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Inflorescence and floral characters indicating C_3 and C_4 photosynthesis in some species of the genus *Cyperus* L. (Cyperaceae)

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ABSTRACT

Inflorescence and floral morphological characters in twelve species of *Cyperus* – a genus known to have C_3 and C_4 photosynthetic species – were investigated in order to check their usefulness in delimiting species into photosynthetic groups. Plant species were collected from different locations within Southwestern Nigeria. Qualitative characters were noted and recorded while some quantitative characters were measured with metric ruler to the nearest centimeter and others were counted. The results revealed that compound umbellate inflorescence, digitately arranged spikelets and short spikelets not over 1cm long are characters that separate *C. difformis* and *C. haspan* which are C_3 species, while the rest with simple umbellate inflorescence, spicate spikelets and spikelet length over 1cm are C_4 species. *Cyperus dilatatus*, a species without a previous record of photosynthetic grouping, is hereby grouped as a C_4 species since it shared characters with the rest C_4 species. From this study, a combination of characters was identified, which can possibly be used along with known data from other sources in the grouping of *Cyperus* species as either C_3 or C_4 species. Data on *C. dilatatus* also showed that it possibly belong to C_4 species. This is probably the first known report on photosynthetic grouping of this species.

Keywords: C_3 - C_4 species, *Cyperus* genus, inflorescence morphology, photosynthetic grouping, taxonomy.

INTRODUCTION

The genus *Cyperus* is widely distributed in both wet and dry habitats as well as in tropical and temperate regions with about 700 species worldwide (Larridon et al., 2011, 2014). In West Africa, the genus is represented with about 67 species (Hutchinson and Dalziel, 1972) and in Nigeria, only 52 species have been identified (Lowe, 1974). The genus is taxonomically complex as it is known to contain species with either C_3 or C_4 photosynthetic pathways (Bruhl and Wilson, 2007). The *Cyperus* genus is divided into six clades, clade 1-5 comprising all C_3 species in 8 different sections and clade 6 comprising all C_4 species (Larridon et al., 2011). Previously, leaf anatomical characters (Kranz anatomy) has been used to divide *Cyperus* species into two subgenera–eucyperus and chlorocyperus (Bruhl and Wilson, 2007; Larridon et al., 2011). It was many years after this grouping that C_4 photosynthetic pathway was identified

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in *Cyperus* by Hatch and co-workers (Sage, 2004). These were the initial basis for the classification of the species in this genus as C_3 and C_4 species. It was only later that stable carbon isotope ratios technique was employed to confirm this classification (Wooller et al., 2001).

However, studies on morphological characters (vegetative or floral) that could possibly be used or even at best, serve as indicator in the classification of plant species into C_3 and C_4 photosynthetic group are rare, most especially in the *Cyperus* genus. This is because most morphological descriptions are intended to achieve identification and taxonomic purposes. Prominent among taxonomic works on *Cyperus* in Nigeria is that by Lowe (1974) which used morphological characters in the description and identification of Nigerian sedges (Cyperaceae) in which *Cyperus* has the largest number of species studied. Carter and Bryson (2000) also carried out a study on the infrageneric taxonomy using habit, general inflorescence form, spikelet form, style number and fruit shape as basis for classifying seven subgenera in *Cyperus* genus.

Interestingly, previous reports have suggested that some morphological characters are related and can be linked with the two identified photosynthetic pathways in the *Cyperus* genus. Muasya (2009) reported that in this genus, those belonging to the C_3 photosynthetic pathways tend to possess spikelets arranged in digitate clusters. This constitutes a form of morphological characters used to distinguish C_3 from C_4 taxa whose spikelets are usually spicately arranged. This delimitation is different from species that have their inflorescence reduced to a head. Larridon et al. (2011) reported that *Cyperus* is most commonly divided into two main infrageneric units, determined by the character of anatomical and inflorescence character set. In the current study, we investigated on some of these identified inflorescence and floral characters which could possibly serve as indicators that can be used to distinguish between the two photosynthetic pathways in the *Cyperus* genus.

