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Genetic variability, traits association and path coefficient analysis of spider plant (*Cleome gynandra* L.) landraces

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ABSTRACT

Spider plant (*Cleome gynandra* L.) is a relatively understudied African indigenous vegetable that has the potential to provide affordable nutrients and improve the livelihoods and incomes of smallholder farmers. A study was conducted to assess genetic variability, correlation, and the potential for indirect selection for yield. A total of 16 landraces were evaluated in a 4x4 α-lattice design at MUAST Agro-Industrial Park and Horticulture Research Institute (HRI) during the 2022 and 2023 summer seasons. This study revealed genotypic variation among the landraces, with significant ($p<0.05$) differences observed in days to 50 % flowering (DF), plant height (PH), leaf length (LL), and edible fresh leaf yield (FY). High to moderate broad-sense heritability and percent genetic advance were observed for DF (0.74; 25.9%), PH (0.32; 11.6%), and FW (0.316%; 26.4%), demonstrating that these traits are controlled by additive gene effects and can be enhanced by selection. Additionally, significant ($p<0.01$) strong positive genotypic correlations were detected between FY and PH ($r_g=0.84$) and between FY and DF ($r_g=0.76$). Furthermore, the results of path analysis for edible fresh leaf yield showed a strong direct effect from PH (0.63) and DF (0.46), while a moderate direct effect was observed from LL (0.20). In conclusion, the results of this study indicate that PH and DF can be used for improving the edible fresh leaf yield of spider plant. Moreover, CGNPGRC353 and CGGURUVE showed superiority for DF, PH, and FY and have the potential to be used as donors or directly. The information obtained from this study can be valuable for spider plant breeding for edible fresh leaf yield.

Keywords: *Cleome gynandra*, direct effect, genetic advance, genotypic, heritability, leaf yield

RÉSUMÉ

Le chlorophytum, ou plante araignée (*Cleome gynandra* L.) est un légume africain indigène relativement peu étudié, qui a le potentiel de fournir des nutriments abordables et d'améliorer les moyens de subsistance et les revenus des petits agriculteurs. Une étude a été menée pour évaluer la variabilité génétique, la corrélation et le potentiel de sélection indirecte pour le rendement. Un total de 16 populations locales a été évalué dans un dispositif en lattices alpha 4x4 au parc agro-industriel de MUAST et à l'Institut de Recherche en Horticulture (HRI) pendant les saisons d'été 2022 et 2023.

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Cette étude a révélé une variation génotypique parmi les populations locales, avec des différences significatives (p<0,05) observées dans les jours jusqu'à 50 % de floraison (DF), la hauteur des plantes (PH), la longueur des feuilles (LL) et le rendement en feuilles fraîches comestibles (FY). Une héritabilité au sens large modérée à élevée et un pourcentage de progrès génétique ont été observés pour DF (0,74 ; 25,9 %), PH (0,32 ; 11,6 %) et FW (0,316 % ; 26,4 %), démontrant que ces caractères sont contrôlés par des effets génétiques additifs et peuvent être améliorés par sélection. De plus, des corrélations génotypiques significatives (p<0,01) fortes ont été détectées entre FY et PH (rg = 0,84) et entre FY et DF (rg = 0,76). En outre, les résultats de l'analyse des chemins pour le rendement en feuilles fraîches comestibles ont montré un effet direct fort de PH (0,63) et de DF (0,46), tandis qu'un effet direct modéré a été observé pour LL (0,20). En conclusion, les résultats de cette étude indiquent que PH et DF peuvent être utilisés pour améliorer le rendement en feuilles fraîches comestibles de la plante araignée. De plus, CGNPGRC353 et CGGURUVE ont montré une supériorité pour DF, PH et FY et ont le potentiel d'être utilisés comme donneurs ou directement. Les informations obtenues de cette étude peuvent être précieuses pour la sélection de la plante araignée pour le rendement en feuilles comestibles.

