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Nutritional compound analysis and morphological characterization of spider plant (*Cleome gynandra*) - an African indigenous leafy vegetable

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ABSTRACT

Spider plant is among the important indigenous African leafy vegetables having the potential to contribute to food and nutritional security in sub-Saharan Africa. The main objective of this study was to quantify the mineral concentration, to identify and quantify glucosinolates and flavonoids in spider plant and further to characterize spider plant entries using important morphological traits. Thirty spider plant entries from different African countries, comprising of farmers' cultivars, gene bank accessions and advanced lines were grown in a field experiment and harvested for leaves, stems, flowers and siliques at different developmental stages. Five plant types based on the stem and petiole colorations were identified. Significant genotypic differences were shown for all the morphological traits except for 100 seed weight and silique weight. High mineral concentrations in the leaf tissue were observed especially for potassium, calcium, magnesium, phosphorus, iron, manganese and zinc. The aliphatic 3-hydroxypropyl glucosinolate was the main glucosinolate detected in all tissues with the highest concentrations in the reproductive organs. Glycosides of quercetin, kaempferol and isorhamnetin were the main flavonoids. Isorhamnetin glycosides were detected in trace amounts in both, leaves and inflorescences, while quercetin and kaempferol glycosides were the dominant flavonoids in the leaves and inflorescences, respectively. This knowledge of beneficial nutrient contents is an incentive for promoting spider plant consumption for improved human health while the morphological diversity analysis will be important for the further development of the spider plant germplasm.

1. Introduction

Spider plant (*Cleome gynandra* L. Briq), also known as cat's whisker or African cabbage belongs to the family *Cleomaceae* (Hall, Iltis, & Sytsma, 2004; Hall, Sytsma, & Iltis, 2002). It is among the main indigenous African leafy vegetables (HCDA, 2014) that form an important part of African traditional diets in the rural households where high levels of under-nutrition prevalence have been reported (FAO, 2010). These vegetables are also now popular in urban areas. Leaves, young shoots and sometimes inflorescences are consumed (Chweya & Nzava, 1997). Spider plant, like other African leafy vegetables, has been considered a seasonal food consumed mostly in periods of major food crop shortage or as supplements to major food crops in some parts of Africa (Tabuti, Dhillion, & Lye, 2004; van Rensburg et al., 2004). It has been reported to contain high levels of mineral elements such as calcium, iron, magnesium and zinc (Jinazali, Mtimuni, & Chilembwe, 2017; Nesamvuni, Steyn, & Potgieter, 2001; Odhav, Beekrum, Akula, & Baijnath, 2007). Furthermore, spider plant is adapted to tropical conditions, responds well to organic fertilizers and is able to tolerate biotic and abiotic stresses, is readily available as wild plant and does not require formal cultivation (Abukutsa-Onyango, 2007; Chweya & Nzava, 1997). Spider plant has also been used as traditional medicine to heal a range of ailments in different communities which include food poisoning, rheumatism, inflammation, toothache, headache, bacterial infections, snake bites among others (Chweya & Nzava, 1997; Meda, Bangou, Bakasso, Millogo-Rasolodimby, & Nacoulma, 2013; Mishra, Moharana, & Dash, 2011). These uses as traditional medicine hint at secondary plant metabolites that are health beneficial. Thus recently, interest has increased in the detailed analyses of secondary plant metabolites in African leafy vegetables (Neugart, Baldermann, Ngwene, Wesonga, & Schreiner, 2017). Cancer preventive potential of certain indigenous African leafy

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vegetable, e.g. Ethiopian Kale (*Brassica carinata*), has been reported (Odongo et al., 2017).

The most interesting secondary plant metabolites in spider plant are glucosinolates and flavonoids as recently demonstrated by Neugart et al. (2017). Glucosinolates are sulphur and nitrogen-containing secondary metabolites mainly in members of the order Brassicales (Hanschen, Lamy, Schreiner, & Rohn, 2014). They play a role in plant defense but are also known for their human health promoting properties depending on the hydrolysis products released following their hydrolysis by the plant's myrosinase enzyme (Latté, Appel, & Lampen, 2011).

Flavonoids are also a class of secondary metabolites in plants which have been described to have functions as antioxidants in higher plants experiencing environmental stress. They are the most common phenolic compounds in all plant parts, especially photosynthesizing cells, and flavonols are the most abundant in vegetables (Kumar & Pandey, 2013). Flavonoids act as growth regulators in plants and also combat oxidative stress in plants and humans (Agati, Azzarello, Pollastri, & Tattini, 2012). Flavonoids are health beneficial in several ways to humans due to their antioxidant, anti-inflammatory, anti-diabetic, antibacterial and sometimes even antiviral effects (Amić et al., 2017; Dueñas, Surco-Laos, González-Manzano, González-Paramás, & Santos-Buelga, 2011; Kumar & Pandey, 2013). Generally, spider plant contains high levels of total phenolic compound which are useful antioxidants (Chweya & Nzava, 1997; Kutsukutsa, Gasura, Mabasa, & Ngadze, 2014; Meda et al., 2013). Further knowledge of the qualitative composition and the contents of these health beneficial compounds in spider plant and other African leafy vegetables is necessary to serve as an incentive for greater consumption of these vegetables to promote healthy diets in the sub-Saharan population where the minimum daily intake recommended by WHO/FAO has not been reached (Ruel, Mino, & Smith, 2005).

Besides being cultivated for domestic consumption in home gardens and being collected from the wild, intercropping systems for large-scale production for urban markets is now taking ground since there is a growing demand for pro-health and micro-nutrient dense properties in food by consumers especially in the locally available vegetables (HCDA, 2014). However, poor seed quality and poorly performing farmers' cultivars are a major production constraint (Abukutsa-Onyango, 2007). Besides genetic diversity analyses (Omondi et al., 2017), morphological characterization of germplasm with diverse origin is, therefore, necessary to facilitate the development of superior and pure cultivars. Characterization will also help providing a basis for identifying cultivar-specific traits on nutrient and health protection.

Overall, the analysis of morphological diversity and nutrient content in local spider plant germplasm will be important to enable their exploitation to combat malnutrition and hunger and to deepen the limited knowledge on the secondary metabolites and their contribution to human health. Thus, the present study focuses on various spider plant entries from different African countries (i) to characterize them for important morphological and agronomic traits and (ii) to obtain detailed knowledge about the composition and concentration of potentially protective glucosinolates, flavonoids and mineral elements. Furthermore, (iii) the glucosinolate and flavonoid concentrations of different plant organs were compared, since previous studies on *Brassicaceae* have shown variations in concentration for different plant organs especially for glucosinolates (Brown, Tokuhisa, Reichelt, & Gershenzon, 2003; Sang, Minchinton, Johnstone, & Truscott, 1984; Velasco, Cartea, Gonzalez, Vilar, & Ordas, 2007; Yim et al., 2016).

2. Materials and methods

2.1. Plant materials

Thirty entries (Supplementary Table A1) consisting of 20 advanced lines and gene bank accessions from the World Vegetable Centre, Arusha, Tanzania, eight farmers' cultivars from Kenya and two advanced lines from Jomo Kenyatta University of Agriculture and Technology (JKUAT), Nairobi, Kenya, were used in this study.

A field experiment was carried out at the Jomo Kenyatta University of Agriculture, Juja, Kenya (S01°05.9′ E037°00.8, 1476 m a.s.l) between October 2015 and January 2016. A randomized block design with four blocks was used with each entry represented once in each block. Each entry was sown in four rows per plot with a spacing of 15 cm between rows in the same plot and 30 cm spacing between plots. Seeds were sown in double density and thinning was done approximately three weeks after seedling emergence. Well decomposed cow manure was applied to the rows and mixed with soil during sowing. Weeding was done manually throughout the experimental period. The experiment was conducted under rain fed conditions with supplemental overhead irrigation at least two times per week after planting until flower initiation.

2.2. Morphological characterization

For each entry, plants in the middle rows were randomly used for data collection. Qualitative traits assessed included stem and petiole coloration and were evaluated using 10 plants per accession in each block by recording the frequencies of plants with different stem and petiole colors.