MATERIALS AND METHODS

Plant materials collection

Twelve species were used for the study. All fresh specimens were collected from different locations in Southwestern Nigeria and transplanted at the Nursery of the Department of Botany, Obafemi Awolowo University (OAU), Ile-Ife (Table 1). Identifications were made at the Forest Research Institute of Nigeria, Ibadan (FHI) and Department of Botany, Obafemi Awolowo University, Ile-Ife (IFE) herbaria as well as using the information in the flora of Nigerian sedges by Lowe (1974).

Data collection

Qualitative floral characters studied include: inflorescence form (branched or unbranched), inflorescence arrangement (simple or compound umbel), spikelet colour and spikelet arrangement (digitate or spicate). Quantitative characters measured include: bract length, bract width, primary ray length, spikelet length, spikelet width and glume length. All measurements were taken with a metric ruler to the nearest centimeter, while counts were also made for number of bracts and rays and glumes. Twenty measurements were taken for each character from different samples and the mean values were recorded.

Statistical analysis

Descriptive statistics involving the use of mean values and standard error was used in analyzing the data from this study.

RESULTS

For the qualitative characters investigated, it can be noted that all the species studied has branched inflorescence form but the arrangement of inflorescence vary between simple umbel type found in *C. articulatus, C. compressus, C. dilatatus, C. esculentus, C. sphacelatus* and *C. tenuiculmis* and compound umbel arrangement found to occur in the remaining species (Figure 1). The spikelet colour ranges from green to yellow for most of the species studied while reddish to brownish colour was observed in *C. distans.* The spikelet arrangement revealed that digitate arrangement is found only in *C. haspan, C. difformis* (Figures 1E and F) and *C. compressus,* while the rest possess spicate spikelet arrangement (Figures 1G and H).

For quantitative characters, the number of bracts could be as few as 3 in *C. compressus* and *C. difformis* and as many as 8 bracts in *C. distans* and *C. imbricatus* while the rest are of intermediate numbers (Table 2). The bract length could be as small as 2 cm in *C. articulatus* and as long as 40 cm in *C. distans* and *C. iria*. Similar trend was recorded for bract width which ranges from 0.2 cm long in *C. articulatus* and *C. compressus* to 0.9 cm in *C. esculentus* and *C. rotundus*. The number of rays could be as few as 3 in *C. compressus* and as many as 22 in *C. haspan* while others have intermediate numbers. The ray length could be as short as 3 cm in *C. difformis* and as long as 22 cm in *C. tenuiculmis*. The spikelet length could be as short as 0.3 cm in *C. difformis* and could be as long as 4.0 cm in *C. distans.* The width of the spikelet is also found to vary among the species; it could be 0.08 cm wide in *C. distans* and 0.3 cm in *C. compressus*. The number of glumes could be as few as 4 in *C. difformis* or as many as 20 in *C. articulatus,* whereas the glume length could be as small as 0.06 cm in *C. difformis* and as wide as 0.4 cm in *C. rotundus* and *C. tenuiculmis*.

Table 1: *Cyperus* species collected from different locations in Southwestern Nigeria.

Species	Sample sites/ GPS coordinate
C. articulatus L.	Badagry(6°24'N 2°53'E),Ikorodu(6°36'N 3°31'E)
C. compressus L.	Lagos (6°29'N 3°22'E), OAU campus (7°28'N 4°32'E)
C. difformis L.	OAU campus (7°28'N 4°32'E),Ondo(7°05'N 4°50'E)
C. dilatatus Schum. &Thonn.	OAU campus (7°28'N 4°32'E), Ado-Ekiti(7°36'N 5°13'E)
C. distans L.	OAU campus (7°28'N 4°32'E), Owo(7°11'N 5°35'E)
C. esculentus L.	Ibadan (7°22'N 3°53'E), Ijebu-Ode (6°48'N 3°55'E)
C. haspan L.	OAU campus (7°28'N 4°32'E), Ibadan (7°22'N 3°53'E)
C. imbricatus Retz.	OAU campus (7°28'N 4°32'E), Ijebu-Ode (6°48'N 3°55'E)
C. iria L.	Lagos (6°29'N 3°22'E), Ado-Ekiti(7°36'N 5°13'E)
C. rotundus L.	OAU campus (7°28'N 4°32'E), Ibadan (7°22'N 3°53'E)
C. sphacelatus Rottb.	OAU campus (7°28'N 4°32'E), Ado-Ekiti(7°36'N 5°13'E)
C. tenuiculmis (Boeck.) Hooper	Ibadan (7°22'N 3°53'E), Ijebu-Ode (6°48'N 3°55'E)

OAU = Obafemi Awolowo University

Table 2: Summary of all important qualitative and quantitative morphological characters of the *Cyperus* species studied.

