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Review

Cleome gynandra L. origin, taxonomy and morphology: A review

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***Cleome gynandra* L. is one of the traditional leafy vegetables in Africa and Asia providing essential minerals and vitamins to the diet and income of resource poor communities. Despite these benefits, the crop has not been studied extensively resulting in lack of scientific information to guide crop improvement research and associated agronomic practices. The taxonomy of the crop, its reproductive behaviour, genome size, ploidy level and origin are neither readily available nor well understood. This paper reviews existing literatures in these areas to provide information for future research and development of the crop. Reading the review, one could appreciate the taxonomic classification of the genus is still under debate despite recent molecular studies that placed the crop in the Cleomaceae family as opposed to previous studies that classified it under Capparaceae family. According to present review the crop belongs to the Kingdom of Plantae, Phylum spermatophyta, Division Magnoliophyta, Class Magnoliopsida, Order Brassicales and the Family of Cleomaceae. Different genome sizes of *C. gynandra* have been reported which still warrant further investigation. Various studies reported different ploidy levels including diploid, triploid and polyploid indicating the need of further investigation to clarify the taxonomy, genome size and ploidy level(s) of the crop.**

Key words: Chromosome, genome size, indigenous leafy vegetables, morphology, ploidy level, spider plant.

INTRODUCTION

The species *Cleome gynandra* L. under the genus *Cleome* is believed to have originated in Africa and Asia, and is known by various common names; African spider-flower, African cabbage, cat's-whiskers, bastard-mustard, shona

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cabbage and spider plant in Africa. The synonyms of *C. gynandra* as reported by various studies (for example, Waithaka and Chweya, 1991; Chweya and Mnzava, 1997) include *Gynandropsis gynandra* (L.) Briq., *Cleome pentaphylla* L. and *Gynandropsis pentaphylla* (L.) DC.. This *Cleome* species share the common name “spider plant” with the ornamental plant known as *Chlorophytum comosum* (Thunb.) Jacq. which also originated in Africa but commonly known in Europe and the New World for its ornamental purpose. *Chlorophytum comosum* belongs to the family Anthericaceae/Asparagaceae (Poulsen and Nordal, 2005; Gudadhe et al., 2012). It is difficult to know how this name started, but it happens that the name spider plant is commonly known to mean *C. gynandra* among people involved in research and development of traditional African vegetables and has been used in many articles (Masinde et al., 2005; Abukutsa-Onyango, 2007; Ara et al., 2007; Edeoga et al., 2009; Nyalala et al., 2011). Therefore, whenever the name “spider plant” is mentioned in this paper it refers to *C. gynandra*. *C. gynandra* is one of several indigenous leafy vegetables with great potential for nutritional security and poverty alleviation because it is easy to grow in areas where cultivation of exotic vegetables is difficult, and is among the cheapest, most readily accessible sources of several essential nutrients (Kwenin et al., 2011). *C. gynandra* and other indigenous leafy vegetables have a short growth period and are ready for first harvest about 30 days after transplanting, usually within 3-5 weeks after sowing. They produce seed under tropical conditions and respond well to organic fertilizers, relatively tolerate biotic and abiotic stresses, and are acceptable to local tastes (Ekesa et al., 2009). These leafy vegetables tend to escape late emerging stresses due to their earliness to first harvest.

Despite the value of several indigenous orphan vegetables including *C. gynandra*, the crops have not been given priority in research and development by scientists, policy makers or funding agencies (Edeoga et al., 2009). As a result some indigenous vegetables, *C. gynandra* not an exception, are threatened with extinction (Adebooye and Opabode, 2004, Abukutsa-Onyango, 2007; Maroyi, 2011; Masayi and Netondo, 2012). It has been reported that indigenous leafy vegetables such as vine spinach (*Basella alba*)*,* yellow commelina/wandering jew (*Commelina Africana*), wild lettuce (*Launaea cornuta*) and wild simsim (*Sesamum calycinum*) in western Kenya are either lost or have become rare as compared to old days (Abukutsa-Onyango, 2007). A significant cultivation decline was also reported in vine/malabar spinach, (*Basella* spp.), *C. gynandra*, amaranth (*Amaranthus blitum*), amaranth/pigweed (*A. dubians),* African nightshade (*Solanum villosum*), Ethiopian kale (*Brassica carinata*)*,* cowpea (*Vigna unguiculata),* pumpkins (*Cucurbita moschata),* sunnhemp (*Crotalaria brevidens*) and jute mallow (*Corchorus olitorius*) in Mumias Division in Kenya during the period of 1970s to 2000s (Masayi and Nentondo, 2012). Due to the lack of scientific knowledge about indigenous vegetables, the importance and value of these crops are determined by local knowledge, cultures and economies, species availability, and the level of influence by exotic species as a substitute (Mibei et al., 2012). In most cases and in many areas, until very recently, indigenous leafy vegetables have been considered to be food of only resource-poor communities. *Cleome* species is found throughout the tropics and subtropics and is among the important species of indigenous leafy vegetables in many African countries, including Benin, Burkina Faso and Ghana in West Africa; Kenya, Uganda and Tanzania in East African, and South Africa, Namibia and Zimbabwe in Southern Africa (Mnzava and Chigumira, 2004; Masinde et al., 2005; Rensburg et al., 2007; Maroyi, 2011). It grows in a wide range of soils, from sandy to clay loam, provided the soil is deep and well drained with a pH of 5.5-7.0. Mostly, the crop thrives in soils with high organic matter and adequate mineral reserves. It grows wild, semi-wild, cultivated, or as a weed in crops on fertile well-manured soils (Mnzava and Chigumira, 2004; Rensburg et al., 2007; Maroyi, 2011). *Cleome* is reported to be well packaged with nutritional and medicinal uses, as well as phytochemical compounds that repel some insect pests (Chweya and Mnzava, 1997; Bala et al., 2010; Nyalala et al., 2011; Moyo et al., 2013; Pillai and Nair, 2013a).

Although there is inadequate information supporting the adaptive responses of the crop to drought, some reports have indicated that it is not tolerant to low moisture stress conditions (Masinde et al., 2005). Nevertheless, other published works indicated that the plant can tolerate drought spells and salt conditions to some extent (Rajendrudu and Rama Das, 1982; Kumar et al., 1984; Kulya et al., 2011), but generally it is sensitive to low soil moisture conditions that cause early flowering, maturity and senescence resulting in reduced leaf yield and quality (Mnzava and Chigumira, 2004; Rensburg et al., 2007). The crop is said to be insensitive to day length but sensitive to cold, and performs poorly under shaded conditions (Rensburg et al., 2007).