Mots clés : *Cleome gynandra*, effet direct, progrès génétique, génotypique, héritabilité, rendement en feuilles

INTRODUCTION

Spider plant (C*leome gynandra* L., *2n=34*) is an important African indigenous vegetable that has been overlooked by research and development (Sogbohossou *et al.,* 2018). This neglected and underutilized crop has a significant role in the nutrition, livelihoods, health and incomes of farmers, especially women and youth, in Africa (Sogbohossou *et al.,* 2019). Spider plant has been reported to have elevated levels of calcium, iron, magnesium, zinc, vitamins and other secondary metabolites, such as flavonoids, phenolics, glucosinolates, and tannins (Omondi *et al.,* 2017; Sogbohossou *et al.,* 2020).

Spider plant production systems are progressing from uncultivated fields to commercial gardens (Maundu *et al.,* 2009; Maroyi, 2011). There are several challenges limiting the commercial production of spider plant, including low productivity, the use of landraces, and the absence of improved varieties. With recent world campaigns focused on fruit and vegetable consumption to promote good health and longevity, it is expected that the consumption and production of spider plants will continue to increase in Zimbabwe and the rest of SSA (FAO, 2021). The spider plant genetic resources available in Zimbabwe are available across a number of institutes, and they have not been sufficiently explored. Previous work has assessed spider plant genetic resources/landraces for agro-morphological diversity, which is the first step in cultivar development and is associated with farmer and consumer preferences/traits (Masuka *et al.,* 2012; Wenyika *et al.,* 2015).

The success of spider plant crop improvement programs is chiefly influenced by numerous factors, including the scale of the available landraces, genetic variability, trait heritability, genetic advancement, and relationships among factors. Furthermore, the direct and indirect effects of these factors on the edible fresh leaf yield of spider plants play a decisive role in shaping the success of the program. Several studies have been conducted on the genetic variability and heritability of indigenous vegetables such as amaranth, okra, and cowpea (Ibrahim and Hussein, 2006; Aremu *et al.,* 2007; Tejaswini *et al.,* 2017; Yeshitila *et al.,* 2023). These studies revealed genetic variation and high heritability in agronomic traits, and superior genotypes with these desirable traits were identified for efficient utilization and conservation. Limited work has been carried out on the germplasm of spider plant, specifically in the Zimbabwean (Wenyika *et al.,* 2015). However, there are some studies available on spider plant in other African countries (Munene *et al.,* 2018; Achigan-Dako *et al.,* 2021; Chatara *et al.,* 2023). Crop yield is a complicated variable that is influenced by numerous factors, and indirect selection through interrelated, less intricate and more easily quantified traits would be worthwhile. The agronomic trait correlation will provide a reasonable indication for selection to improve the edible fresh leaf yield and for a more well-organized breeding programme. The use of indirect selection before harvesting is economical because it accelerates the process of selection by immediately discarding undesirable genotypes. Knowledge of the indirect traits for selection with high heritability and genetic gains would help aide achieve greater progress in selection and the existence of additive gene effects (Johnson *et al.,* 1955). Understanding the associations between spider plant traits via path analysis can provide valuable insights into selecting desirable traits for improving edible fresh leaf yield (Bhatt, 1973). Incorporating secondary traits in the selection process can lead to significant genetic gains (Bänziger and Lafitte, 1997; Musvosvi *et al.,* 2018). There is a lack of information on the correlations and direct and indirect selection traits of spider plant of which have been used in other crop species to clearly explain the relationships among yield-enhancing traits (Sogbohossou *et al.,* 2018a; Sogbohossou *et al.*, 2018b). This study aimed to assess spider plant landrace germplasm variability, correlations among traits and their direct and indirect effects on the edible fresh leaf yield of spider plants.

MATERIALS and METHODS

Genetic resources and experimental design. Sixteen (16) spider plant landraces were kindly provided by the various research institutes (Table 1). These accessions were planted during the rainy seasons of December 2022/23 and 2023/24. The trial were planted in a simple 4 x 4 alpha lattice design with two replications. The accessions were established through the drilling of seeds in 0.5 m rows and 30 cm in rows with a depth of 20 mm. Basal fertilizer was applied through the rows at a rate of 300 kg/ha of NPK (7:14:7) fertilizer. The seeds were drilled along rows, with plot sizes of 1m^2 consisting of 4 rows x 1 m. A pathway of 0.5 m was left between the rows for data collection. The plants were thinned to 30 cm within the rows. The net plot consists of two center rows measuring 1m in length. At 21 days after crop emergence, a top dressing of ammonium nitrate (34.5% N) was applied at a rate of 100 kg/ha.

