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Anatomy and nutritional value of *Dracaena camerooniana* Baker - an African wild vegetable

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ABSTRACT

Background: Even though some *Dracaena* species are used as medicine, their utilization as food is rather unusual. In northern Angola, however, leaves and underground tubers of *Dracaena camerooniana* Baker are frequently consumed. In particular, the leaves are of increasing economic value in the region. But the anat omy and nutritional aspects of the plant have not been studied so far. Therefore, a detailed anatomic descrip tion of the plant was conducted. In a second step the nutritional value of the defined material was analysed, providing a basis for the discussion of a more intensive utilisation of this rainforest shrub.
Results: The leaf anatomy of *Dracaena camerooniana* differs from the species of the genus that have been examined so far, in showing adaptations to wet climatic conditions. The stems produce a secondary thicken ing meristem with amphivasal secondary vascular bundles. During tuber formation, the parenchyma of the pith in the vascular cylinder of the root markedly increases. From a nutritional point of view, leaves do not noteworthy contribute to vitamin intake. The nutritional composition of the tubers is comparable to that of cassava (*Manihot esculenta* Crantz) and potatoes (*Solanum tuberosum* L.). However, a high fructose value indi cates inulin as a storage carbohydrate.
Conclusion: Inspite of its rather moderate nutritional values, *Dracaena camerooniana* is an indigenous addi tion to the diet of the Angolan population that could also be cultivated in the future due to the easy vegeta tive propagation.

1. Introduction

The genus *Dracaena* L. belongs to the Asparagaceae family and actually comprises between 116 to 190 accepted species (Damen *et al.,* 2018, POWO 2019). Despite this considerable number of spe cies, *Dracaena* is not known as a widely used genus. Some species are planted as ornamentals (Singh and Dadlani 2000) or for ritual pur poses (Sheridan 2008), or used as a remedy. In addition, 21 species are listed as traditional medicine for the whole African continent (Neuwinger 2000), or as vegetable like *D. mannii* Baker in the Demo cratic Republic of the Congo (Kibungu Kembelo and Kibungu Kem belo 2010).

Dracaena camerooniana Baker, which is phylogenetically close to *D. surculosa* LINDL. and *D. ovata* KER GAWL. (Bos 1984), up to now, has not been documented as natural resource except its use as vege table in the area around Kinshasa (Biloso and Lejoly 2006) and the northern Angolan province Uíge (Monizi *et al.,* 2019). Both references report trading of leaves, locally known as *Nsala bakala*, in huge quan tities at local markets. They are cooked like the leaves of *Gnetum afri canum* Welw., another very important traditional vegetable in African cuisine, but are considered as softer, more digestible and more appe tizing as the latter (Monizi *et al.,* 2019). Used as a side dish, it is served with fufu (Manioc pudding), and, if available, with meat or fish. Due to the overexploitation and the habitat loss of *Gnetum africanum* (Lakeman and Bachman, 2011, Doungous *et al.,* 2019) as well as its difficult cultivation (Biye 2013), the prices at urban markets are con stantly increasing (Biloso and Lejoly 2006). Here, the leaves of *D. camerooniana* are a cheap and tasty alternative for local people in Uíge.

In contrast to the intensive use of the leaves, the root tubers of *Dracaena camerooniana* (Fig. 1), locally called *Madioko ma mfinda*, are eaten only by few people (Monizi *et al.,* 2019), mostly by men as a snack during their trips in the forests. For that purpose, the tubers are peeled and eaten raw. In addition, the root is thought to have an aphrodisiac effect. Data concerning nutritional composition of the

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Fig. 1. Used plant organs: (left) leaves are cut into narrow strips using a sharp knife before boiling for 30-45 minutes; (right) the root tubers are peeled and eaten raw.

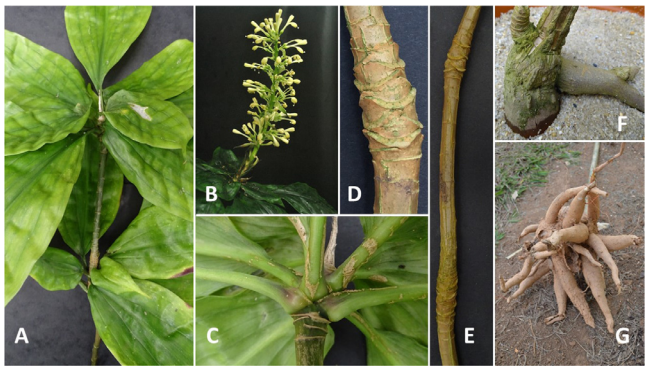

Fig. 2. *Dracaena camerooniana*. Gross morphology. **A** distant pseudo-whorls of leaves along the stem, **B** terminal inflorescence, **C** attachment of leaves to the stem, **D** leaf scars of pseudo-whorl, **E** stem with two sections of former pseudo-whorls, **F** wood-crown with new shoots and tuberous roots, **G** harvested tuberous roots.