Quantitative traits assessed included: germination percentage, days to 50% flowering, plant height, number of primary branches, 100 seeds weight, number of seeds per silique, total shoot fresh and dry mass as well as leaf fresh and dry mass. Field measurements and observations of traits were done on the same day to avoid any differences due to developmental stages of plants. Percentage germination was determined before thinning as the percentage of the seeds that were germinated based on the number of seeds that were sown for each entry. Days to flowering was recorded as the number of days from sowing to the date when approximately 50% of the plants in each plot flowered. Data for plant height and number of primary branches was taken just after the onset of flowering since the flower develops constantly and after flowering branching for more vegetative biomass production stops. Plant height was measured in centimeters from the base of the plant to the tip of the main stem using a meter rule by selecting ten plants at random from the inner rows of a plot. The number of primary branches was determined as the counts of branches at the main stem. The silique weight was calculated as the mean value of 50 pods harvested from ten plants of each entry for each block. A hundred seeds weight was calculated as the mean value of seeds from fifteen plants of each entry. Dry and fresh mass of the leaves were determined by pooling together twenty plants per plot after 7 weeks. The plants were cut at the base and the leaves separated from the stems.

Sampling for the glucosinolate, flavonoid and mineral concentration analyses was carried out between 09.00 a.m. and 12.00 a.m. in three stages (S1–S3), for the different plant organs: S1; the leaves and stems were collected before the start of the reproductive phase (23 days after sowing); S2, the flowers (36 days after sowing) and; S3, the siliques (63 days after sowing). Sampling was done for fifteen plants from each of the four blocks for each spider plant entry and finally pooled into two with each of the two pooled samples containing the plants from two blocks. In order to avoid degradation or losses in secondary metabolite contents due to microbial activity the samples were transferred immediately to the laboratory and stored at − 80 °C before freeze drying and later milling into powder. All following analyses were carried out on portions of the same homogenized samples for each of the spider plant entries.

2.3. Mineral analysis

Mineral element concentrations in the freeze dried material were

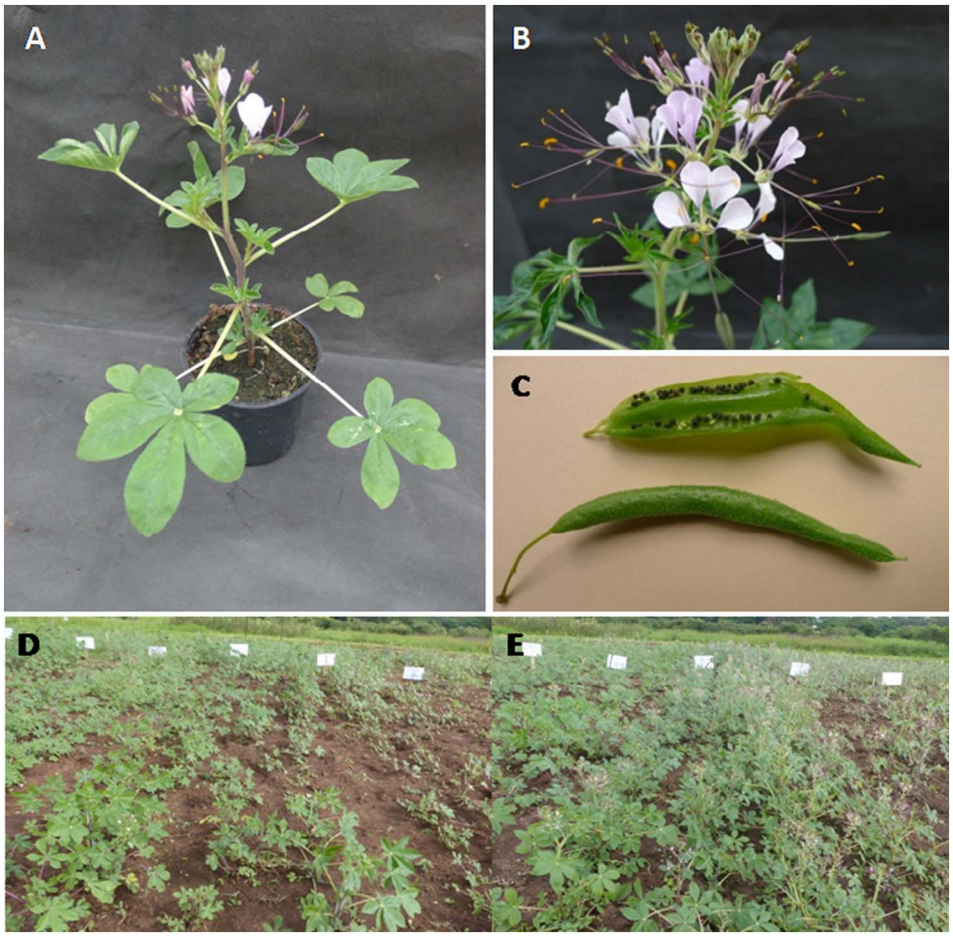


Fig. 1. *C. gynandra*, A - UGSF2 under greenhouse conditions at 5 weeks after sowing, B - close up of the characteristic flowers, C - siliques. D - entry Abuku2 under field conditions at 5 weeks and E - 7 weeks after sowing.

determined with an inductively coupled spectrophotometer (ICP-OES) after ashing at 450 °C for 8 h, and dissolving the ash in 1:3 diluted HNO_3 (Jones, 2001).

2.4. Glucosinolate analyses

The glucosinolate composition of the samples was determined as desulfo-glucosinolates, using a slightly modified method according to Wiesner, Hanschen, Schreiner, Glatt, and Zrenner (2013). The modifications were as follows: The various desulfo-glucosinolates were separated by a UHPLC-DAD device (UHPLC Agilent 1290 Infinity System, Agilent Technologies, Böblingen, Germany) equipped with a Poroshell 120 EC-C18 column of dimension 100 mm × 2.1 mm containing particles of size 2.7 µm (Agilent Technologies). The solvent gradient was formed by water (A) and 40% acetonitrile (B), starting at 0.5% B for 2 min, rising to 49.5% B over the next 10 min, then held for a further 2 min, increased to 99.5% B over the course of 1 min and finally held for a final 2 min. The flow rate was 0.4 mL min^{-1} and the injection volume 5 µL. Desulfo-glucosinolates were identified by comparing retention times and UV absorption spectra with those of known standards. Quantification was done at 229 nm using the response factor of the glucosinolates relative to 2-propenyl glucosinolate (external standard). Determination of glucosinolates was performed in duplicate.

2.5. Flavonoid analyses

Flavonoids were analyzed according to Schmidt et al. (2010) with slight modification. Lyophilized, ground plant material (0.02 g) was extracted with 600 µL of 60% aqueous methanol on a magnetic stirrer plate for 40 min at 20 °C. The extract was centrifuged at 3396 × *g* for 10 min at the same temperature, and the supernatant was collected in a reaction tube. This process was repeated twice with 300 µL of 60% aqueous methanol for 20 min and 10 min, respectively; the three corresponding supernatants were combined. The extract was subsequently evaporated until it was dry and was then suspended in 200 µL of 10% aqueous methanol. The extract was centrifuged at 1509 × *g* for 5 min at 20 °C through a Corning® Costar® Spin-X® plastic centrifuge tube filter (Sigma Aldrich Chemical Co., St. Louis, MO, USA) for the HPLC analysis. Each extraction was carried out in duplicate.

Flavonoid composition (including hydroxycinnamic acid derivatives and glycosides of flavonoids) and concentrations were determined from the filtrate using a series 1100 HPLC (Agilent Technologies, Waldbronn, Germany) equipped with a degaser, binary pump, autosampler, column oven, and photodiode array detector. An Ascentis® Express F5 column (150 mm × 4.6 mm, 5 µm, Supelco) was used to separate the compounds at a temperature of 25 °C. Eluent A was 0.5% acetic acid, and eluent B was 100% acetonitrile. The gradient used for eluent B was 5–12% (0–3 min), 12–25% (3–46 min), 25–90% (46–49.5 min), 90% isocratic (49.5–52 min), 90–5% (52–52.7 min), and 5% isocratic (52.7–59 min). The determination was conducted at a flow rate of 0.85 mL min^{-1} and a wavelength of 280 nm, 320 nm, 330 nm, 370 nm and 520 nm. The hydroxycinnamic acid derivatives and glycosides of flavonoids were tentatively identified as deprotonated molecular ions and characteristic mass fragment ions according to Schmidt et al. (2010) and Neugart, Rohn, and Schreiner (2015) by HPLC-DAD-ESI-MS^n using an Bruker amazon SL ion trap mass spectrometer in negative ionization mode. For the identification of the peaks the data were compared to the literature of the investigated species and their relatives. In the mass spectrometer, nitrogen was used as the dry gas (10 L min^{-1}, 325 °C) and the nebulizer gas (40 psi) with a capillary voltage of − 3500 V. Helium was used as the collision gas in the ion trap. The mass optimization for the ion optics of the mass spectrometer

for quercetin was performed at *m/z* 301 or arbitrarily at *m/z* 1000. The MS^n experiments were performed in auto up to MS^3 in a scan from *m/z* 200–2000. Standards (chlorogenic acid, quercertin 3-glucoside, kaempferol 3-glucoside and isorhamnetin-3-glucoside Roth, Karlsruhe, Germany) were used for external calibration curves in a semi-quantitative approach. Results are presented as mg g^{-1} dry weight.