The placement of *C. gynandra* in the family Cleomaceae or Capparaceae and the recognition of Cleomaceae as a separate family are still debatable. Its breeding/reproductive behaviour, genome size, ploidy level, origin and ecology are not well understood. Recently the genus Cleome has attracted the attention of the scientific community because it contains both C3, C3-C4 intermediates and C4 plants, thus enabling fundamental research on the evolution of the C3 and C4 (*C. gynandra*) traits from within the same genus. This manuscript reviews literatures on the taxonomy, origin

Table 1. Geographical distribution of *C. gynandra* obtained from various sources.

Region by continent	Country	Specific locality	Sources
Africa			
East tropical Africa	Kenya, Tanzania, Uganda	Coastal regions for Kenya and Tanzania; central semi-arid areas of Tanzania	Waithaka and Chweya, 1991, Chweya and Mnzava, 1997; Mnzava and Ngwerume, 2004
Northeast tropical Africa	Somalia, Sudan, Ethiopia		Chweya and Mnzava, 1997; Mnzava and Ngwerume, 2004
Northern Africa	Egypt		Chweya and Mnzava, 1997
South tropical Africa	Malawi, Mozambique, Zambia, Zimbabwe		Maroyi, 2011; Mnzava and Ngwerume, 2004
Southern Africa	Botswana, Namibia, South Africa	Natal, Orange Free State, Transvaal, Cape province	Waithaka and Chweya, 1991; Maroyi, 2011
West tropical Africa	Burkina Faso, Ghana, Guinea, Ivory Coast, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone		Waithaka and Chweya, 1991; Chweya and Mnzava, 1997
West-Central tropical Africa	Cameroon, Rwanda, Zaire		Waithaka and Chweya, 1991; Chweya and Mnzava, 1997
African Islands/Western Indian Ocean	Aldabra, Madagascar, Mauritius, Reunion, Seychelles		Chweya and Mnzava, 1997
Asia			
Asia-temperate	Arabian Peninsula, Oman		Chweya and Mnzava, 1997
Western Asia/Far East	Afghanistan		Chweya and Mnzava, 1997
Asia-tropical	India, Malaysia, Philippines	Indian Subcontinent	Waithaka and Chweya, 1991; Chweya and Mnzava 1997; Aparadh et al*.,* 2012
South America	Brazil, Colombia, Mexico, Venezuela, Bolivia, Peru, Brazil, Paraguay, Argentina, Uruguay, Chile, Puerto Rico,		Kuhn, 1988; Chweya and Mnzava, 1997
Australia	Australia, New Zealand		Kuhn, 1988
Europe	Italy, France, Great Britain,		Kuhn, 1988

and morphology of the genus with emphasis on the species *C. gynandra* L. to highlight important areas for future research and development endeavours.

ORIGIN AND GEOGRAPHICAL DISTRIBUTION

Despite the fact that *C. gynandra* is believed to be a native of Africa and Asia (Iltis, 1960; Chweya and Mnzava, 1997) it is nowadays reported to be widespread in tropical, subtropical, Pacific regions and The New World, commonly occurring as a weed; in some cases is semi-cultivated as a traditional leafy vegetable (Iltis, 1960; Waithaka and Chweya, 1991; Chweya and Mnzava, 1997; Mnzava and Chigumira, 2004; Mnzava and Ngwerume, 2004; Maundu et al., 2009; Maroyi, 2011; Aparadh et al., 2012). Table 1 shows the geographical areas where the crop has been commonly observed and recorded. Among all the species of the genus *Cleome*, *C. gynandra* is the most common species occurring throughout tropical Africa and Asia. It is mainly found near human settlements, possibly indicating earlier introduction routes. *C. gynandra* grows in wastelands and arable lands as an annual species, as well as in grasslands.

Apart from *Cleome gynandra* L.*,* there are other *Cleome* species, that have been reported to be used as leafy vegetables including *C. allamani, C. monophylla* L.*,*

C. rutidosperma DC*., C. viscosa* L.*,* and *C. hirta* (Klotzsch) Oliv., and are found both in rainy and dry seasons at varying temperatures (Chweya and Mnzava, 1997; Rensburg et al., 2007; Pillai and Nair, 2013a). However, *C. gynandra* is the most widely used species as a vegetable (Chweya and Mnzava, 1997; Rensburg et al., 2007; Maroyi, 2011). The species *C. hirta* is characterised by bright pink, purple and white flowers and has become a popular ornamental plant in South African gardens (Chweya and Mnzava, 1997). Basically, *C. gynandra* is adapted to a range of environmental conditions in the tropics and sub-tropics including ability to survive in drier and hot environments, such as semi-iarid, subhumid and humid climates consisting of many soil types, probably due to its advantageous C4 photosynthetic pathway (Osborne and Freckleton, 2009; Mishra et al., 2011; Raju and Rani, 2016;). It mainly occurs from sea level up to 2400 masl, and grows best during summer or warm conditions (Chweya and Mnzava, 1997; Raju and Rani, 2016).

It is said to tolerate high and low temperatures, but thrives best from 18 to 25°C as optimum temperature, does not grow well at temperatures below 15°C and thrive less in very humid areas (Chweya and Mnzava, 1997). *C. gynandra* is reported to be a suitable plant for consideration in the restoration of ecologically degraded and warm habitats but also sustain a diverse insect pollinators (Cane, 2008; Raju and Rani, 2016). The countries where the crop has been reported to be widely found and treated as a weed might constitute key centres of origin and genetic diversity and as well act as source of *Cleome* species genetic resources. Farmers grow local landraces or collect from voluntary plants growing as weeds along roadsides and farm edges, and in fallow fields and wastelands. According to Chweya and Mnzava (1997), released cultivars of the crop have not been reported. However, there are lines developed from WorldVeg-ESA germplasm but not improved, that have been registered and commercialized by some seed companies in Kenya and Tanzania. For instance, WorldVeg-ESA has a number of spider plant advanced lines developed by mass selection from accessions that were collected from different African countries (Dinssa et al., pers. comm., 2016). Moreso, Professor Mary Abukutsa-Onyango of Jomo Kenyatta University of Agriculture and Technology, under the Department of Horticulture, Kenya released some cultivars from evaluation and selection of Kenyan local accessions (Abukutsa-Onyango, pers. comm., 2014). Of recent several research activities have been launched on the crop in various African countries with the goal of developing improved cultivars including WorldVeg-ESA, Jomo Kenyatta university of Agricultural and Technology, Ergaton University, Wageningen University, Benin, Burkina Faso and in Ghana (Onyango et al., 2013; Stoilova et al., 2015; Wu et al., 2017; Sogbohossou et al., 2018).