Table 1. List of spider plant accessions

Accession number	Treatment code	Source
1	CGMRR2	UZ
2	CGUZG1	UZ
3	CGUZG2	UZ
4	CGMRGP-M	UZ
5	CGKEX	UZ
6	CGMRGZ	UZ
7	CGMRR1	UZ
8	CGMRG1	HRI
9	CGSKGP1	UZ
10	CGSKGP2	UZ
11	CGNPGRC355	NGB
12	CGNPGRC356	NGB
13	CGNPGRC353	NGB
14	CGGURUVE	MUAST
15	CGKENYA	HRI
16	CGZIM	MUAST

NB: HRI – Horticulture Research Institite, MUAST- Marondera University of Agricultural Sciences and Technology. UZ- University of Zimbabwe. NGB- National Genetic Resources Institute

Table 2. Soil summary results for the MUAST AIP and HRI sites

Description	Measurement	
	AIP	HRI
pH	6.25	6.57
Mineral Nitrogen %	0.052	0.063
Available Phosphorus (mg/kg)	80.8	83.8
Potassium	0.46	0.59
Calcium	3.305	3.6
Magnesium	0.705	1.4
CEC	66.4	56.0
Clay %	14	15.5
Silt %	8	9.4
Sand %	78.5	75
Soil Color	Light brown	Reddish
Soil Texture	Sandy loam	Sandy loam

Agronomic trial: Study site.The field trial was conducted at the Marondera University of Agricultural Science and Technology (MUAST), Agro-Industrial Pack and Horticultural Research Institute (HRI), Department of Research and Specialist Services. The AIP is located at coordinates S18''23'31,66753 and E31''48'0.51484, with an elevation of 1450 meters above sea level (MASL). The site is in the agroecological region of the IIB. On the other hand, the HRI is positioned at coordinates S18''17'41417 and E31''46'.43133 with an elevation of 1615.1 MASL. The HRIs are located within agroecological zone IIA (Manatsa *et al.*, 2020). The soil samples were collected from the 0-15 cm profile and had a neutral soil pH, and most of the soil characteristics were within this range (Table 2).

Data collection and analysis. In the present study, agronomic trait data were collected for various parameters, including days to 50% flowering, leaflet length and width, plant height and edible fresh leaf yield (Table 3). To analyse the collected data, descriptive statistics were calculated using R version 4.2.2 with the aid of the package variability package. Analysis of variance (ANOVA) was carried out using the restricted maximum likelihood (REML) method. The environments were considered random effects, while genotypes were considered fixed effects. The genotypic and phenotypic coefficients of variation and genetic advances as percentages of the mean, broad-sense heritability were derived (Lush,1949, Robinson *et al*., 1949; Burton and Devare, 1953; Johnson *et al*., 1955; Hanson *et al.*, 1956). Path analysis was performed to determine the direct and indirect effects of the traits on the edible fresh leaf yield.

The genotypic variance was calculated using the following formula:

$$d^2\text{g} = \frac{MGE-MSE}{\text{r}} \qquad \text{equation (1)}$$

where d^2g is the genotypic variance, MSG is the mean sum of squares for genotypes,

and MSE is the mean sum of squares for error.

Table 3. Agronomic trait descriptions for the spider plant trial

Trait	abbreviation and unit of recording	Description
plant height	PH (cm)	The above ground measurement of plant to top of the plant at physiological maturity
days to 50% flowering	DF (days)	The number of days from emergence to the day 50 percent of the plot stand is at flowering
leaf blade length	LL (mm)	The average of 3 three longest/middle leaflet lob length of 3 plants
leaf blade width	LW (mm)	The average corresponding leaflet lob width
Edible fresh leaf yield	FY (grams)	The average fresh shoots yield per plant from the 3 plants at 42 days after emergence

phenotypic variance can be derived from:

$$=d^2\text{g} + d^2e \qquad \text{equation (2)}$$

where d2g is the genotypic variance and d^2e is the environmental variance,
which is equal to the mean square error.