2.6. Statistical analysis

The quantitative trait data was expressed as the mean ± standard deviation (SD) of at least four determinations. Statistical analysis (ANOVA with a statistical significance level set at $p < 0.05$ and means separated using Tukey test) was carried out using XLSTAT ver7.1. The nutritional compound data was also expressed as the mean ± standard deviation (SD) of two determinations. Due to the limited number of replicates ($n = 2$) statistical comparisons were not possible.

3. Results

3.1. Morphological characterization

Characteristics of spider plant, including the inflorescences, seeds and siliques and the field plots are shown in Fig. 1. Spider plant is characterized by polymorphism in hairiness and different colors of the stems and leaf petioles among genotypes. The three main color variations observed among the plants in each entry were purple, green and a mix of purple and green parts (Fig. 2). The stem color for all the entries was dominantly purple (above 70% of plants for each entry) except for Abuku1, Acc26, Acc28, Acc3, Acc30 and GS (Fig. 3). Entry PS had purely purple stems for all the plants assessed which suggests homogeneity with respect to this trait. A majority of the accessions showed leaves with green or purple petioles with few having petioles with a mix of green and purple. Acc28 contained plants with purely purple petioles while Acc6, IP7, HTT, MLSF12, MLSF17, MLSF27, RWSF2, Site 94, ST93-1(GS), ST73-3, UGSF19 and UGSF29 all showed over 70% of the plants having green petioles. The accessions with green petioles were mainly from Tanzania, Rwanda, Malawi and South Africa. Generally, the farmers' cultivars were composed of almost equal proportions of plants with different stem and petiole color variants, whereas the advanced lines and gene bank accessions were mainly dominated by purple stems and green petioles.

Mean values for the quantitative traits measured are shown in Table 1. Percentage germination for the accessions showed significant variation among the entries with an average of 53.4% and a range from 24% (GS) to 77.8% (Acc28). The average number of days to 50% flowering was 36.1 days and was significantly different ($p < 0.05$) among the entries with a range from 31 days for Abuku1 to 40 days for IP8. Number of seeds per silique also showed significant differences ($p < 0.05$) among the entries with a maximum of 199 seeds for Accession 21 and a minimal number of 133 seeds for Acc26. There were no significant differences for 100 seed weight for all the entries. A hundred seed weight ranged from 0.144 g to 0.171 g for Abuku1 and Acc20, respectively. Significant ($p < 0.05$) variation was observed for plant height among the accessions of this study ranging from 53.3 cm to 77.4 cm for entries UGSF2 and IP7, respectively.

Other traits included silique weight, primary branch number, leaf and total fresh and dry mass (see Supplementary Table S2). No significant differences were observed for silique weights ranging between 1.08 g for GS to 0.63 g for ST73-3 with an average of 0.8 g. Primary branch numbers ranged from 13.2 (entry IP7 and ST93-1(GS)) to 8.5 for Acc5.

Leaves are the edible parts of the spider plant. Stems are sometimes consumed together with the leaves, especially for tender young shoots. The average leaf fresh and dry mass per plant were 14.4 g and 2 g, respectively (Fig. 4). The leaf fresh mass per plant ranged from 9 g (Acc28) to 24.4 g (UGSF13). The dry mass per plant, on the other hand, ranged between 1.4 g (Acc28 and Acc5) and 3.7 g (RWSF2) (Fig. 4). Total plants fresh mass per plant ranged between 25.7 g and 70.4 g for Acc5 and Acc20, respectively, while total dry mass per plant ranged from 3.7 g to 12.7 g for Acc28 and Acc20, respectively (see Supplementary Table A2).

3.2. Mineral concentration

Mineral concentrations in leaves of the spider plant entries are shown in Table 2 for macro-elements, micro-elements, and potentially toxic elements. In average of all entries, the macro-element concentration in g kg^{-1} DW was 31 for K, 23 for Ca, 4.3 for Mg, 6.6 for P and 4.0 for S. The variability of macro-element concentrations among all entries as indicated by the standard deviation was lowest for Mg and highest for S. For all macro-elements except Ca, the concentrations of the two advanced lines from JKUAT (Abuku1 and Abuku2) were markedly higher than those of the farmer's cultivars and the entries from WorldVeg, whereas farmer's cultivars in average had similar concentrations as the entries from WorldVeg. There was considerable variance in macro-element concentrations within the entries from farmer's fields and WorldVeg. For example, Mg concentrations varied from 3.5 (Acc20) to 5.0 mg kg^{-1} DW (Acc3) for farmer's cultivars, and from 3.2 (RWSF3) to 5.0 mg kg^{-1} DW (IP12) for the entries from WorldVeg.

In average of all entries, the micro-element concentration in mg kg^{-1} DW was 3603 for Fe, 393 for Mn, 60 for Zn,13 for Cu, 2.5 for

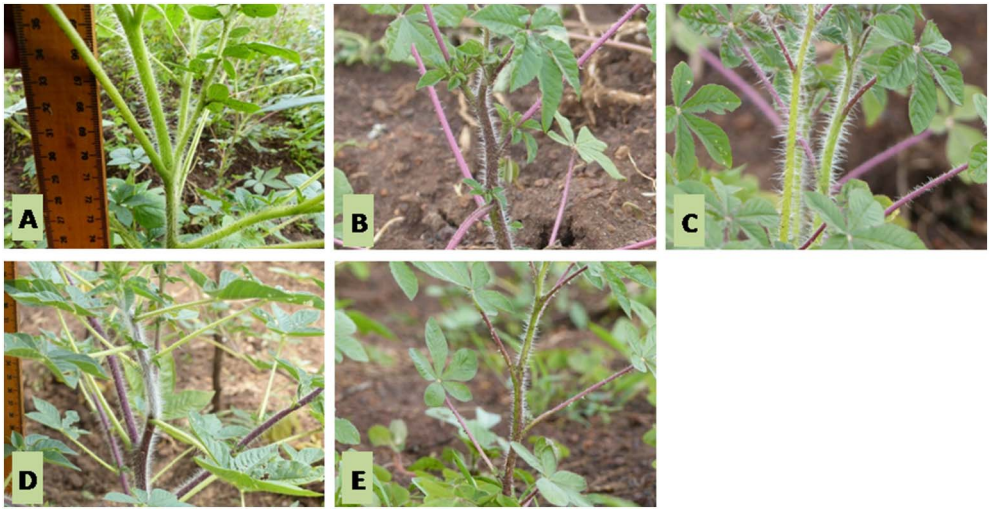


Fig. 2. Stem and petiole color variation in *C. gynandra* entries grown under field conditions. A - UGSF13, green stem/green petiole; B - Acc21, purple stem/purple petiole; C - green stem/purple petiole; D - UGSF29, purple stem/green petiole; E - Site94, purple/green.