Taxonomy

The genus *Cleome* was first described by Linnaeus in Species Plantarum in 1753 (Iltis, 1960; Ara et al., 2007). One of the reasons we carried out this review was the recent questioning of the monophyly of Capparaceae. There are two perspectives or scenarios regarding the taxonomy of *C. gynandra* under the genus *Cleome*. The first perspective reported that *Cleome* belongs to the family Cleomaceae (Edeoga et al., 2009; Muasya et al., 2009; Koteyeva et al., 2011; Panduraju et al., 2011; Pillai and Nair, 2013a). The evidence that the genus *Cleome* belongs to the family Cleomaceae was given by Hall et al. (2002, 2008), who studied the phylogeny of Brassicaceae and Capparaceae and the relationship within Capparaceae using chloroplast sequence data. Molecular studies by Hall et al. (2002, 2008) introduced three strongly supported monophyletic families, Capparaceae, Cleomaceae and Brassicaceae, and concluded that Capparaceae must be considered a separate family, although previously it had been included in Brassicaceae. This was supported by another study that put Capparidaceae and Cleomaceae as two separate families, and indicated that *C. gynandra* belongs to the Cleomaceae family. This forms a sister-clade and actually is more closely related to Brassicaceae than it is to Capparidaceae. In addition, the two families, Cleomaceae and Brassicaceae together form a sister-clade to Capparaceae (Tucker, 2009).

The second argument classified the genus *Cleome* (that is, *C. gynandra* L.) under the botanical family Capparaceae (Iltis, 1957; Chweya and Mnzava, 1997; Mnzava and Ngwerume, 2004; Rensburg et al., 2007; Maundu et al., 2009). More other studies reported the argument that *C. gynandra* L. belongs to the family Capparidaceae (Waithaka and Chweya, 1991; Bala, 2010; Anburaj et al., 2011; Ranjitha et al., 2013). It should here be noted that, Capparaceae and Capparidaceae are synonymous, because formerly Capparaceae was known as Capparidaceae (Waithaka and Chweya, 1991; Chweya and Mnzava, 1997; Bala, 2010) under which the *C. gynandra* was put in the subfamily Cleomoideae (Chweya and Mnzava, 1997; Ngwerume and Mvere, 1997). Nevertheless, the second argument was nullified by recent studies, including a study that proposed that recognition of Cleomaceae as a family was "a logical necessity" (Airy-Shaw, 1965). Iltis and Cochrane (2007), Hall et al. (2008), Inda et al. (2008) and Iltis et al. (2011) concluded, based on morpho-

Table 2. Some characteristics of the three families from various studies under the order Brassicales.

Family	Characteristics	Sources
Cleomaceae	Herbs or shrubs; inflorescence bracts usually present; leaves usually palmately compound; fruits capsules; nutlets, or schizocarps; seeds 0.5-4 mm, subglobose, triangular, oblong, or horseshoe-shaped, usually not arillate (except Hemiscola); cotyledons incumbent, radicle-hypocotyl elongated, showy zygomorphic flowers and the occurrence of C4 photosynthesis	Brown et al., 2005; Cornejo, 2009; Tucker, 2009
Brassicaceae	Herbs; telltale actinomorphic cruciform flower, with a 2 + 4 arrangement of stamens; characteristic silique fruit type; high percentage of plants with a base chromosome of n = 8; the occurrence of C4 photosynthesis	Hall et al., 2002; Al-Shehbaz et al., 2006; Schranz and Mitchell-Olds, 2006
Capparaceae	Woody growth plants; leaves simple or 3-foliolate in Crateva; floral bracts highly reduced (usually absent), deciduous, flowers with 4 scales, glands or appendages; or a nectary dish/bowl within the hypanthium; ovary subtended by a usually exerted gynophores; fruits capsules or berries without replum, usually fleshy; stamens (in 95% of cases) numerous are usually exerted; fleshy fruits; seeds 4-30 mm, globose to reniform, usually arillate; cotyledons incumbent to accumbent, radicle-hypocotyl relatively short and conical	Cornejo, 2009; Tucker, 2009

anatomical and molecular phylogenetic studies, that the genus Cleome belongs to an independent Cleomaceae family, separate from but related to Capparaceae and Brassicaceae. The more recent and extensive study conducted by Patchell et al. (2014) using chloroplast, nuclear and mitochondrial DNAs in 103 accessions resolved relationships within the family Cleomaceae that Inda et al. (2008) and other researchers did not clearly explain. This study brought to attention up to date taxonomic phylogeny and associated the genus *Cleome* with the family Cleomaceae. Despite this detailed study Patchell et al. (2014) admitted setting the generic boundaries in the family is still problematic, and suggested the importance of more extensive study involving more number of sample species and accessions.

From these two arguments, it is obvious that the taxonomy of *C. gynandra* requires further research to unlock more taxonomic information. Some of the characteristics of the Cleomaceae as distinguished from the other two families, viz. Capparaceae and Brassicaceae, are given in Table 2 (Cornejo, 2009). Based on studies supporting the first view that *C. gynandra* under the genus *Cleome* belongs to the family Cleomaceae, it is most likely that *C. gynandra* L. belongs to the Kingdom Plantae, Phylum spermatophyta, Division Magnoliophyta, Class Magnoliopsida, Order Brassicales and Family Cleomaceae.

The genus *Cleome* is reported to be the largest group in the family of Cleomaceae with approximately over 200 annual or perennial herb and shrub species belonging to the genus out of a total of 275 species in the family (Sanchez-Acebo, 2005; Raju and Rani, 2016). Of these *Cleome* species, about 50 are said to occur in Africa (Chweya and Mnzava, 1997; Pillai and Nair, 2013b) and 15 are found in India (Iltis, 1967; Aparadh et al., 2012). The phylogeny of the genus could not be resolved by morphological characters but the use of integration of internal transcribed spacer (ITS), a piece of non-functional RNA sequence and chromosome data led to a better resolution of the relationships and biogeographical explanations of the genus (Inda et al., 2008). Table 3 has indicated characteristics of some *Cleome* species as compared to the different taxonomy of *C. gynandra* L. given in Table 4 both extracted from various sources.