The GCV and PCV were derived with the following formulas (Burton, 1952):

$$\text{GCV}= \frac{dg \times 100}{\text{x}} \qquad \text{equation (3)}$$

$$\text{PCV}= \frac{dp \times 100}{\text{x}} \qquad \text{equation (4)}$$

Broad-sense heritability was derived from the following formula (Robinsoon *et al*., 1949):

$$H_b=\frac{d^2\text{g}}{d^2\text{p}} \; x\, 100 \qquad \text{equation (5)}$$

The genetic advance is computed as follows:

$$\text{GA} = \text{K}.\, H_b.\, dp \qquad \text{equation (6)}$$

where K is the selection intensity, the value is 2.06 at 5% selection intensity,
dp is the phenotypic standard deviation, H_b is the broad-sense heritability, d^2g
is the genotypic variance and d^2p is the phenotypic variance.
The percentage of genetic advancement is derived from Johnson *et al*. (1955).

$$\text{GA}\ \%=\frac{\text{GA}}{\text{x}}\text{X}100 \qquad \text{equation (7)}$$

RESULTS AND DISCUSSION

The soils at the study sites resemble the sandy loam commonly found in smallholder farming systems (Manzeke *et al.*, 2019). The study areas are located within agro-ecological zones IIA and IIB, which represent regions of high agricultural potential. In terms of soil pH, we detected a range from 5.5-7.0, which is ideal for spider plant growth and development (DPP, 2010). Significant ($p<0.05$) genotypic differences in the following agronomic traits were detected among the different spider plant landraces: days to 50% flowering (DF), plant height (PH), leaf length (LL), leaf width (LW) and edible fresh leaf yield (FY) (Table 4). DF ranged from 19 to 42 days (Table 4), with CGNPGRC353 having a greater mean of 38.8 days, along with a greater mean PH (115.5 cm) and FY (93.2 g/plant) (Table 4). The average number of days to flowering was comparable to that of CGUZG2 (38.3 days), showing no significant difference. On the other hand, CGKENYA exhibited a shorter flowering time of 20.4 days (Table 4). The detected variation in DF among the spider plant landraces provides an opportunity for selection based on this trait. Late flowering, in particular, is a farmer-preferring trait, as it enables multiple harvests and increased leaf production (Mosenda *et al.*, 2020). This means that landraces with extended DFs can be selected to meet the precise needs of farmers who prioritize prolonged harvest periods and higher leaf yields. Notably, other studies have reported a range of DF values in spider plant landraces of 32 to 95 days (Houdegbe *et al.*, 2022) and 42 to 73 days (Sogbohssou *et al.*, 2018), while a narrower range of 36 to 47 days was reported by Wenyika *et al.* (2015). These results highlight the variability in DF across different spider plant landraces, showing that flowering time can vary significantly depending on the genotype or environmental circumstances. By understanding the range of DF stakeholders, landraces with preferred flowering characteristics can be selected to develop improved varieties that align with their product profiles, such as prolonged harvesting periods or higher leaf yields (Kholová *et al.*, 2021). The leaf length ranged from 24 to 93.2 mm, with CGMRR2 having the greatest mean value of 73.4 mm (Table 4). The LW ranged from 12 to 42 mm. Among the landraces, CGMRR2 had the highest mean value of 30.6 mm. PH and FY ranged from 42.0 - 127.0 cm and 8 - 164.3 g/plant, respectively (Table 4). CGNPGRC 353 was significantly taller and comparable to CGGURUVE and CGUZG2, while CGKEX was shorter with a corresponding lower FY. Plant height variation is an important trait, as taller plants tend to have greater biomass yields. This characteristic is considered favourable from the farmer's perspective (Onyango *et al.*, 2013; Mosenda *et al.*, 2020). The significance of plant height in relation to biomass yield cannot be understated, as it plays a crucial role in agricultural productivity and economic returns for farmers. In our study, we observed higher plant height values than those reported in previous studies conducted by Wenyika *et al.* (2015) and Omondi *et al.* (2017). Our findings are consistent with the observations of Sogbohssou *et al.* (2018) and Houdegbe *et al.* (2022), who reported a range of 19-168 cm for plant height. The disparity in plant height values across different studies could be attributed to several factors, including genetic variation among the studied landraces, environmental factors, and cultural practices. Our findings revealed that the FY values obtained in our study were greater than those detected by Wenyika *et al.* (2015) and Omondi *et al.* (2017). However, the FY values are comparable to those reported by Houdedge *et al.* (2022), who reported a range of 1.2 - 101.9 g/plant for edible fresh leaf yield. The genetic variability detected in the FY among the spider plant landraces studied suggests the potential for selecting and breeding specific lines for use in crop improvement programs. By concentrating on FY and other key agronomic traits, breeders can identify and develop varieties with enhanced leaf yield potential and desirable traits. Significant ($p<0.05$) genotype by site and genotype by site by year interactions were observed for DF, PH, and FY (Table 4). These findings highlight the importance of selecting different genotypes that have greater performance in specific environments, incorporating different sites and years. The presence of genotype-by-site interactions suggests that certain genotypes may exhibit superior performance in particular environments. This indicates the necessity for site-specific selection and adaptation of genotypes to optimize their growth and productivity based on the specific conditions of each location. Furthermore, the genotype by site and year interaction signifies the influence of season variations on the performance of different genotypes. The environmental factors included rainfall patterns, temperature fluctuations, humidity levels and other environmental variables.