Species/ Character	*C. articulatus*	*C. compressus*	*C. difformis*	*C. dilatatus*	*C. distans*	*C. esculentus*	*C. haspan*	*C. imbricatus*	*C. iria*	*C. rotundus*	*C. sphacelatus*	*C. tenuiculmis*
Inflorescence form	Branched	Branched	Branched	Branched	Branched	Branched	Branched	Branched	Branched	Branched	Branched	Branched
Inflorescence arrangement	Simple umbel	Simple umbel	Compound umbel	Simple umbel	Compound umbel	Simple umbel	Compound umbel	Compound umbel	Compound umbel	Compound umbel	Simple umbel	Simple umbel
Spikelet color	Yellow to brown	Green	Green	Green with reddish sides	Reddish to brownish	Golden yellow	Green	Green	Greenish yellow	Pale green to reddish	Green with purplish sides	Golden to brown
Spikelet arrangement	Spicate	Digitate	Digitate	Spicate	Spicate	Spicate	Digitate	Spicate	Spicate	Spicate	Spicate	Spicate
Bract number	6 ± 0.010	3 ± 0.000	3 ± 0.001	4 ± 0.002	8 ± 0.010	4 ± 0.009	3 ± 0.001	8 ± 0.001	5 ± 0.003	6 ± 0.005	4 ± 0.002	5 ± 0.001
Bract length (cm)	2 ± 0.001	12 ± 0.012	35 ± 2.351	37.5 ± 2.101	40 ± 1.931	21 ± 1.121	16 ± 1.360	38 ± 1.982	40 ± 2.013	25 ± 1.221	16 ± 0.962	27.5 ± 0.571
Bract width (cm)	0.2 ± 0.005	0.2 ± 0.002	0.8 ± 0.002	0.4 ± 0.003	0.7 ± 0.002	0.9 ± 0.001	0.3 ± 0.100	0.8 ± 0.002	0.6 ± 0.001	0.9 ± 0.002	0.5 ± 0.004	0.7 ± 0.001
Ray number	8 ± 0.250	3 ± 0.250	18 ± 0.120	5 ± 0.250	10 ± 0.310	8 ± 0.150	22 ± 0.130	8 ± 0.110	6 ± 0.090	8 ± 0.240	7 ± 0.070	7 ± 0.110
Ray length (cm)	12.5 ± 0.350	3.5 ± 0.060	3 ± 0.110	14 ± 0.220	18 ± 0.170	8.5 ± 0.140	9.5 ± 0.090	8.5 ± 0.210	5 ± 0.200	12 ± 0.180	10 ± 0.280	22 ± 0.110
Spikelet length (cm)	3.5 ± 0.070	1.8 ± 0.060	0.3 ± 0.030	3.0 ± 0.040	4.0 ± 0.020	1.9 ± 0.020	0.5 ± 0.010	0.7 ± 0.010	1.2 ± 0.020	3.3 ± 0.040	3.3 ± 0.040	3 ± 0.020
Spikelet width (cm)	0.13 ± 0.002	0.3 ± 0.001	0.09 ± 0.001	0.2 ± 0.020	0.08 ± 0.001	0.1 ± 0.002	0.15 ± 0.002	0.15 ± 0.002	0.1 ± 0.001	0.2 ± 0.002	0.2 ± 0.002	0.2 ± 0.001
Glumes number	20 ± 0.250	10 ± 0.250	4 ± 0.150	10 ± 0.202	12 ± 0.223	7 ± 0.161	4 ± 0.200	7 ± 0.250	5 ± 0.250	12 ± 0.162	10 ± 0.300	9 ± 0.244
Glume length (cm)	0.3 ± 0.001	0.3 ± 0.005	0.06 ± 0.001	0.2 ± 0.001	0.15 ± 0.005	0.2 ± 0.001	0.1 ± 0.005	0.15 ± 0.005	0.1 ± 0.005	0.4 ± 0.001	0.2 ± 0.005	0.4 ± 0.005

Values are Mean ± Standard Deviation, n = 20.