Genome size and ploidy level

Different chromosome numbers have been reported for *C. gynandra* and other *Cleome* species. Number of chromosomes of some *Cleome* species as extracted from various sources is presented in Table 5. The basic chromosome number of *Cleome* genus has not been determined clearly. According to Raghavan and Kamble (1979), Chweya and Mnzava (1997) and Schranz and Mitchell-Olds (2006), the diploid chromosome number of *C. gynandra* is 2n=20. However, Inda et al. (2008) reported that *C. gynandra* has basic chromosome number ranging from 16 (2n = 32) to 17 (2n = 34). Furthermore, chromosome numbers of (2n) = 18, 22, and 32 have also been reported (Hanumantha Rao et al., 1978; Raghavan and Kamble, 1979; Koshy and Mathew, 1985; Mnzava and Chigumira, 2004). A very recent

Table 3. Characteristics of some *Cleome* species as reported by different studies.

Species	Characteristics*	Other information	Sources
C. gynandra L.	Annual herb, mostly 5 foliate pinnately compound, Corymbose – racemes, white flowers, 6 androecium, Gynandrophore 1 cm long, 4-8 cm capsule length, muricate, dark brown, globose	Grows throughout the year but more vigorously during rainy; predominantly in waste places along waste water; belongs to subgenus-Eucleome, section 2-gymnogonia; C4 plant	Marshall et al., 2007; Inda et al., 2008; Short, 2010; Aparadh et al., 2012
C. speciosa Raf.	Semi-shrub, 3-7 foliate pinnately compound, racemes, beautiful showy inflorescence, pink/ purple flowers, 6 androecium, gynophore elongated, 3-6 cm capsule length, grey black, seeds strongly curved and nearly circular, more or less horseshoe shaped.	Cultivated species growing widely in shadow places in red soil particularly during rainy season; used in gardens; belongs to subgenus-Eucleome, section 2-gymnogonia, C3 plant	Burkill, 1985; Voznesenskaya et al., 2007; Inda et al., 2008; Aparadh and Karadge, 2010; Aparadh et al., 2012
C. aculeata L.	Erect annual herb up to 50 cm tall, with prickles on stem; trifoliate leaves with simple leaves or bracts produced below each flower, leaflet stalks nil or 2-3 mm long. Stipules spiny, curved, 1-3 mm long; pedicels 20-30 mm long, flowers 10-12 mm diameter. Calyx lobes about 3 mm long. Corolla lobes 6-7 mm long, clawed, i.e. stalked. Anthers about 2 mm long, filaments about 4 mm long. Pollen yellow. Stamens and ovary seated on a green disk. Ovary about 2 mm long. Stigma sessile. Ovules numerous on each placenta; Fruits 4-6 mm long. Seeds numerous; seed about 2 mm diameter, coiled like a snail; grow in disturbed and sunny places at lower elevations, between 300 and 500 masl	Common name: Prickly Spider Flower; originally from Mexico, South America and Northern Venezuela; Grouped in Subgenus – Neocleome, Section 6- Tarenaya	Ruiz-Zapata, 2006; Inda et al., 2008; Short, 2010
C. diffusa Banks ex DC.	Erect, annual bushy herb, up to 70 cm high. Stem cylindric. Leaves palmately compound; leaflets 3-5, subsessile, lanceolate to elliptic-lanceolate, acute, entire, flowers white; gynophore 2 mm long	Spreading spider flower; grouped in Subgenus – Neocleome, Section 6-Tarenaya	Ara et al., 2007; Inda et al., 2008
C. hassleriana Chodat	Annual growing to a height of 150 cm; spirally arranged leaves palmately compound, with 5-7 leaflets; leaflets 12 cm in length and 4 cm width; leaf petiole up to 15 cm. Has purple, pink, or white flowers, four petals and 6 long stamens. Fruit/capsule up to 15 cm long and 3 mm broad. In cultivation it has at times been misidentified as *C. arborea, C. pungens* or *C. spinosa*	Tetraploid annual garden plant; Grouped in Subgenus – Neocleome, Section 6- Tarenaya, C3 plant	Koevenig and Sallix, 1973; Khan et al., 1978; Ara et al., 2007; Voznesenskaya et al., 2007; Inda et al., 2008; Nozzolillo et al., 2010; Bhide et al., 2014
C. spinosa Jacq.	Annual herb or shrub found between 25-1800 m above sea level. Grows in disturbed and sunny places at lower elevations. Androgynophore absent, or at most 3 mm long. Gynophore about 4 cm in flower, up to 8 cm in fruit.	Northern Venezuela; Grouped in Subgenus – Neocleome, Section 6-Tarenaya; C3 plant	Kuhn, 1988; Ruiz-Zapata, 2006; Marshall et al., 2007; Voznesenskaya et al., 2007; Inda et al., 2008; Orrell, 2013

Table 3. Contd.