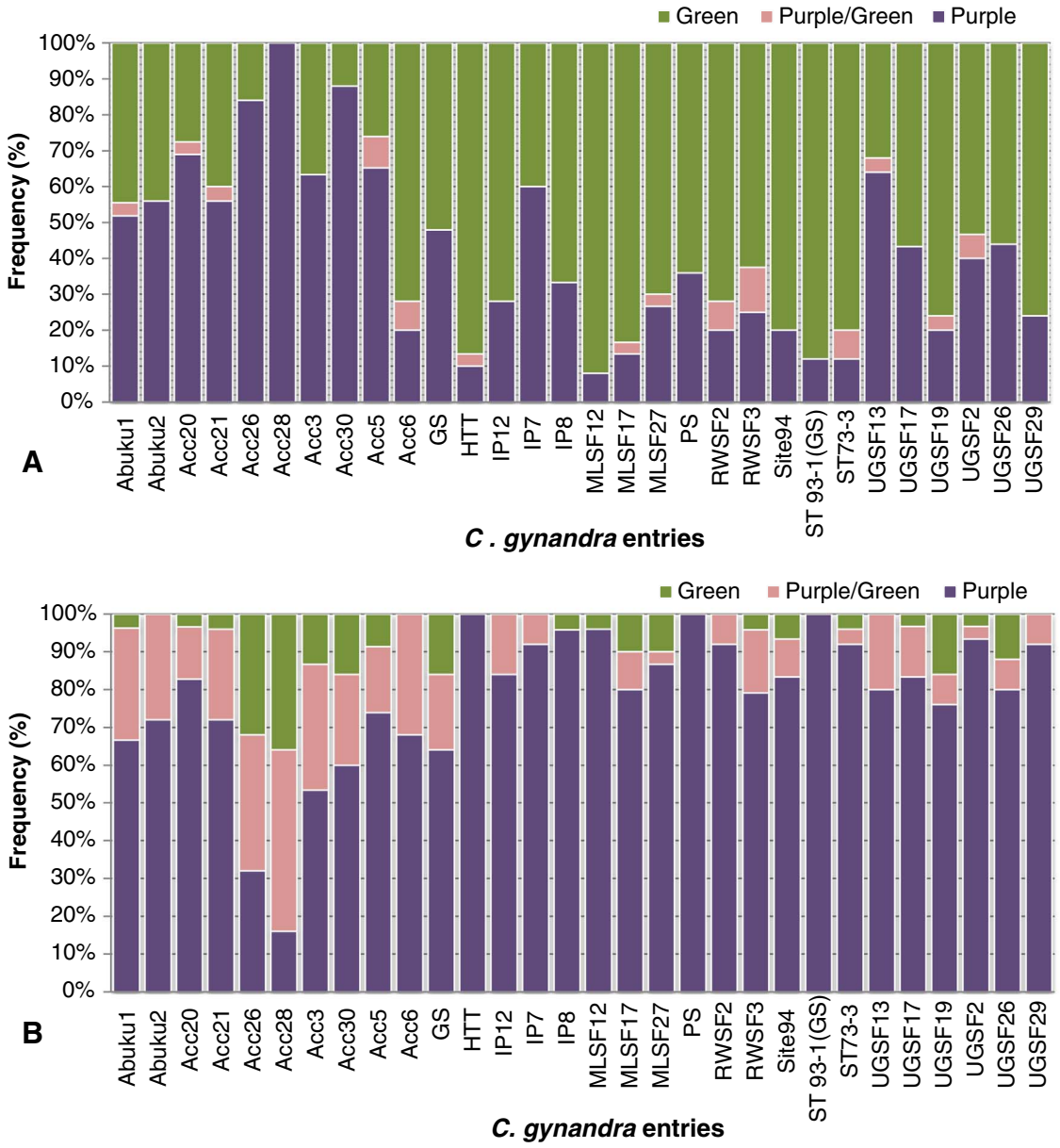


Fig. 3. Stem and petiole color variations within spider plant entries as shown in Fig. 2. A - percentage frequencies of petiole colors and B - percentage frequencies of stem color. $n = 28$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Ni, and 2.1 for Mo. The standard deviation of the mean of all entries, for all micro-elements except Zn was substantially larger than that for the macro-elements. The large standard deviations for the mean of the two analyses for each entry do not allow statements about differences in micro-element concentrations among the different origins (JKUAT, farmer's fields, WorldVeg). For Zn, there was considerable variance among entries, the concentrations varying from 44 (IP7) to 80 mg kg^{-1} DW for MLSF17 and ST93-I(GS).

In average of all entries, the concentrations of potentially toxic elements in mg kg^{-1} DW were 5.1 for Cr, 0.30 for Cd, 3.1 for Pb and 2952 for Al. The standard deviation of the mean of all entries for the toxic elements except Cd was substantially larger than that for the macro-elements. The large standard deviations for the mean of the two analyses for each entry do not allow statements about differences in toxic element concentrations among the different origins (JKUAT, farmer's fields, WorldVeg). There was considerable variance for Cd among entries with concentrations varying from 0.21 (Acc20) to 0.42 mg kg^{-1} DW (UG SF 13).

3.3. Glucosinolates

The aliphatic 3-hydroxypropyl glucosinolate – as predominate glucosinolate in spider plant - was quantitatively determined at all plant organs, especially in the siliques and inflorescences in nearly all investigated entries (Table 3). Also the aliphatic 2-propenyl glucosinolate was assessed, but only in the leaves of one entry (PS) and as a minor glucosinolate (Table 3). In addition, indole glucosinolates were quantitatively measured. The group of indole glucosinolates comprised the indole 3-indolylmethyl glucosinolate and its derivative 4-hydroxy-3-indolylmethyl, but only in trace concentrations (Supplementary Table A3).

The mean values for glucosinolates are presented in Table 3. The 3-hydroxypropyl glucosinolate concentrations varied in different plant organs from 7.8 µmol g^{-1} DW in the leaves to 37.1 µmol g^{-1} DW in the inflorescences. The stems and the siliques had mean values of 19 µmol g^{-1} DW and 19.3 µmol g^{-1} DW, respectively. Acc20 showed the highest 3-hydroxypropyl glucosinolate concentration in leaves at 11 µmol g^{-1} DW of all entries, while ST93-1(GS) had the lowest at

Table 1
Five morphological traits of 30 entries of *C. gynandra*.

Entry	Germination (%)	Days to 50% flowering	No. of seeds/ silique	100 seed weight (g)	Plant height (cm)
Abuku1	71.3^{ab}	31.0^{j}	151.6^{bc}	0.144^{a}	66.1^{abcde}
Abuku2	69.2^{ab}c	33.8^{hij}	149.0^{bc}	0.146^{a}	60.3^{bcde}
Acc20	72.5^{ab}	35.5^{efghi}	163.7^{abc}	0.171^{a}	66.0^{abcde}
Acc21	36.9^{gh}	39.3^{ab}	199.0^{a}	0.157^{a}	58.8^{cde}
Acc26	73.4^{ab}	35.3^{efghi}	133.9^{c}	0.153^{a}	76.4^{a}
Acc28	77.8^{a}	35.3^{efghi}	157.4^{abc}	0.155^{a}	76.6^{a}
Acc3	72.2^{abcd}	35.8^{defgh}	134.4^{c}	0.151^{a}	60.0^{bcde}
Acc30	60.4^{abcde}	35.5^{efghi}	157.4^{abc}	0.153^{a}	61.2^{bcde}
Acc5	71.5^{ab}	34.5^{fghi}	147.0^{bc}	0.154^{a}	56.2^{de}
Acc6	69.7^{ab}	35.3^{efghi}	152.8^{abc}	0.159^{a}	58.9^{cde}
GS	24.0^{i}	34.5^{fghi}	182.9^{ab}	0.170^{a}	64.7^{abcde}
HTT	41.7^{efg}	34.5^{fghi}	157.8^{abc}	0.145^{a}	66.8^{abcde}
IP12	57.3^{abcdef}	32.8^{ij}	167.5^{abc}	0.155^{a}	74.7^{ab}
IP7	51.6^{bcdefg}	36.8^{bcdefg}	167.0^{abc}	0.159^{a}	77.4^{a}
IP8	56.8^{abcdef}	40.0^{a}	154.6^{abc}	0.146^{a}	76.2^{a}
MLSF12	54.2^{abcdefg}	39.0^{abc}	164.3^{abc}	0.164^{a}	76.4^{a}
MLSF17	47.3^{cdefg}	38.8^{abcd}	137.4^{c}	0.153^{a}	64.1^{abcde}
MLSF27	68.3^{abc}	34.3^{ghi}	170.1^{abc}	0.160^{a}	71.1^{abc}
PS	66.8^{abcd}	35.5^{efghi}	153.9^{bc}	0.158^{a}	70.0^{abcd}
RWSF2	36.5^{gh}	33.3^{hij}	144.0^{bc}	0.155^{a}	70.3^{abcd}
RWSF3	39.7^{fg}	39.3^{ab}	164.7^{abc}	0.158^{a}	64.3^{abcde}
Site 94	63.3^{abcd}	34.5^{fghi}	164.0^{abc}	0.146^{a}	58.7^{cde}
ST73-3	51.7^{bcdefg}	38.8^{abcd}	134.2^{c}	0.155^{a}	71.4^{abc}
ST93-1 (GS)	54.2^{abcdefg}	36.0^{cdefgh}	156.8^{bc}	0.157^{a}	77.0^{a}
UGSF13	25.0^{hi}	36.8^{bcdefg}	179.9^{ab}	0.151^{a}	68.8^{abcd}
UGSF17	46.3^{efg}	35.0^{fghi}	183.1^{ab}	0.153^{a}	57.8^{cde}
UGSF19	54.1^{abcdefg}	38.3^{abcde}	144.6^{bc}	0.153^{a}	74.5^{ab}
UGSF2	40.7^{fg}	37.5^{abcdef}	144.0^{c}	0.167^{a}	53.3^{e}
UGSF26	46.3^{defg}	38.8^{abcd}	144.8^{c}	0.167^{a}	60.1^{bcde}
UGSF29	51.4^{bcdefg}	36.8^{bcdefg}	181.1^{a}	0.151^{a}	61.0^{bcde}

Given are means of $n = 4$ replicates. Mean values within columns indicated by the same letter are not significantly different according to the Tukey test employing all pair-wise comparisons of the 30 entries ($p \leq 0.05$). Cells with the minimum and maximum values within a column are highlighted by green and yellow color, respectively.