leaves as well as the tubers of this species are lacking up to now. *D. camerooniana* is a shrub of 0.3 8 m height in the forest undergrowth (Hepper 1968; Mwachala and Mbugua 2007). The branched stems produce cane like shoots. The leaves are arranged in pseudowhorls and are up to 33 cm long. Its distribution ranges from West Tropical to East Tropical Africa with Angola marking its southern most occur rence. The extreme form in northern Angola that exhibits 20 cm long petioles was formerly called *D. oddonii* but is now included in *D. camerooniana*. According to the IUCN Red List of Threatened Species, the population is stable (Least Concern) (Crook 2013). Nevertheless, pessimistic climate change scenarios are indicating a significant decrease of the species' distribution area with a loss of up to 60.5% until 2050 (Bogawski et al., 2019). On the other hand, Bogawski et al., (2019) suggest that at the same time the forest loss may exert a stronger impact than the climate change. As the economic value of the species should not be underestimated, the use as a non timber forest product (NTFP) could be an alternative of increasing impor tance for the future. This background has motivated us to take a closer look on the anatomy and in particular on the nutritional values of the used plant organs to collect arguments for the farming of this traditionally used vegetable. As *Dracaena* species are easy to propa gate via stem cuttings, an extended cultivation of this plant would be possible in contrast to many growing trails with *Gnetum africanum* that were unsuccessful.

2. Materials and Methods

2.1. Sampling and preservation of vouchers

The different plant parts used for anatomical analysis as well as the tuberous roots of *Dracaena camerooniana* were collected from the municipality Ambuila (Floresta de Kananga, aldeia Kisengi: 7° 37′30.8″S 14°43′21.8″E, 537 m alt.) in the Province Uíge, northern Angola and sent to Germany. Leaves were bought on the central mar ket of Uíge city. While one part was immediately frozen, the other part was traditionally prepared by locals. The leaves were cut into narrow strips (Fig 1), boiled in (unsalted) water for 35 minutes, cooled down and subsequently frozen. For documentation of the spe cies, vouchers were collected, dried, stored and digitalized at the Her barium Dresdense (DR), Technische Universitat Dresden, Germany (DR055146, DR055147, DR056371, DR056371) complemented by photographs. All sample data are available at Virtual Herbaria JACQ. The Ministry of the Environment, Republic of Angola, and the Prov ince Government of Uíge issued the required collection and export permits in accordance with a Memorandum of Understanding between the Instituto Nacional da Biodiversidade e Áreas de Con servaçao (INBAC), Angola and the Technische Universitat Dresden, Germany, signed in 2014, and the regulations on Access and Benefit sharing as well as with the Nagoya Protocol Fig 2.

2.2. Anatomical investigation

To observe the distribution of the tissues within the different plant parts, fresh leaves, shoot axes as well as roots of *D. camerooni ana* were preserved in 96% ethanol (subsequently diluted to 70%). The axes were cut with a razor blade, stained with Astra blue/Safra nin (Morphisto GmbH, Frankfurt a.M., Germany) or Sudan III (Mor phisto GmbH, Frankfurt a.M., Germany), and analyzed using a light microscope (Carl Zeiss Axioskop 2, Jena, Germany) as well as a reflected light microscope (Olympus SZX16, Jena, Germany). To com plete the microscopic analysis of the leaf, samples were studied by cryo scanning electron microscopy (Carl Zeiss Supra40VP, Jena, Ger many). These pictures gave an insight in the distribution of stomata as well as in the thickness of the cuticle. In the anatomical part, aver age values are given within its range: (minimum value *average* maximum value).