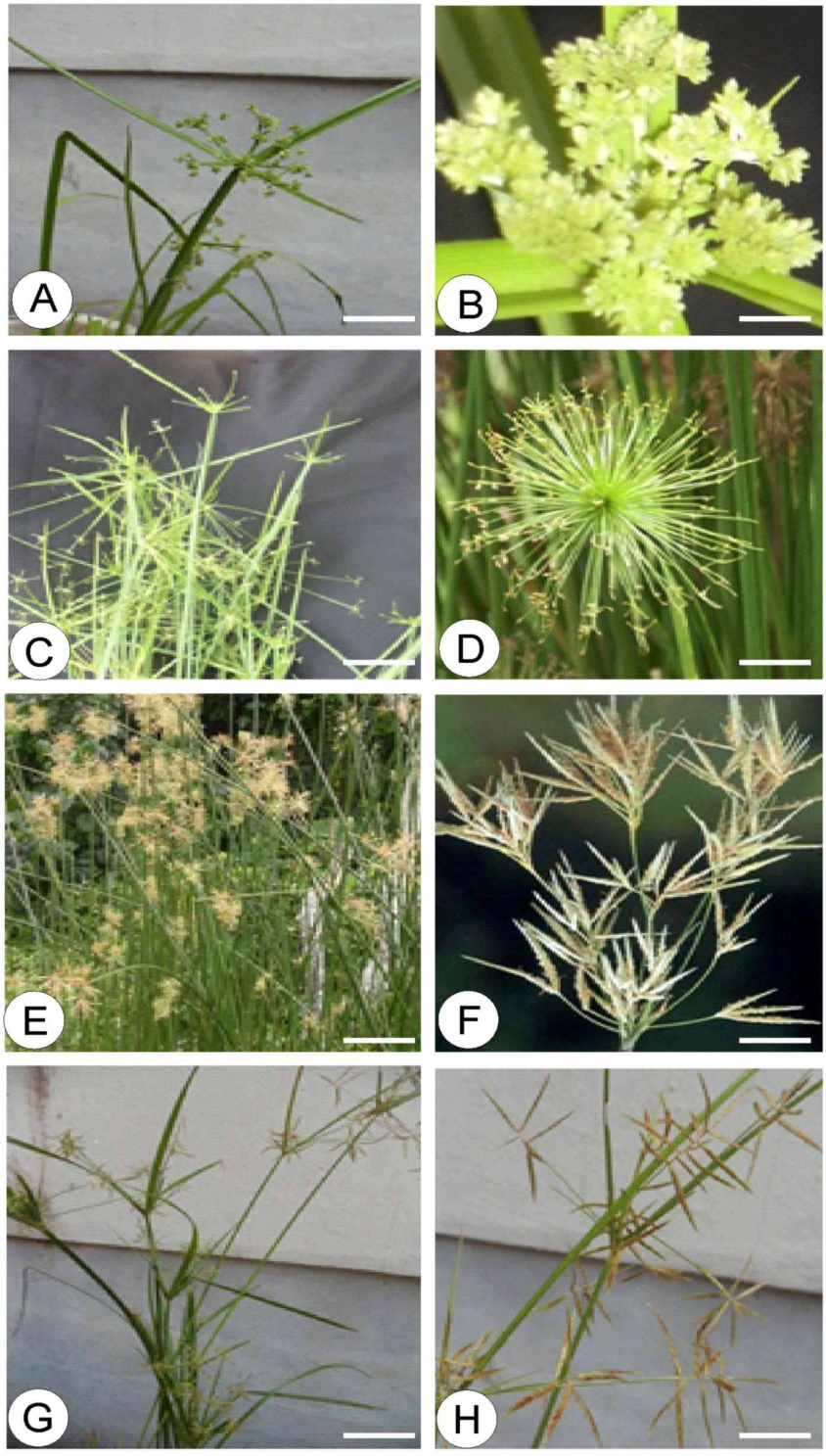

Figure 1: Vegetative and floral morphology of some *Cyperus* species studied. *C. difformis* (C_3) **A** (vegetative), **B** (Floral); *C. haspan* (C_3) **C** (vegetative), **D** (Floral); *C. articulatus* (C_4), **E**(vegetative), **F** (Floral); *C. dilatatus* (C_4), **G** (vegetative), **H**(Floral); Scale = A, C, E and G = 5cm; B, D, F and H = 0.5cm.