Table 4. Estimation of genetic parameters for the agronomic traits of the *Cleome gynandra* landraces.

Genotype	DF	LL	LW	PH	FY
CGMRR2	34.4bc	73.4a	30.6a	102.3bc	67bc
CGUZG1	31.8d	52.9d	22.3c	88.9d	54.5c
CGUZG2	38.3a	57.4cd	23.5c	108.7ab	67bc
CGMRGP-M	28.3f	54.7d	24.1c	90.8d	45.4de
CGKEX	27.5d	53d	23.9c	78.1e	33.4e
CGMRGZ	31.5d	56.7cd	25.6bc	84.5e	60.54c
CGMRR1	26.5d	59.5cd	23.3c	89.9d	41.9de
CGMRG1	29.8ef	56cd	26.7abc	86.1de	48.53de
CGSKGP1	32.6cd	63.9bc	27.3ab	94.6cd	55cd
CGSKGP2	31.6d	64.4abc	26.4abc	102.1bc	70.5bc

CGNPGRC355	26.5d	59.6cd	24.4c	86.8d	46.8de
CGNPGRC356	31.1de	67.5ab	29.1ab	89.9d	62.8c
CGNPGRC353	38.8a	63.6b	26abc	115.5a	93.2a
CGGURUVE	35.1b	70.6ab	30.4a	113.5a	83.8ab
CGKENYA	20.4 h	67.5ab	29.9a	95.8cd	59.1c
CGZIM	30.1e	62b	26.4abc	90.1.d	58.7c
Grand mean	30.9	61.4	26.2	95.2	59.3
LSD %	2.0	8.6	4.6	10.9	20.49
CV%	6.6	14.1	17.6	11.6	34.8
Sig G	***	***	**	***	***
Sig S	NS	NS	*	NS	NS
Sig Y	*	***	**	**	*
Sig GSY	*	NS	NS	**	*
sig GS	***	*	NS	**	*

*NB: p<0.05=**, p<0.001=***, p<0.01=*, p>0.05=NS, DF= days to 50% flowering, PH=plant height*
G=genotypes, S=Site, Y=Year, GS=genotype by the site interaction, GSY=genotype by site by year interaction