5.1 μmol g^{-1} DW. The 3-hydroxypropyl glucosinolate concentration in stems ranged between 11.5 μmol g^{-1} DW (IP12) and 27.4 μmol g^{-1} DW (UGSF17); between 11.7 μmol g^{-1} DW (Acc26) and 85.3 μmolg^{-1} DW (MLSF17) in inflorescences and between 12.6 μmol g^{-1} DW (Acc26) and 27.5 μmol g^{-1} DW (RWSF2) in siliques. Generally, 3-hydroxypropyl glucosinolate was most abundant in the inflorescences and lowest in the leaves, while the stems and the inflorescences were comparable in amounts for most of the entries.

3.4. Flavonoids

Flavonoid contents in leaves and flowers of the spider plant entries are shown in Fig. 5. The flavonols detected in both, leaves and flowers, were glycosides of quercetin, kaempferol and isorhamnetin. In the leaves, quercetin glycosides were the most abundant compounds and followed by kaempferol and isorhamnetin glycosides in traces. The total leaf flavonoid content among the spider plant entries ranged between

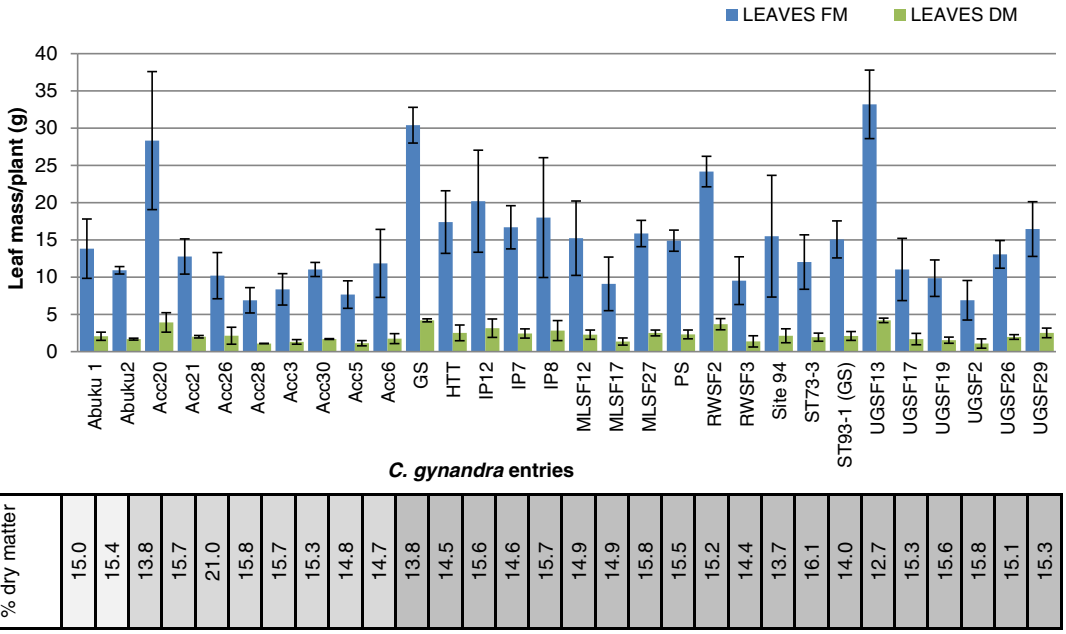


Fig. 4. Leaf fresh and dry mass with percentage of dry matter of *C. gynandra* entries grown in the field. $n = 4$. Results of the statistical analysis are presented in Supplementary Table S2.

Table 2
Mineral concentrations in dry mass of leaves from selected *C. gynandra* entries.

Entry	Macro-elements (g kg^{-1} DW)					Micro-elements (mg kg^{-1} DW)						Potentially toxic elements (mg kg^{-1} DW)			
	K	Ca	Mg	P	S	Fe	Mn	Zn	Cu	Ni	Mo	Cr	Cd	Pb	Al
Abuku1	37±0.4	22±1.8	5±0.1	9±0.6	5±0.9	3457±177	372±18	53±4	10±2	2.3±0.2	0.8±0.0	6.0±0.9	0.30±0.01	1.9±0.3	3081±23
Abuku2	39±0.8	23±0.4	5±0.1	7±0.0	6±0.2	5420±316	542±9	61±6	10±0.2	3.0±0.3	0.7±0.1	6.4±2.3	0.41±0.04	2.9±0.2	4989±337
Acc20	28±1.8	22±0.8	4±0.1	7±0.5	4±0.3	2384±1112	246±73	54±2	10±0.4	1.4±0.2	1.1±0.1	2.7±1.2	0.21±0.00	2.4±0.5	2114±971
Acc21	32±5.4	24±0.5	5±0.5	7±0.1	4±0.4	4089±172	476±35	52±0.2	17±4	2.9±1.4	2.1±1.2	4.9±0.6	0.31±0.08	3.4±1.0	3492±188
Acc26	28±1.1	24±2.7	4±0.6	7±1.3	3±0.1	5601±4690	481±338	58±16	9±0.9	3.3±3.1	3.5±0.6	8.2±7.7	0.28±0.16	3.8±2.5	3536±2224
Acc28	28±1.5	25±1.4	4±0.7	6±0.4	4±0.3	2330±974	302±76	52±4	11±2	1.4±0.2	2.4±1.5	2.9±0.3	0.26±0.01	2.1±0.8	1851±834
Acc3	31±1.4	24±2.4	5±0.4	6±1.5	4±0.6	4366±523	465±71	53±3	23±13	2.9±0.3	0.9±0.4	5.8±1.5	0.42±0.04	3.6±1.1	3880±250
Acc30	30±0.7	23±3.8	4±1.1	6±0.2	3±0.2	4980±869	540±70	49±10	10±3	2.7±0.1	3.8±3.2	6.3±0.7	0.36±0.03	3.4±0.5	4038±249
Acc5	32±0.9	26±1.9	5±0.3	7±0.4	3±0.7	2532±50	309±3	67±24	10±1	1.3±0.5	3.1±2.5	3.4±0.1	0.22±0.00	2.1±0.4	2138±71
Acc6	29±3.3	23±5.9	4±1.5	6±1.9	4±0.8	4409±1491	439±137	54±9	14±6	2.1±0.1	2.0±0.2	6.7±0.9	0.26±0.03	3.6±1.3	3609±910
IP12	33±1.9	22±0.2	5±0.1	8±0.2	4±0.1	4728±373	525±57	62 ±2	n.a.	3.4±0.9	1.1±0.2	8.5±5.0	0.31±0.01	10.8±4.1	3901±100
IP7	27±0.7	22±0.3	4±0.1	5±0.2	4±0.8	1336±18	185±10	44±4	9±0.3	1.9±0.6	1.7±0.7	1.9±0.1	0.34±0.17	1.3±0.04	1096±35
IP8	32±3.2	24±1.1	5±0.0	6±0.2	4±0.3	2132±241	305±27	63±3	26±8	1.8±0.2	0.8±0.2	3.9±0.8	0.27±0.01	3.1±0.3	1722±254
MLSF17	33±5.2	23±0.4	5±0.0	8±0.1	4±0.4	3334±625	416±95	80±13	20±12	2.7±1.3	2.7±2.6	4.4±0.1	0.26±0.06	2.8±1.5	2825±465
MLSF27	27±3.6	23±0.5	4±0.6	6±0.8	4±0.0	2008±776	210±29	57±11	10±3	1.5±0.4	1.0±0.2	2.6±0.2	0.27±0.08	1.7±0.3	1771±726
PS	30±3.9	26±2.1	4±0.8	6±1.8	4±0.2	3399±62	391±31	74±33	n.a.	3.3±2.3	2.8±0.6	5.3±2.3	0.29±0.16	n.a.	2719±271
RWSF3	28±4.3	19±0.6	3±0.0	6±0.7	4±0.3	5892±3476	400±183	56±8	11±3	2.3±0.9	1.2±0.2	5.6±2.2	0.27±0.10	3.3±0.7	3608±854
Site94	34±4.0	23±1.8	5±0.1	7±0.7	3±0.4	5857±1572	662±205	72±23	19±3	3.1±0.1	3.1±2.5	6.9±0.3	0.30±0.02	3.9±1.0	4917±1023
ST73-3	33±2.5	22±1.1	4±0.4	7±0.6	4±0.7	2734±364	361±32	67±3	14±2	1.8±1.0	3.3±2.9	7.0±6.1	0.25±0.11	2.0±0.01	2178±366
ST93-1(GS)	38±1.9	21±1.1	4±0.1	7±0.2	4±0.2	3788±393	431±36	80±30	n.a.	3.9±1.5	0.8±0.0	7.8±4.8	0.37±0.08	n.a.	3289±352
UG SF 13	29±0.4	23±2.2	5±1.1	6±1.2	5±0.2	5455±3014	552±196	64±0.2	12±0.6	4.2±1.3	0.9±0.4	6.0±3.9	0.42±0.06	3.5±1.8	5224±3086
UG SF 19	33±1.3	22±1.2	4±0.7	7±1.4	4±0.1	2521±108	313±30	47±8	9±2	3.6±3.2	1.9±0.8	4.0±2.0	0.24±0.04	1.8±0.1	2006±286
UG SF 2	31±6.5	23±0.6	4±0.2	6±1.4	4±0.2	2693±15	342±14	52±2	24±18	1.9±0.6	2.4±1.9	3.5±0.6	0.25±0.09	3.7±1.1	2128±8
UG SF 29	29±2.1	28±2.1	4±0.1	7±0.0	5±0.1	1036±98	161±5	76±6	8±0.3	0.6±0.1	6.1±0.1	1.4±0.2	0.24±0.02	1.5±0.6	735±98
Mean	**31**	**23**	**4**	**7**	**4**	**3603**	**393**	**60**	**14**	**2.5**	**2.1**	**5.1**	**0.30**	**3.1**	**2952**
SD	**3.3**	**1.8**	**0.6**	**0.9**	**0.7**	**1464**	**127**	**10**	**5.5**	**0.9**	**1.3**	**2.0**	**0.1**	**1.9**	**1213**