C. anomala Kunth.	-	Venezuela, Colombia, Ecuador (South America); grouped in subgenus-Neocleome Section 4- Rimosperma, C3 plant	Jansen, 2004; Voznesenskaya et al., 2007; Inda et al. 2008; Saharan et al., 2014
C. ciliata D. Dian	-	Is a synonym to *C. rutidosperma* DC, C3 plant	Jansen, 2004; Voznesenskaya et al., 2007
C. chelidonii L. f.	Annual herb, adapted to moist black soil formed due to rock erosion, leaves mostly 3 sometime up to 7 foliate pinnately compound; simple leaves also at basal region, axillary and terminal racemes, violet/pink flowers, many androecium, gynophore absent, 5-8 cm capsule length. Grey brown seeds, strongly curved and nearly circular, more or less horseshoe shaped.	Grows vigorously in moist places and also in the rocky regions, several medicinal properties	Aparadh and Karadge, 2010; Aparadh et.al., 2012
C. guianensis Aubl.	Leaves sessile, narrowly linear; stamens 6-9, heteromorphic, the 3-4 shorter ones sterile, with a reduced anther and an apical swelling (apophysis) to the filament.	C3 plant	Rodríguez, 2003; Voznesenskaya et al., 2007
C. isomeris Greene	Shrub (1.5-2 m) height; leaves have three equal leaf like leaflets (1-4 cm) long, oval and pointed; inflorescences consist of ends of the stem cluster of bright yellow flowers; flowers have 4 petals, 6 stamens; style is centrally protruding; fruit is oval and inflated capsule 4 cm long.	Bladderpod, burrofat, and California cleome; intermediate C3-C4 plant	Marshall et al., 2007
C. lutea Hook.	Annual; sprawling plant often exceeding 1 m height; compound leaf 3-5 leaflets; showy inflorescence with many yellow flowers; oblong petal, stamen with knobby anthers; racemes are indeterminate; plant glabrous and malodorous.	Yellow bee plant and yellow spiderflower; belongs to subgenus–Neocleome, section 5- Peritoma	Cane, 2008; Inda et al., 2008
C. serrulata Pursh	Annual plant (10-150 cm tall); spirally arranged trifoliate leaves; 3 slender leaflets (1-7 cm) long; Hermaphroditic flowers reddish-purple (magenta), pink or white; 4 petals; 6 long stamens; 3-6 cm fruit capsule with several seeds; racemes are indeterminate; plant glabrous and malodorous.	syn. *Peritoma serrulata*; native to British Columbia, Minnesota, Illinois, New Mexico, northern California. Used as a food, medicine, or dye since prehistoric times, commonly referred to as Rocky mountain bee plant, stinking-clover bee spider-flower, skunk weed and Navajo spinach; belongs to subgenus–Neocleome, section 5- Peritoma	Cane, 2008; Inda et al., 2008; Nozzolillo et al., 2010
C. sparsifolia S. Watson	Erect branching not exceeding 1 m tall; sparse leaves with 3 thick, oval leaflets; flowers bright yellow; petals curving; long stamens with tipped knobby anthers.	Few leaf cleome and few leaf spiderflower, native to California and Nevada in desert sand; belongs to subgenus–Neocleome, section 5- Peritoma	Inda et al., 2008

Table 3. Contd.

C. stenophylla Klotzsch ex Urban	Annual herb found Puerto Rico between 1-40 m above sea level	Belongs to subgenus– Neocleome, section 5- Peritoma	Inda et al., 2008; Orrell, 2013
C. ornithopodioides L.	Annual plant up to 3 m high; flowers have both male and female organs	Birds-foot like; bird spider flower, C3 plant	Orrell, 2013; Voznesenskaya et al., 2007
C. monophylla L.	Seeds strongly curved and nearly circular, more or less horseshoe shaped, all leaves simple.	Grouped in Subgenus –Eucleome, Section 3-Rutidosperma, C3 plant	Kuhn, 1988; van Wyk and Malan, 1988; Pooley, 1998; Voznesenskaya et al., 2007; Inda et al., 2008 Aparadh and Karadge 2010
C. rutidosperma DC.	Erect, branched, annual herb, growing up to 15-100 cm tall; as angular stems and trifoliate leaves; leaflet is somewhat diamond-shaped; small flowers (15 mm across); purple upward pointing petals; protruding stamens and pistil	Fringed spider flower or purple Cleome, native to tropical Africa and invasive in lowland wet tropics; Grouped in Subgenus –Eucleome, Section 3-Rutidosperma, C3 plant	Kuhn, 1988; Ara et al., 2007; Inda et al., 2008; Shu, 2008; Edeoga et al., 2009; Short, 2010
C. simplicifolia (Camb.) Hook f. & Thoms.	Annual semi-erect/prostrate herb, simple leaves, solitary axillary inflorescence, violet / pink flowers. Many androecium and gynophores absent, 2-4 cm capsule length, brown seed colour, seeds strongly curved and nearly circular, more or less horseshoe shaped.	Grows luxuriantly in the black soil in rainy season; very short life cycle, up to 3-4 months only	Aparadh and Karadge, 2010; Aparadh et al., 2012
C. viscosa L.	Bushy aromatic herb with glandular trichomes; 3-5 foliate pinnately compound; axillary racemes; yellow flowers; gynophore absent; 5-7 cm capsule length; brownish-black subglobose seed.	Grows luxuriantly in the black soil; throughout the year but more vigorously during rainy season; belongs to subgenus-Eucleome, section 1- Ranmanissa; C3 plant	Rukmini, 1978; Kuhn, 1988; Ara et al., 2007; Marshall et al., 2007; Inda et al., 2008; Edeoga et al., 2009; Mali, 2010; Short, 2010; Aparadh et al., 2012

*(-), indicates the information was not found.

study by Omondi et al. (2017a) reported chromosome numbers of 2n = 34 as investigated from the root tip metaphase cells of *C. gynandra*. The literature thus indicates that the chromosome number of *C. gynandra* needs further investigation. On the other hand, DNA content was previously estimated for one model species *C. hassleriana*, with 0.31 pg/1C, equivalent to 299 Mb and this is approximately double the size of *Arabidopsis thaliana* (Johnston et al., 2005). Different genome sizes of *C. gynandra* have been documented, including size of approximately 1Gb (van der Bergh et al., 2014) and the size of 2.31 to 2.45 pg/2C (Omondi et al., 2017a). The lack of consensus among different studies on genome size of the crop species indicates the need of further studies in the area.

Polyploidy has been observed in the genus *Cleome* (Darlington and Wylie, 1955; Hanumantha Rao et al., 1978; Raghavan and Kamble, 1979; Chweya and Mnzava, 1997). The genomic triplication ploidy of the genus *Cleome* is strongly supported and is hypothesized that polyploidization of *Cleome* occurred independently and is younger to that of a sister clade Brassicaceae (Schranz and Mitchel-Olds, 2006). However, it was as well argued that unless complete genome data are available, the findings are not confirmatory. In another study, with regards to photosynthetic genes, no difference was observed between the polyploidy of C3 and C4 *Cleome* species (van der Bergh et al., 2014). Contrary to this, diploid level has been shown to exist among 30 *C. gynandra* entries (Omondi et al., 2017a). Authors of this article suggest that further investigation is warranted on the genome size and ploidy level of *Cleome*

Table 4. Different taxonomic classifications of *C. gynandra* as referred from various studies*.