The following broad-sense heritability estimates were detected: DF (0.74) had high heritability, PH (0.32) and FY (0.32) had moderate heritability, while LL (0.24) and LW (0.15) had low heritability (Robinson *et al.*,1949). High broad-sense heritability indicates that traits are less affected by environmental effects, allowing selection centred on phenotypic performance. Munene *et al*. (2018) also detected high heritability for DF. Moderate heritability suggests potential for improvement through selection for PH and FY, while low heritability implies that direct selection is ineffective. Wenyika *et al.* (2015) also reported moderate heritability for FY; conversely, high broad-sense heritability was detected for PH, FY, LL, and LW (Achigan-Dako *et al*., 2021), indicating generally strong environmental effects in our study. Furthermore, previous studies on amaranths detected high heritability of LL, LW, PH and FY, among other agronomic traits (Buhroy *et al*., 2017).The genotypic coefficient of variance (GCV) was inferior to the phenotypic coefficient of variance (PCV) for all the traits, indicating that all the traits were highly determined by the environment, with small differences observed for DF and PH (Table 5). The GCV and PCV are classified as low (0-4%), moderate (5-14%), high (15-20%) or very high (>20%) (Burton, 1952). Moderate GCV and PCV were detected for DF and PH, while low GCV and moderate PCV were detected for LL and LW. High GCV and PCV were detected for FY. These results show the existence of high and moderate variability among the landraces. GAMs are categorized as low (0-10%), moderate (10-20%) or high (>20%) (Jonhson *et al*., 1955). A high GAM indicates that the trait is under the significant control of additive genetic effects, while a low GAM suggests the control of nonadditive genetic effects. In this study, a high GAM was detected for DF (25.9%) and FY (26.4%), while a moderate GAM was detected for PH (11.6%). Low levels were observed for LL (8.7%) and LW (6.0%). Broad-sense heritability alone may be deceptive, but it should be coupled with GAM in selection and forecasting (Johnson *et al*., 1955). High (>60%) heritability and GAM (>20%) were detected only on DF (H=74%, GAM=25.6). Similar results were observed in spider plant, where high broad-sense heritability and GAM % were detected for DF (Kiebre *et al*., 2015, Munene *et al*., 2018). These results of high heritability (>0.60) and GAM% (>20%) suggest that these traits are highly heritable, and there is opportunity for improvement by mass selection, as the traits are controlled by additive gene action. High broad-sense heritability shows that the characters are controlled by genetic effects, and direct selection might yield gains, even though it has limitations compared to narrow-sense heritability (Visscher *et al.*, 2008). Moderate heritability (30-60%) and GAM (10-

20%) were detected for PH (H = 32%, GAM = 11.6%), while moderate heritability and high GAM were detected for FY (H = 32%, GAM = 26.4%), suggesting that these traits could be improved through careful selection. Low heritability (<30%) and GAM (<10%) were detected for LL (H = 24%, GAM = 8.7%) and LW (H = 15%, GAM = 6%), suggesting that nonadditive gene action and direct selection for these traits were ineffective. Therefore, other breeding methods can be employed, namely, marker-assisted selection, backcrossing, genome editing, and mutation breeding. Previous studies have shown contrasting results of high heritability and high GAM for PH, FY, LL, and LW in spider plants (Achigan-Dako *et al.*, 2021**).**

Both genotypic and phenotypic correlations ranged from 0.02 to 0.84 and from 0.06 to 0.73, respectively. Generally, the genotypic correlations were greater than the matching phenotypic correlations (Table 6). The strength of the correlation can be categorized into three groups: weak (0-0.3), moderate (0.3-0.7), and strong (>0.7). There were exceedingly significant (p<0.01) strong positive genetic associations between DF and FY (rg=0.76), between PH and FY (rg=0.84), between LL and LW (rg=0.83), and between DF and PH (rg=0.74). Moderately significant (p<0.05) associations were detected between LL and FY (rg=0.66) and between LL and PH (rg=0.62). These significant and strong positive genetic associations among the traits suggest that there is a genetic basis for the detected relationships. Indirect selection for higher FY can be achieved through selection for late flowering plants, taller plants, and longer and wider leaves. These traits play an important role in yield and can indirectly contribute to the success of spider plant breeding. Indirect selection or secondary traits have been successfully used in maize (Bänziger and Lafitte, 1997; Musvosvi *et al.*, 2018). A positive association between FY and agronomic traits has also been observed in spider plants (Munene *et al.*, 2018; Sogbohossou *et al.*, 2019; Houdegbe *et al.*, 2022) and the vegetable amaranth (Tejaswini *et al.*, 2017; Yeshitila *et al.*, 2023). The greater genotypic correlation than the phenotypic correlation further supports the greater contribution of genetic factors and the possibility of selection gains, and further research and confirmation in various environments are needed.

Table 5. Estimation of genetic parameters for the agronomic traits of Cleome gynandra landraces across sites

Trait	Mean	Mini	maxi	GCV (%)	PCV (%)	H_b	GA %
DF(day)	30.9	19	42	14.6	17	0.74	25.9
PH (cm)	94.8	42	127	10	17.8	0.32	11.6
LL (mm)	61.4	24	93.2	8.5	17.5	0.24	8.7
LW (mm)	26.2	12	42	7.7	20	0.15	6
FW (g)	59.3	8	164.3	22.8	40.6	0.32	26.4

NB: p<0.05=**, p<0.001=***, p<0.01=*, p>0.05=NS

Table 6. Genotypic (above) and phenotypic (below) characteristics of the Cleome gynandra landraces.