Given are means ± SD. $n = 2$ biological replicates. n.a. = not analyzed. Cells with the minimum and maximum values within a column are highlighted by green and yellow color, respectively. The three gray scales represent the source of the seeds used as JKUAT, farmers' cultivars and WorldVeg respectively.

2.2 mg g^{-1} DW (MLSF27) and 12.5 mg g^{-1} DW (MLSF17). With respect to the type of flavonols detected, quercetin glycoside content ranged from 2.12 mg g^{-1} DW (MLSF27) to 12.19 mg g^{-1} DW (MLSF17); isorhamnetin glycosides ranged from 0.04 mg g^{-1} DW (MLSF27) to 0.41 mg g^{-1} DW (Abuku1); and kaempferol glycosides ranged between 0.00 mg g^{-1} DW (Acc26 and Acc30) and 0.47 mg g^{-1} DW (Abuku1).

In more details, the main glycosides of quercetin, kaempferol and isorhamnetin were diglucosides and rutinosides (Fig. 6). In leaves, quercetin-3-diglucoside was the main compounds except for Abuku1 in which quercetin-3-rutinoside (rutin) was the main quercetin glycoside. The corresponding kaempferol glycosides were present in 17 of the 19 entries analyzed with kaempferol-3-diglucoside as main compound whereas for isorhamnetin glycosides, mainly isorhamnetin-3-rutinoside was found the in spider plant entries (Fig. 6).

Unlike the leaves, kaempferol glycosides were the most abundant flavonoids while isorhamnetin glycosides being the least in the flower tissue (Fig. 5B). Total flavonoids in flowers of spider plant varied between 4.3 mg g^{-1} DW (Acc20) and 12.22 mg g^{-1} DW (MLSF17). The single flavonoids were represented among the entries analyzed as follows: kaempferol glycosides ranged between 3.46 mg g^{-1} DW (Acc20) and 8.75 mg g^{-1} DW (UGSF26); quercetin ranged between 0.13 mg g^{-1} DW (Abuku1) and 4.6 mg g^{-1} DW (Acc5); and isorhamnetin ranged between 0.03 mg g^{-1} DW (Acc21) and 0.52 mg g^{-1} DW (Acc 5).

4. Discussion

4.1. Phenotypic characterization

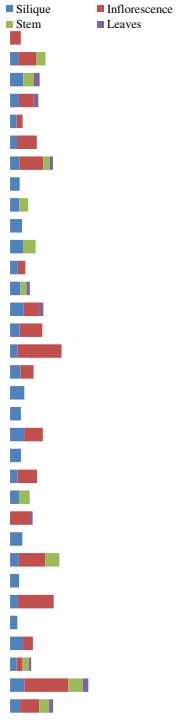
Spider plant germplasm is continuously collected from farm populations and from the wild and transferred to the gene banks and institutions for propagation and development. Morphological characterization in spider plants is important for proper systematic identification of traits to presumably categorize this germplasm into similar groups and to describe morphological diversity to enable exploitation in genetic development programs. Our findings here show a mix of plant types with regard to stem and petiole colors (Fig. 2), an observation also made in previous studies including spider plant germplasm from different sites and populations (K'Opondo, 2011; Stoilova, Dinssa, Ebert, & Tenkouano, 2015; Wasonga, Ambuko, Chemining'wa, Odeny, & Crampton, 2015). The coloration is due to anthocyanins accumulation (Chalker-Scott, 1999). These anthocyanins are sometimes stress indicators in response to environmental stressors such as strong light, temperature extremes, drought, nitrogen and phosphorus deficiencies (Chalker-Scott, 1999; Hatier & Gould, 2009), but they are also attractants for insect pollinators (Dasgupta & De, 2007). The farmer's cultivars show more variations in the color pigmentation than the gene bank accessions and the advanced lines indicating more diversity among the farm collections (Fig. 3).

The results for most of the quantitative traits in this study are comparable to results from other studies (Onyango, Onwonga, & Kimenju, 2016; Stoilova et al., 2015; Wasonga et al., 2015). Germination percentage number of seeds per silique were higher than those reported by Onyango et al. (2016). This might be explained by favorable environmental conditions, since temperature ranges of 20–30 °C and darkness are optimal for spider plant germination (K'Opondo, Muasya, & Kiplagat, 2005). Poorly germinating entries resulted in weaker plants and poor yield, strongly pointing to the importance of high quality seed.

The period between sowing and flowering significantly limits leaf productivity and yield (Ojiewo, Mwai, Abukutsa-Onyango,

Table 3
Contents of 3-hydroxypropyl glucosinolate (μmol g^{-1} dry weight) in various organs of selected *C. gynandra* entries.

Accession	Silique	Inflorescence	Stem	Leaves
Abuku1	n.a	20.7±10.8	n.a.	n.a.
Abuku2	15.7±1.6	35.6±18.3	17.2±5.2	n.a.
Acc20	25.7±2.4	n.a.	20.5±1.2	11.0±1.6
Acc21	17.1±11.5	28.7±3.8	n.a.	8.9±2.1
Acc26	12.6±7.3	11.7±0.4	n.a.	n.a.
Acc28	13.4±6.1	38.2±25.3	n.a.	n.a.
Acc 3	17.8±7.7	46.1±26.0	12.7±1.4	6.3±1.5
Acc30	18.5±1.0	n.a.	n.a.	n.a.
Acc5	18.1±2.0	n.a.	17.0±1.7	n.a.
Acc6	23.2±0.7	n.a.	n.a.	n.a.
GS	24.9±2.0	n.a.	24.5±2.9	n.a.
HTT	15.0±3.0	14.4±9.8	n.a.	n.a.
IP12	20.0±3.7	n.a.	11.5±3.7	6.9±2.9
IP7	27.2±13.9	36.0±1.4	n.a.	n.a.
IP8	26.4±7.9	29.3±3.2	n.a.	8.6±2.1
MLSF12	18.2±8.0	44.0±19.1	n.a.	n.a.
MLSF17	14.1±5.4	85.3±18.4	n.a.	n.a.
MLSF27	20.0±5.8	25.5±14.6	n.a.	n.a.
PS	21.1±0.6	n.a.	n.a.	n.a.
RWSF2	27.5±9.9	n.a.	n.a.	n.a.
RWSF3	21.0±4.8	n.a.	n.a.	n.a.
Site94	14.4±3.4	37.6±0.4	n.a.	n.a.
ST73-3	17.1±6.0	n.a.	20.9±1.0	n.a.
ST93-1(GS)	n.a.	38.5±0.4	n.a.	5.1±1.5
UGSF13	23.8±7.8	n.a.	n.a.	n.a.
UGSF17	16.9±10.6	51.1±24.7	27.4±1.9	n.a.
UGSF19	17.4±1.1	n.a.	n.a.	n.a.
UGSF2	15.1±2.6	69.1±19.0	n.a.	n.a.
UGSF26	14.0±3.3	n.a.	n.a.	n.a.
UGSF29	25.1±4.1	19.1±5.4	n.a.	n.a.
Min	**12.6**	**11.7**	**11.5**	**5.1**
Max	**27.5**	**85.3**	**27.4**	**11**
Mean	**19.3**	**37.1**	**19**	**7.8**



Given are mean ± SD. $n = 2$. n.a. = samples could not be analyzed in at least one replicate.
The three gray scales represent the source of the seeds used as JKUAT, farmers' cultivars and WorldVeg respectively.