2.3. Analysis of major nutrients in roots

Prior to analyses, the roots were cut in slices, freeze dried (Beta 1 8K, Martin Christ Gefriertrocknungsanlagen GmbH, Osterode, Ger many) and ground for 20 s at 1000 rpm in a Grindomix 200 knife mill (Retsch GmbH, Hahn, Germany). The resulting powders were stored at 18°C until analysis. Water content and dry matter were calculated from the loss of mass during freeze drying. Protein analysis was car ried out by determination of the nitrogen content according to Kjel dahls method (System of Buchi Labortechnik AG, Flawil, Switzerland) and application of a conversion factor of F= 6.25 for protein content calculation (Matissek and Steiner 2006). Analysis of amino acid com position was carried out as described previously, using ion exchange chromatography with post column ninhydrin derivatisation (Lautenschlager *et al.*, 2017). Glucose, fructose and sucrose contents were determined enzymatically using the kit ENZYTECTM, N° E1247 (R Biopharm AG, Darmstadt). Total carbohydrate amount was calcu lated as difference from the sum of protein, fat and ash to 100% of dry matter. For the determination of the fat content, samples were extracted with petroleum ether for 5 h in a Soxhlett extractor. After evaporation of the solvent and drying of the remaining fraction, the fat content was quantified gravimetrically (Matissek and Steiner 2006). For ash determination, the freeze dried samples were pre incinerated with a Bunsen burner. Main incineration was carried out in a muffle furnace for 3h at 550°C. The last step was repeated until constant masses were achieved (VO (EG) 152/2009, appendix 3M).

2.4. Vitamin analyses in leaves

For sample preparation, the frozen leaves were cut into pieces and freeze dried. The resulting powders were analysed for vitamins B1 and B2 by HPLC with post column derivatization and fluorescence detection, previously described in Oguntoyinbo et al., (2016).

For analyses of vitamin C, a HPLC separation was followed by post column in line oxidation, subsequent derivatisation and fluores cence detection (Bognar and Daood 2000).

3. Results

3.1. Morphology of D. camerooniana

Dracaena camerooniana is a shrub of the rainforest understory that reaches a height of up to 8 m (Hepper 1968; Bos 1984, Mwachala and Mbugua 2007). Depending on the variation of climatic conditions and distribution areas of this variable species the stems are more or less branched (Bos 1984). The leathery entire leaves are up to 33 cm long and 8 cm broad and clustered in pseudo whorls. Its apex is acumi nate, its base is cuneate and narrowed into a pseudopetiole with an amplexicaul base that clasps the stem. When fresh, the parallel leaf veins are usually indistinct. The terminal racemes exhibit several alternate lateral spikes with 2 20 flowers (Baker 1874, Mwachala and Mbugua 2007).

3.2. Anatomy of D. camerooniana

The leaf of *Dracaena camerooniana* is bifacial at its pseudopetiole and lamina. Its thickness decreases from the pseudopetiole (2 mm), to the lamina base (1.2 mm) and to the middle of the leaf where it varies from the stronger veins (0.6 mm) to the very thin leaf margins (0.2 *0.3* 0.4 mm).

The vascular bundles are scattered in the mesophyll. While the collateral vascular bundles in the pseudopetiole are orientated with its phloem pole pointing outwards, most of them in the lamina region are horizontally orientated (more or less rotated 90° with respect to the adaxial abaxial axis) towards the nearest leaf margin (section B D in Fig. 3). A few bundles only show the normal orientation with phloem on the abaxial leaf side. Phloem and xylem are covered by sclerenchymatous tissue, which is more pronounced on the phloem side as compared to the xylem side. The average thickness of fibre bundles is 23 *46* 74 μm. The vascular bundles are surrounded by parenchymatous bundle sheaths. The mean length of their long axis is 163 $\pm$ 36 μm (70 *163* 300 μm).

The mesophyll is subdivided into the chlorenchyma that contains chloroplasts and the non photosynthetic central mesophyll. In the pseudopetiole with a thickness of 2 mm, the chlorenchyma on the adaxial side is 500 μm thick (10 11 cell layers) while on the abaxial side only 400 μm (8 9 cell layers). The number of chlorenchyma cell layers in the lamina (section B and C in Fig. 3) is reduced up to 3, caused by the low thickness of the blade. In the thin intercostal areas of the lamina, at least a few chloroplasts can be found in all cell layers of the mesophyll.

No hypodermal fibre bundles that are typical for leaves of other *Dracaena* species (Klimko *et al.*, 2018) have been found.

The stomata of *D. camerooniana* are anomocytic, with linear axilar orientation. While on the adaxial leaf surface, only a few randomly distributed stomata (3 stomata per mm^2) can be detected (Fig. 4C), the abaxial epidermis exhibits a mean number of 44 stomata per mm^2 (Fig. 4A). These stomata are found at the same level of the other elongated epidermis cells. The guard cells are of equal length (20 μm) on both sides and contain chloroplasts. In surface view, the epidermis cells are 336 $\pm$ 74.1 μm long (220 *336* 440 μm) and 25.4 $\pm$ 2.50 μm wide (22 *25.4* 30 μm). Its thickness is 20.3 $\pm$ 3.01 μm (14 *20.3* 24 μm). The outer periclinal wall is