Common names	Class	Subclass	Order	Family	Genus	Species	Synonyms	References
Spider flower, spider weed, spider wisp	Magnoliopsida – Dicotyledons	Dilleniidae	Capparales	Capparaceae Caper family	*Cleome* L.	*C. gynandra* L.	*C. pentaphylla* L., *Gynandropsis gynandra* (L.) Briq.	USDA, NRCS database
Spider flower, cat's whiskers	-	-	-	Capparaceae (Capparidaceae)	*Gynandrop-sis*	*G. gynandra* (L.) Briq.	*G. pentaphylla* D.C., *C. gynandra* (L.) Briq.	Waithaka and Chweya, 1991
African cabbage, spider flower, Spider wisp	-	-	Capparidales	Capparaceae	*Cleome* L.	*C. gynandra* L.	-	Chweya and Mnzava, 1997
Spider wisp, cat's whiskers, African cabbage	Magnoliopsida	Dilleniidae	Capparales	Capparidaceae	*Cleome* L.	*C. gynandra* L.	-	Ecoport database
Spider plant	-	-	Brassicales	Cleomaceae	*Cleome* L.	*C. gynandra* L.	-	Hall et al., 2002
Spider plant, cat's whiskers, spider flower, bastard mustard	-	-	-	Capparaceae (APG: Brassicaceae)	*Cleome* L.	*C. gynandra* L.	*C. pentaphylla* L. (1763), *G. pentaphylla* (L.) DC. (1824), *G. gynandra* (L.) Briq. (1914).	Mnzava and Ngwerume, 2004
Spider plant	Equisetopsida C. Agardh	Magnoliidae Novák ex Takht.	Brassicales Bromhead	Cleomaceae Bercht. and J. Presl	*Cleome* L.	*C. gynandra* (L.) Briq.	*G. gynandra* (L.) Briq.	Tropicos database (2019)

*(-), indicates information was not found; APG, Angiosperm Phylogeny Group.

as a genus in general and in *C*. *gynandra* in particular. As well the complete genome sequence of *C*. *gynandra* might clarify most areas that are still debatable.

Morphology

C. gynandra L. germplasm accessions grown in Africa and Asia are morphologically highly diverse as compared to the ones in New World (Iltis, 1960). *Cleome gynandra* is reported to be related to *C. hirta*, *C. rutidosperma* and *C. monophylla;* the latter are relatively less important *Cleome* species and are also used only sparingly as vegetables (Maundu et al., 2009; Tibugari et al., 2012). The species *C. hirta*, *C. rutidosperma* and *C. monophylla* are much smaller and are time consuming to harvest. *Cleome rutidosperma* is an erect annual herb, up to 50 cm tall and branches from the base with pubescent stems. *Cleome viscosa* has yellowish glandular hairs on stems, and reaches about 1 m tall. The characteristics of the different plant parts of *C. gynandra*, as described by Waithaka and Chweya (1991), Chweya and Mnzava (1997), Mnzava and Chigumira (2004), Rensburg et al. (2007), Edeoga et al. (2009) and Raju and Rani (2016) in different studies are briefly summarized below.

Mature plant

C. gynandra L. is an herbaceous, erect, and annual plant that grows to a height ranging from 0.5 m to 1.5 m at maturity, depending on the growing environment. It has many branches. In moderately wet soils the plant can grow throughout the year, while flowering and fruiting events occur simultaneously at population level.

Roots

C. gynandra L. has a long tap root with root hairs and has few secondary roots. Based on a preliminary observation conducted in Arusha, Tanzania at the World Vegetable Center, Eastern and Southern Africa (WorldVeg-ESA) in 2013, the tap root of some plants measured 60 cm long (Dinssa et al., pers. comm. AVRDC, 2013).

Table 5. Chromosome numbers of eight *Cleome* species from various sources.

Species name	Chromosome (n)	Sources
C. gynandra L.	10	Raghavan and Kamble, 1979
C. gynandra L.	17	Renard et al., 1983; Koshy and Mathew, 1985
C. gynandra L.	16-17	Inda et al., 2008
C. gynandra L.	17	Omondi et al., 2017a
C. hassleriana Chodat	10	Johnston et al., 2005
C. viscosa L.	10	Renard et al., 1983
C. schimperi Pax	11	Renard et al., 1983
C. monophylla L.	11	Renard et al., 1983
C. rutidosperma DC.	15	Renard et al., 1983
C. coluteoides Boiss.	17	Renard et al., 1983
C. serrulata Pursh.	17	Renard et al., 1983

Figure 1. *C. gynandra* stem and petiole colour variation; A – purple stem and petiole, B – green stem and petiole, C – purple stem and green petiole, D – green stem and purple petiole.
Source: Shilla O., WorldVeg-ESA.

Stem

The stem of *C. gynandra* is sticky with glandular hairs, marked with longitudinal parallel lines. The stem pigmentation varies from green to pink and purple. However, based on our observations at WorldVeg-ESA, four pigmentation types were noted: (1) purple stem and purple leaf petiole, (2) green stem and green leaf petiole,