Agong, & Nono-Womdim, 2013). Late flowering is, therefore, an advantage since late flowering allows a prolonged period of harvesting. Flower removal as soon they appear has been suggested to increase leaf yield and longer periods of harvesting (Ojiewo et al., 2013; Wangolo, Onyango, Gachene, & Mong'are, 2015). Leaf yield per plant in the present study (14.11 g) was much lower compared to 135.65 g reported by Stoilova et al. (2015) who carried out three successive harvests.

The number of seeds per silique is important for seed production while 100 seed weight is a criterion for seed quality determination since seed mass affects seed germination and emergence (Li, Lu, Yang, Kong, & Deng, 2015). A higher number of seed per silique and higher seed mass are preferred for commercial seed production because the seeds are sold by weight.

4.2. Mineral concentration

Mineral elements are essential for normal and healthy growth and development in both children and adults (FAO/WHO, 2004). This study is the first dealing mineral analyses in a wide range of spider plant genotypes with different genetic backgrounds. The spider plant entries were rich in potassium, calcium, magnesium, phosphorus, iron, manganese and zinc which were also comparable to the levels previously reported for *Cleome* species for some of the elements (Jinazali et al., 2017; Odhav et al., 2007) (see Supplementary Table A5 for a comparison of our data to previously published data). However, higher Fe and Cr concentrations were realized in this study and this could be attributed to surface contamination by dust (soil), as also indicated by the high Al concentrations since Al transfer from the roots to shoots in plants is usually negligible in herbaceous species except for Al accumulators (Klug, Kirchner, & Horst, 2015; Metali, Salim, & Burslem, 2012). A strong correlation for the three elements (Fe, Al and Cr) (Supplementary Table A4) may further point to contamination as a source of their elevation.

Minerals concentrations in the edible leaf portions of spider plant are mainly dependent on the soil mineral concentrations. Various mineral concentrations could be altered by different fertilizer applications, for instance, increased calcium ammonia nitrate fertilizer enhanced calcium in spider plant (Hutchinson, 2011). Our results showed higher amounts for lead and cadmium exceeding the allowable limits of 0.30 mg kg^{-1} and 0.20 mg kg^{-1} respectively in leafy vegetables (Commission Regulation No 629/2008, 2008). The bioavailability of mineral nutrients in these vegetables remains a challenge considering that some traditional methods of cooking involve boiling to eliminate bitter taste and most of these minerals leach to the cooking water which is normally discarded (Hutchinson, 2011; Mziray, 1999).

In order to make use of the variation detected in mineral concentrations for the different entries in future breeding programs, in-depth analyses of single genotypes, preferably under different nutrient supplies, would be the first step, followed by investigations in progenies of genotypes with high and low concentrations of the most relevant nutrients.

4.3. Glucosinolates

Cleomeaceae family, to which spider plant belongs, is a family of the overall order Brassicales (Hanschen et al., 2014). The present study shows 3-hydroxypropyl glucosinolate as the main glucosinolate present in the selected spider plant entries, but the aliphatic methyl glucosinolate (glucocapparin), the 2-hydroxy-2-methylbutyl glucosinolate (glucocleomin) and the methyl glucosinolate have also been previously identified in the genus *Cleome* (Abdullah, Elsayed, Abdelshafeek, Nazif, & Singab, 2016; Neugart et al., 2017; Songsak & Lockwood, 2002). The health-promoting effects of *Cleome* has recently been studied suggesting to be partly effective against malaria, tuberculosis,

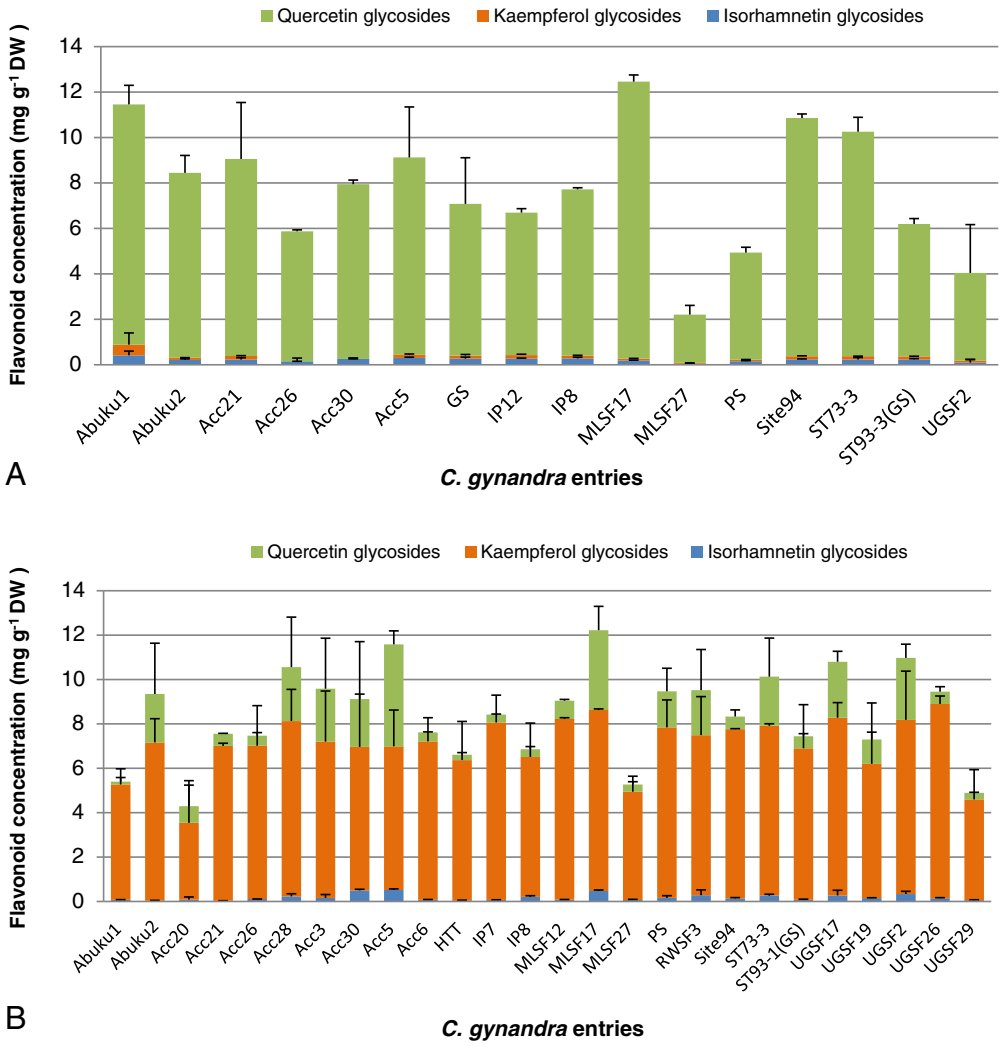


Fig. 5. Flavonoids in A - leaves and B - flowers from selected *C. gynandra* entries. Whiskers indicate standard deviations. $n = 2$.

