selection of Spider Plant (Cleome Gynandra) Accessions from Kenya and South Africa," *Asian Journal of Agricultural Sciences*, vol. 7, no. 4, pp. 36–44, 2015.

[23] C. O. Ojiewo, O. Mbwambo, I. Swai et al., "Selection, evaluation and release of varieties from genetically diverse African nightshade germplasm," *International Journal of Plant Breeding*, vol. 7, no. 2, pp. 76–89, 2013.

[24] Z. Kiebre, P. Bationo-Kando, N. Sawadogo, M. Sawadogo, and J. D. Zongo, "Selection of phenotypic interests for the cultivation of the plant Cleome gynandra L. in the vegetable gardens in Burkina Faso," *Journal Of Experimental Biology and Agriculture Sciences*, vol. 3, pp. 288–297, 2015.

[25] E. D. Sogbohossou, E. G. Achigan-Dako, P. Maundu et al., "A roadmap for breeding orphan leafy vegetable species: a case study of Gynandropsis gynandra (Cleomaceae)," *Horticulture Research*, vol. 5, no. 1, p. 2, 2018.

[26] N. Ali, F. Javidfar, J. Y. Elmira, and M. Y. Mirza, "Relationship among yield components and selection criteria for yield improvement in winter rapeseed (Brassica napus L.)," *Pakistan Journal of Botany*, vol. 35, no. 2, pp. 167–174, 2003.

[27] Z. Kiebre, P. Bationo-Kando, A. Barro et al., "Estimates of genetic parameters of spider plant (Cleome gynandra L.) of Burkina Faso," *International Journal of Agricultural Policy and Research*, vol. 5, no. 9, pp. 138–144, 2017.

[28] S. Guler and H. Ozcelik, "Relationships between leaf chlorophyll and yield related characters of dry bean (Phaseolus vulgaris L)," *Journal of Plant Sciences*, vol. 6, no. 4, pp. 700–703, 2007.

[29] N. Sabaghnia, H. Dehghani, B. Alizadeh, and M. Mohghaddam, "Interrelationships between seed yield and 20 related traits of 49 canola (*Brassica napus* L.) genotypes in non-stressed and water-stressed environments," *Spanish Journal of Agricultural Research*, vol. 8, no. 2, pp. 356–370, 2010.

[30] C. C. Nwangburuka, O. J. Olawuyi, K. Oyekale, K. O. Ogunwenmo, O. A. Denton, and E. Nwankwo, "Growth and yield response of Corchorus olitorius in the treatment of Arbuscular mycorrhizae (AM, Poultry manure (PM)," *Combination of AM-PM and Inorganic Fertilizer (NPK). in Applied Science Research*, vol. 3, no. 3, pp. 1466–1471, 2012.