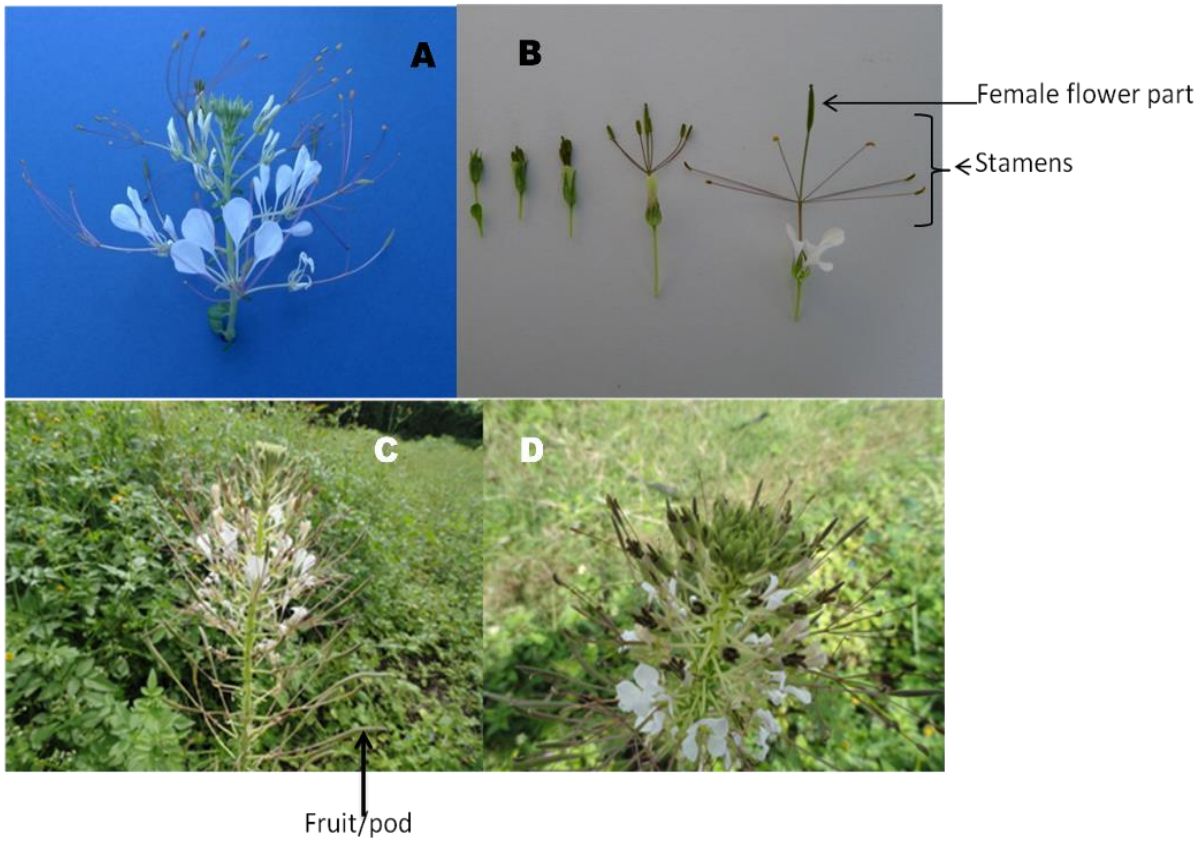

Figure 2. *C. gynandra* inflorescence; A – male flower parts, B – female flower parts at different growth stages (Omondi. E.O., Leibniz Universität Hannover), C – sparse type flowers, D – dense flowers.
Source: Shilla O., WorldVeg-ESA.

(3) purple stem and green leaf petiole, and (4) green stem and purple leaf petiole, of which the purple stem and green leaf petiole being more common (Figure 1). This agrees with Onyango et al. (2013), Wasonga et al. (2015), Wenyika et al. (2015) and Omondi et al. (2017b). The colour is not stable in most lines, and is not tagged/bound to any specific line or accession but more than one mixed colour is common in line or accession, an area that needs thorough study.

Leaves

Leaves are alternate and palmately compound with three to seven, but commonly five leaflets, and a long leaf stalk. The leaf stalk ranges from 20 to 50 mm long with glandular hairs. Leaves are sparsely hairy with margins either toothed or round. The leaf shape varies from obovate to elliptic whereas the leaf colour is from green to deep green. The leaf size commonly ranges from 2 to 10 cm length and 2 to 4 cm width.

Inflorescence and flower

The plant has axillary and terminal, determinate raceme inflorescence (flowers having short floral stalks called pedicels along its axis), with many flowers arising from the small bract trifoliate, resembling the leaves but smaller and sessile (Figure 2). The flower stalk (10-20 mm long) is also glandular haired. Each flower has 4 corolla/petals that are white, pink or lilac in colour, 10 to 20 mm, rounded at the apex and abruptly narrowed to a basal claw. The flower has 4 sepals and 6 stamens with long purple filaments. According to Raju and Rani (2016), two types of flowers have been recognized in *C. gynandra*. The first is Staminate Short Gynoecium flower (SGF; 60%) with a residual ovary lacking ovule (percentage in brackets indicates the plant proportion of each type, at population level), and second is bisexual (hermaphrodite) one with functional ovary and fertile stamens. Based on gynoecium length, four different flower morphs are categorized within the bisexual floral type: (1) Medium Gynoecium Flowers (MGF; 60%), (2)

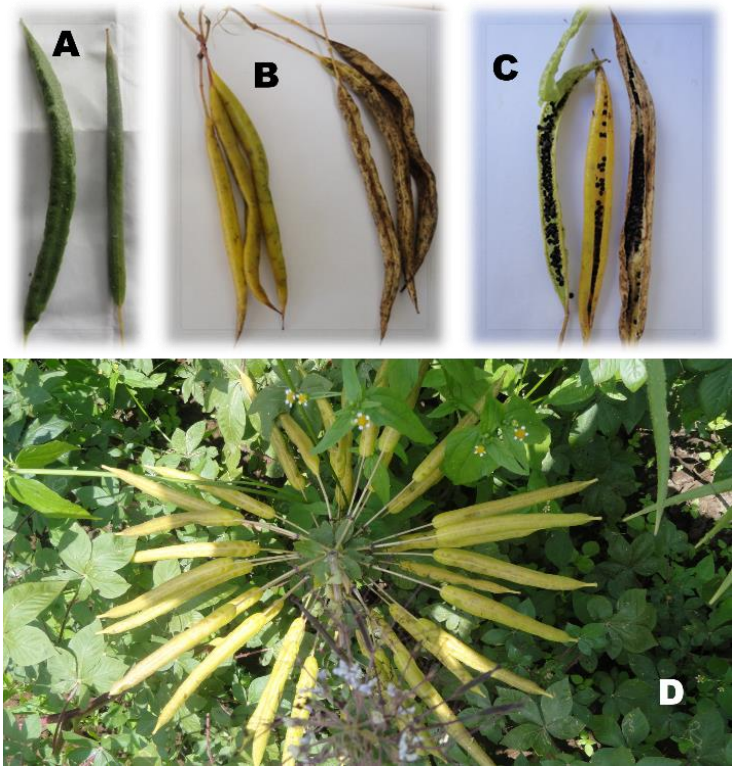

Figure 3. *C. gynandra* pods at different physiological maturity stage: A – mature green pods, B – yellow mature pods, and brown/straw colour dry pods, C – mature (black) seeds from pods in A and B, respectively, D – pods on a plant in slender and linear shape.
Source: Shilla O., WorldVeg-ESA.

Long Gynoecium Flowers (LGF; 60%), (3) Medium Gynoecium Short Stamen Flowers (MGSSF; 18%) and (4) Medium Gynoecium Sessile Shortest Stamen Flowers (MGSeSF; 22%). Normally, SGF, MGF and LGF are produced in the same individual, while MGSSF and MGSeSF morphs are produced singly on different individual plants.