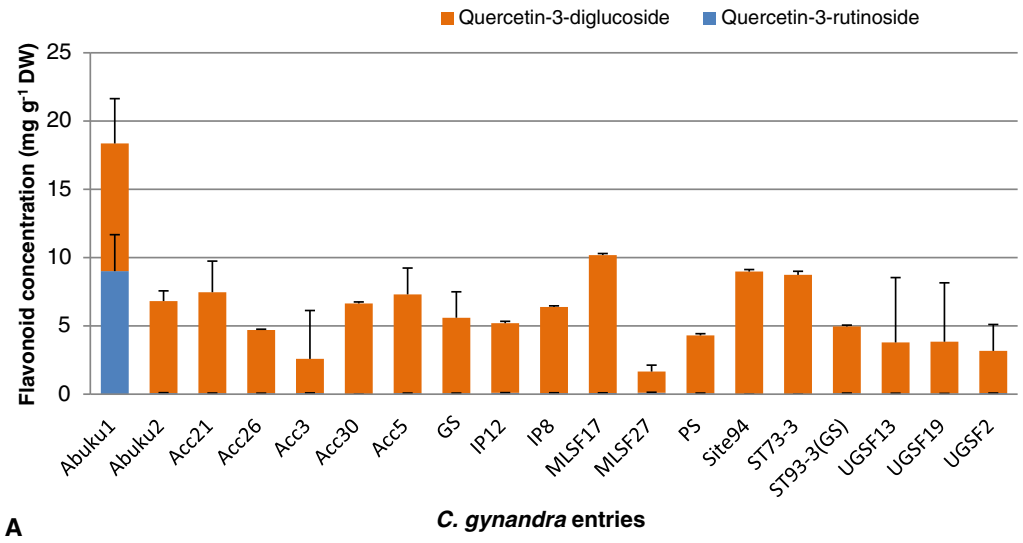
pneumonia and fungal skin infection (Chinsembu, 2016) that might be also induced by its glucosinolates and their corresponding hydrolyses products.

Our preliminary glucosinolate quantification for the same spider plant entries grown in the greenhouse or in the field (Supplementary Table A3) generally indicated higher amounts of total glucosinolates and indole glucosinolates of the field-grown plants which might be due to the different climate conditions, e.g. higher irradiation intensities especially of UVB radiation (Mewis et al., 2012) (Table 3). The indole glucosinolates identified in greenhouse-grown plants were 3-indolylmethyl glucosinolate and its hydroxylated derivative 4-hydroxy-3-indolylmethyl glucosinolate (Supplementary Table A3) indicating that in spider plant indole glucosinolate biosynthesis is strongly environmentally regulated as demonstrated in other Brassicales (e.g. Verkerk et al., 2009).

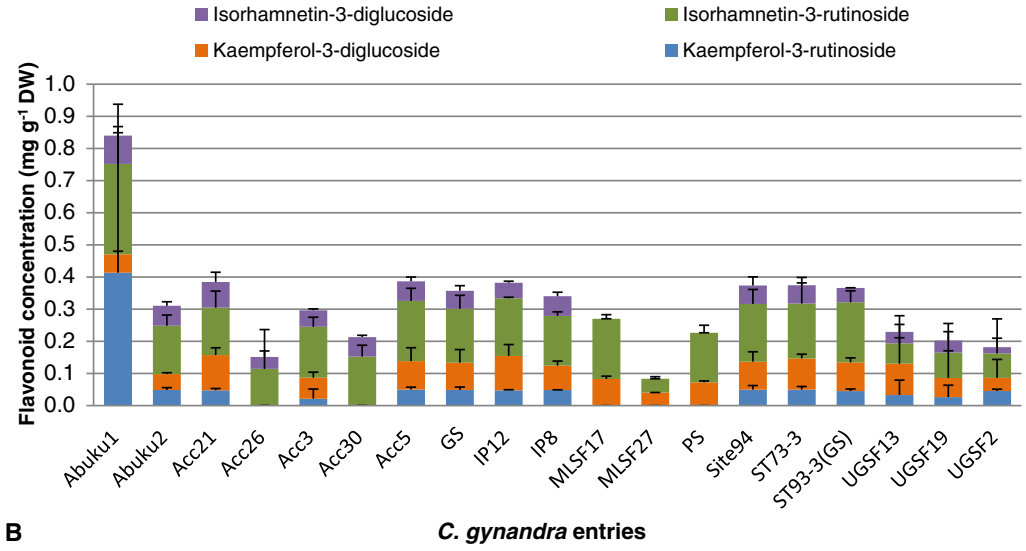
The glucosinolate concentrations among the selected entries were different and most likely due to genotypic effects. However, the standard deviations point to variation among the biological replicates clearly indicating the need for further analyses employing more biological replicates to allow detailed statistical analyses. The total glucosinolate concentration was lowest in leaves and highest in the inflorescences in the present study (Table 3). This is in agreement with previous studies that have demonstrated glucosinolate transport through the phloem from the mature leaves to floral tissues and fruits (Chen, Petersen, Olsen, Schulz, & Halkier, 2001). The reproductive organs can also synthesize additional glucosinolates (Reintanz, 2001). High glucosinolate concentrations in reproductive organs (seeds, inflorescences and fruits) is predicted to be for maximum defense since these organs contribute most to plant fitness (Brown et al., 2002).

4.4. Flavonoids

The major flavonoids identified in spider plant were glycosides of the flavonols kaempferol, quercetin and isorhamnetin. These are generally the main flavonoids in food plants. Comparable concentrations to our results were reported for kale (*Brassica oleracea* var. *sabellica*) that ranged between 6.0 and 14.8 mg g^{-1} DW (Schmidt et al., 2010). Differences in the concentration of these flavonoids in leaf and floral tissues were observed. Quercetin glycosides were dominant in the leaves with rutin as main compound in most genotypes while kaempferol glycosides were dominant in the flowers. These variations in quantities of the flavonols in the different plant parts could be explained by the fact that kaempferol is a precursor to quercetin while isorhamnetin is a methylated product of quercetin. A higher antioxidant activity for quercetin glycosides compared to kaempferol glycosides in curly kale reported by Zietz et al. (2010) could explain its high content in the photosynthetic tissues. No correlation was noted, however, for the flavonoid content in leaves and flowers for the specific entries. Important biological activities of flavonoids contributing to human health have been pointed out in several studies. An antioxidant effect of quercetin and kaempferol on the nasal mucosa, synergistic effects in reducing cell proliferation hence reducing the risk of cancer, and anti-inflammatory effects in microphages have been reported (Ackland, van de Waarsenburg, & Jones, 2005; Hämäläinen, Nieminen, Vuorela,



A



B

Fig. 6. Main glycosides of: A - quercetin; B - kaempferol and isorhamnetin in the leaves of *C. gynandra* entries. $n = 2$; given are means + SD.

Heinonen, & Moilanen, 2007; Lin et al., 2007; Reiter, Rupp, Baumeister, Zieger, & Harreus, 2009). Higher quercetin intake was associated with reduced mortality from ischemic heart diseases and protection for several types of cancers (Knekt et al., 2002), blood pressure reduction, vascular protective effect and improved vasodilator functions (Ibarra et al., 2003). Quercetin-3-rutinoside (rutin) is nowadays studied for its antioxidant, anti-inflammatory, anti-allergy, and anti-tumor activity (Habtemariam, 2016; Hosseinzadeh & Nassiri-Asl, 2014; Koval'skii et al., 2011). The other identified quercetin glycosides are rare and not yet studied but might also have an effect on the antioxidant activity of spider plant.

Flavonoid concentrations are affected by genetics, temperature and radiation as reported for kale (Schmidt et al., 2010). Species and cultivars usually show similar flavonoid profiles while differing in quantities (Krumbein, Saeger-Fink, & Schonhof, 2007). The entries in this study are of the same species and generally showed the same flavonoid profiles while differing in the concentrations. The farmers' accessions collected directly from the farmers and markets in Kenya did not show noticeable flavonoid profile variation compared to the rest of the entries sourced from the WorldVeg except for accession Abuku1 that showed unique profiles for the flavonoid glycosides (Fig. 6). This could be due to a genetic influence since the plants were grown in the same environmental condition. Higher concentrations of flavonoids have been associated with low temperatures leading to higher quantities of reactive oxygen species (Klimov et al., 2008) thereby necessitating an increase in antioxidants in the plant. Increased radiation also increases the flavonoid concentration since flavonoids are shielding components against radiation in plants (Neugart et al., 2012). No obvious correlation between flavonoid contents and coloration of stems and petioles was observed in the present study.

4.5. Conclusion

As main indigenous African leafy vegetables spider plant is rich in minerals, glucosinolates and flavonoids and hence can greately contibute to nutrition and health promotion in the diet particularly of African consumers in rural and urban areas. The concentrations of the glucosinolates and flavonoids vary in different plant organs and also among the selected entries analyzed. This study serves as a valuable knowledge base for improvement of the nutrient diets and food selection. Further in-depth analyses with a higher number of replicates and also single plant analyses to identify variarions between genotypes and accessions coupled with health/medical studies are needed before recommendations of specific entries for breeding focusing on enhancing these nutrients can be concluded. Our previous genetic diversity study of these entries (Omondi et al., 2017) and also the high variation within

entries regarding the morphological data presented in this study show a pronounce variability between the genotypes within the entries, thus demonstrating the great potential of spider plant as nutritious and protective food plant accompanied with a distinct environmental plasticity for growing also in marginal areas.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.foodres.2017.06.050.

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