Parameter	LL	LW	DF	PH	AFW
LL		0.83 **	0.15 NS	0.62 **	0.66 **
LW	0.73**		0.02 NS	0.46NS	0.61 *
DF	0.21*	0.06NS		0.74 **	0.76 **
PH	0.50**	0.26**	0.42**		0.84 **
FW	0.51**	0.31**	0.47**	0.54**	

NB: p<0.05 =, p<0.01 =**, p<0.001=***, NS = not significantly correlated*

The correlation results aid in the determination of yield components; however, they do not partition yield components into direct and indirect cause–effect relationships, as demonstrated by path analysis (Dewey and Lu, 1959). Yield is an intricate trait that is directly and indirectly influenced by numerous traits, necessitating a comprehensive understanding of each trait's impact on edible fresh leaf biomass yield in spider plants. Path analysis was performed for the edible fresh leaf yield per plant (refer to Table 7). Lenka and Misra (1973) classified path coefficients as negligible (0.0-0.09), low (0.1-0.19), moderate (0.2-029), or high (0.3-0.99). A notable positive direct effect on fresh yield was detected for plant height (0.63) and days to flowering (0.46), while leaf length (0.20) had a moderate direct effect. These traits are considered pivotal contributors to the overall yield. Contrasting outcomes were reported in prior studies, depicting moderate direct effects of days to flowering (0.11) and leaf length (0.14) (Chatara *et al.,* 2023). Furthermore, a negative indirect effect on edible fresh leaf yield was noted for leaf width (-0.10), indicating that selecting for leaf width is ineffective for directly influencing fresh yield, and indirect selection through other traits is recommended (see Table 7). An indirect positive effect on edible fresh leaf yield and days to flowering via plant height (0.39), leaf width (0.36), and leaf length (0.02) was also observed. Additionally, a positive indirect effect on edible fresh leaf yield and plant height was identified via days to flowering (0.131). Moreover, there was a positive indirect effect on fresh yield and leaf length via leaf width (0.68), plant height (0.04), and days to flowering (0.18). The residual effect of 0.0185 indicates that the causative features explain approximately 98.15%, signifying their reliability, with 1.85% remaining unexplained (Singh and Chaudhury, 1995). These findings indicate that plant height, days to flowering, and leaf length are viable candidates for direct selection for edible fresh leaf yield, consistent with prior studies on amaranths, which demonstrated a positive direct effect of plant height and leaf length on fresh yield (Tejaswini *et al.,* 2017). Conversely, in amaranth, leaf width had a positive direct effect on edible fresh leaf yield, in contrast to our findings, where leaf width had a negative direct effect on edible fresh leaf yield (Tejaswini *et al.,* 2017).

Table 7. Direct (bold diagonal) and indirect effects of path analysis between fresh leaf weight and associated traits on Cleome gynandra at both sites.

Parameter	LL	LW	DF	PH
LL	**0.20**	0.74	0.02	-0.29
LW	0.67	**-0.10**	0.36	-0.33
DF	0.18	-0.02	**0.46**	0.13
PH	0.04	-0.23	0.39	**0.63**

Residual=0.0185

CONCLUSION

This study revealed variability in the quantitative traits of spider plant landraces, which is essential for improving crop leaf yield. Moderate to high estimates of genetic coefficient of variation (GCV), heritability, and genetic advance as percent of mean (GAM) were observed for leaf number (LL), plant height (PH), and days to flowering (DF), signifying the presence of additive gene action and effective indirect selection for increasing fresh yield in a short time. The strong genotypic correlations and direct effects of PH, LL, and DF indicate that they have an impact on the edible fresh leaf yield of spider plant. Among the landraces, CGNPGRC353 was superior for DF, PH and FY, while CGMRR2 was superior for LL and LW. These genotypes are potential candidates for future crop improvement. This information can be considered for upcoming research intended to improve the yield of spider plant vegetables.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest

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