Pollination mechanism

C. gynandra L. is polygamodioecious, consisting of andromonoecious individuals producing both staminate and fertile hermaphrodite floral types and fertile hermaphrodite individuals hence practicing both self-compatibility and autogamous (Chweya and Mnzava, 1997; Mnzava and Chigumira, 2004; Raju and Rani, 2016). Nevertheless, the details on the percentage rates of self- or cross-pollination are not well understood. Cross-pollination is expected to increase with insect activities; we usually see bees visiting the plant in the field at WorldVeg-ESA in Arusha during the less-rainy season, mainly September - January. Raju and Rani (2016) found that 69% of total foraging visits of insects were made during dusk hours and the remaining percentage during the morning hours of the following day. Common visitors are bees (90%), flies (7%) and butterflies (3%). Interspecific crosses between *C. gynandra* L. and its relatives may be possible (Chweya and Mnzava, 1997; Wang et al., 2004) and this has been observed in the spider plant preliminary crossing experiment we did in screen house at WorldVeg-ESA in 2014.

Pod

The polygamodioecious sexual system is associated with high pod and seed production rates in hermaphrodite floral types (Raju and Rani, 2016). The pod (also called capsules, fruit or siliques) is slender and linear or spindle shaped, sub-erect to spreading with a length that reaches 12 cm and 2.5-5 mm in width, 8 - 10 mm long according to Waithaka and Chweya (1991). The plant has a

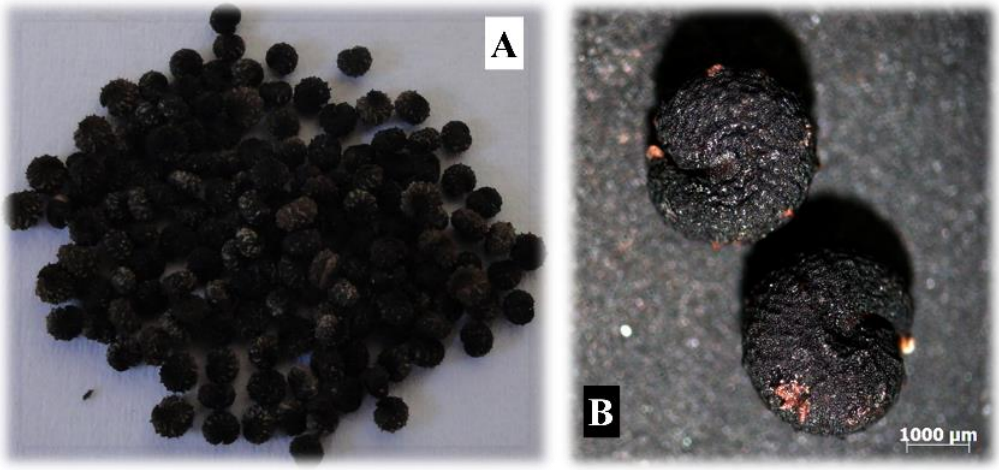

Figure 4. *C. gynandra* seeds; A – irregular and rough seed coat (Source: Shilla O., WorldVeg-ESA), B – Snail-shaped seed coat in close-up view.
Source: Winkelmann T., Leibniz Universität Hannover.

persistent style that is 2 mm long with a thin-textured valve and glandular hairs. The immature pods are green in colour. The maturity starts by seeds turning black in late green pods then turning yellow when ripe and brown when dry before dehiscing (when the capsule bursts open to release seeds) (Figure 3). Each pod contains dehiscence but also by birds (Chweya and Mnzava, 1997). Seeds of all *Cleome* species contain from 17 to 19% oil (Aparadh et al., 2012). The seeds from *C. gynandra* have been observed to germinate immediately after release from pods when soil has moisture (Raju and Rani, 2016; Shilla et al., 2016). However, other studies have indicated erratic seed germination due to dormancy that may prolong to as long as one year thus leading poor propagation of the plants (Chweya and Mnzava, 1997; Keller and Kollmann, 1999; Essou et al., 2017). Seed germination of this plant may again warrant further investigation.

CONCLUSION

C. gynandra is a highly appreciated and valued leafy vegetable in many communities in tropical Africa and Asia. It has good potential for further development. This review article provides highlights on crucial information related to the taxonomy, morphology and origin of the crop to help guide future research and breeding activities. Quite substantial but scattered information are available on the taxonomy of the crop. We attempted to bring together such information for researchers including breeders to easily access in one document. Reading through the review, one could understand that the taxonomic classification of the genus is still under debate, especially at the level of clades and lineages of Cleomaceae, despite a number of studies that have been conducted on the subject. However, at the family level, recent molecular studies strongly support the placement of the crop in the genus *Cleome*, of the family Cleomaceae, although previously it was classified under Capparaceae. The Cleomaceae family has been shown to be more closely related to Brassicaceae than it is to Capparaceae, justifying that it was wrongly placed under Capparaceae. In the light of these two scenarios, although a recent study by Patchell et al. (2014) to a larger extent gave very strong evidence of Cleomaceae taxonomy and its clades, yet it has been concluded that there is still a work to be done, in particular, in the conflicting areas of clades and associated lineages. Authors of this review, therefore, recommend further coordinated study involving more number of *Cleome* accessions from various origins, probably including recent germplasm collections and using modern high-tech molecular tools. WorldVeg-ESA has a large number of accessions, and advanced lines developed by single plant selections, and can be one of potential sources of germplasm for more extensive studies in the future. The chromosome numbers and ploidy level of the genus *Cleome* as well have not been clearly determined with different studies giving varying results. A study on resolving the chromosome number and ploidy level will strongly complement the taxonomy of *Cleome*, and provides useful information primarily for breeders working on the crop improvement. *Cleome* deserves the attention

of the world science for its potential multiple uses that ranges from dense nutritional to medicinal properties. Moreover, being widely distributed around the world, *C. gynandra* has been considered to be a suitable plant for ecologically degraded and for warm habitats restoration and in horbouring diverse insect pollinators, as well as herbivore communities. Studies on the genetic diversity of *C. gynandra* will open new avenues for research, especially for crop improvement. The genus *Cleome* has both C3 and C4 plants, hence attracting the attention of the scientific community involved in fundamental research on the evolution of the C3 and C4 photosynthetic pathways from within the same genus. The knowledge gaps dealt with in this article will help researchers focus on areas to be further addressed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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