DISCUSSION

The previous classification of plants as C_3 or C_4 species especially in the genus *Cyperus* has been based largely on any or a combination of the followings; stable carbon isotope ratio, CO_2 compensation point analyses (Bruhl and Wilson, 2007), leaf anatomical characteristics such as Kranz anatomy (Martins and Alves, 2009; Ayeni et al., 2015), interveinal distance (Ueno et al., 2006; Faniyan et al., 2013) and one cell distant criterion (Bruhl and Wilson, 2007; Faniyan et al., 2013; Ayeni et al., 2015). Out of all the species investigated in this study, only *C. difformis* and *C. haspan* have been previously reported to be C_3 species, the rest are C_4 species (Bruhl and Wilson, 2007; Martins and Alves, 2009) with the exception of *C. dilatatus* with yet to be identified photosynthetic pathway status.

However, Muasya et al. (2009) and Larridon et al. (2011) reported on a number of inflorescence or floral characters that may be indicative of photosynthetic grouping in *Cyperus* genus. The current study then investigates these floral morphological characters and many others that are considered stable enough and which can be justifiably employed to classify the studied *Cyperus* species into photosynthetic pathway group. The data obtained suggest that there are some floral characters which are peculiar to only *C. difformis* and *C. haspan* and which may serve as diagnostic characters for their grouping as C_3 species. Although, no single character separates these two species from their C_4 counterparts, but a combination of stable and reliable characters which includes occurrence of compound umbellate inflorescence, digitate spikelets and spikelets length not more than 1cm (Table 2) are diagnostic for C_3 species considered in this study. It is obvious that apart from other characters, most C_3 taxa tend to have their spikelets arranged in digitate clusters while spikelets in C_4 taxa are usually spicately arranged, this position was strongly canvassed by Muasya et al. (2009). This is one of the few critical morphological characters used to distinguish C_3 from C_4 species. Interestingly from this study, our data revealed that *C. dilatatus* a species with no known record of photosynthetic status, shared characters with other established C_4 species by having simple umbellate inflorescence, spicate spikelets and spikelets length over 1cm long.

Digitate and spicate arrangement of spikelets observed in this study corresponds largely with a number of pioneer studies which recognised the presence of two inflorescence types in *Cyperus* genus and used these attributes to divide the species into two subgenera with the arrangement of spikelets in the delimitation as '*Eu-cyperus'* subgenus (Muasya et al., 2009). Larridon et al. (2011, 2014), also reported that *Cyperus* is most commonly divided into two main infrageneric units, the eucyperoid – consisting of species without the Kranz tissue and digitately clustered spikelets inflorescence; and the chlorocyperoid – consisting species with the Kranz tissue and spicate spikelets inflorescence. Additional characters established in this study are the compound umbellate inflorescence and spikelets length not over 1cm which are found to be useful in the delimitation of the investigated species in this study and which were not used by these previous authors.

Conclusion

This study revealed floral morphological characters with the potential of being useful in the grouping of *Cyperus* species as either C_3 or C_4 species. These include compound umbellate inflorescence, digitate spikelets and spikelet length not over 1cm for C_3 species while C_4 species has simple umbellate inflorescence, spicate spikelets and spikelet length over 1cm. This study also reports possibly for the first time, the grouping of *C. dilatatus* as a C_4 species. However, we are of the opinion that data from other sources such as leaf anatomy, stable carbon isotope ratio and other studies are needed to strengthen and justify this report.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

OBA collected the data and partly analyzed it; MAJ designed the study, analyzed the data and wrote the paper jointly with SAS.

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