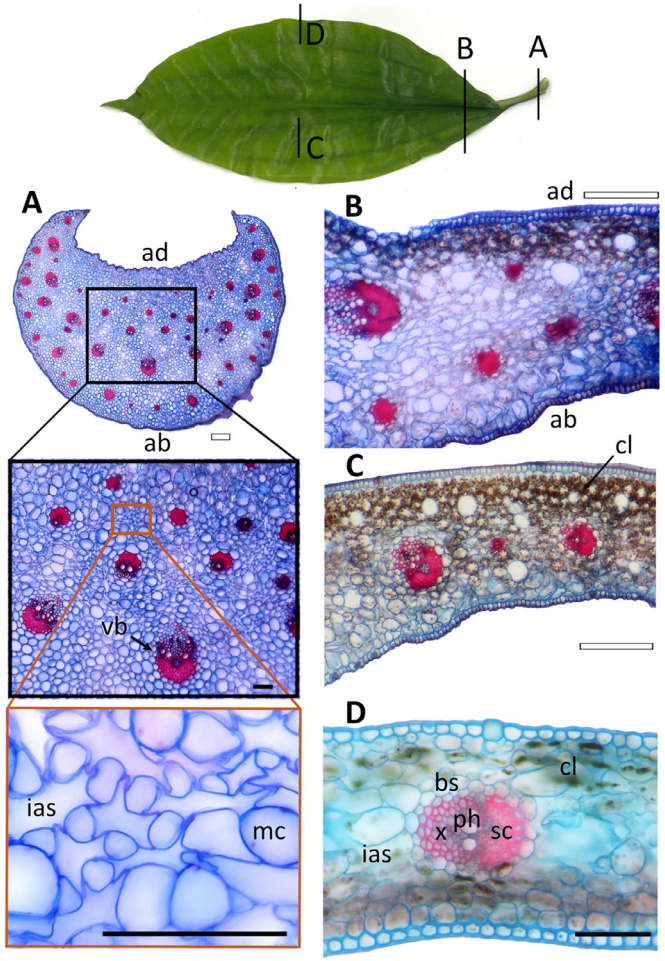

Fig. 3. Cross sections of the *Dracaena camerooniana* leaf, stained with astrablue-safranin. **A** pseudopetiole with several vascular bundles, **B** lamina base, **C** middle of the lamina with veins, **D** lamina near leaf margin. **ab** abaxial leaf side, **ad** adaxial leaf side, **bs** parenchymatous bundle sheath, **cl** chlorenchyma, **ias** intercellular air spaces, **mc** mesophyll cell, **ph** phloem, **sc** sclerenchyma, **vb** vascular bundle, **x** xylem. White scale bar 200 μm, black scale bar 100 μm.

1.6 $\pm$ 0.44 μm thick (1.1 *1.6* 2.6 μm). while the anticlinal wall is only 0.4 μm thick.

The thickness of the cuticle of the epidermis decreases from the pseudopetiole to the center of the lamina. Regarding the adaxial side,

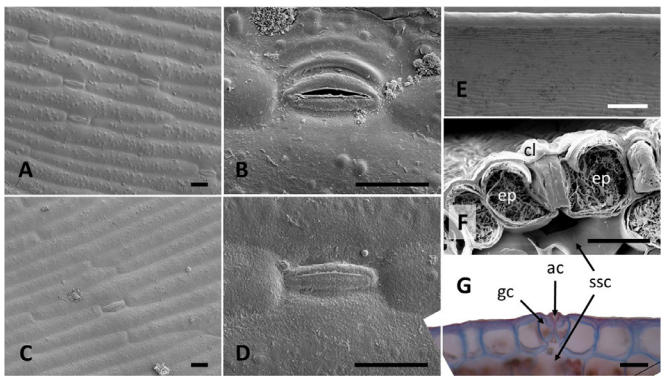

Fig. 4. Stomata and leaf margin of *D. camerooniana*. **A-F** SEM-photography, **G** light microscopic picture. **A** stomata distribution on abaxial leaf surface, **B** anomocytic stomata of abaxial side, **C** stomata distribution on adaxial leaf surface, **D** anomocytic stomata of adaxial side, **E** slightly enrolled entire leaf margin, **F** epidermal layer with cuticula forming the cuticular clasps of the stomata, guard cells not seen, **G** section of stomata. **ac** antechamber, **cl** cuticular ledges, **ep** epidermis cells, **gc** guard cells, **ssc** substomatal cavity. Black scale bar 20 μm, white scale bar 200 μm.

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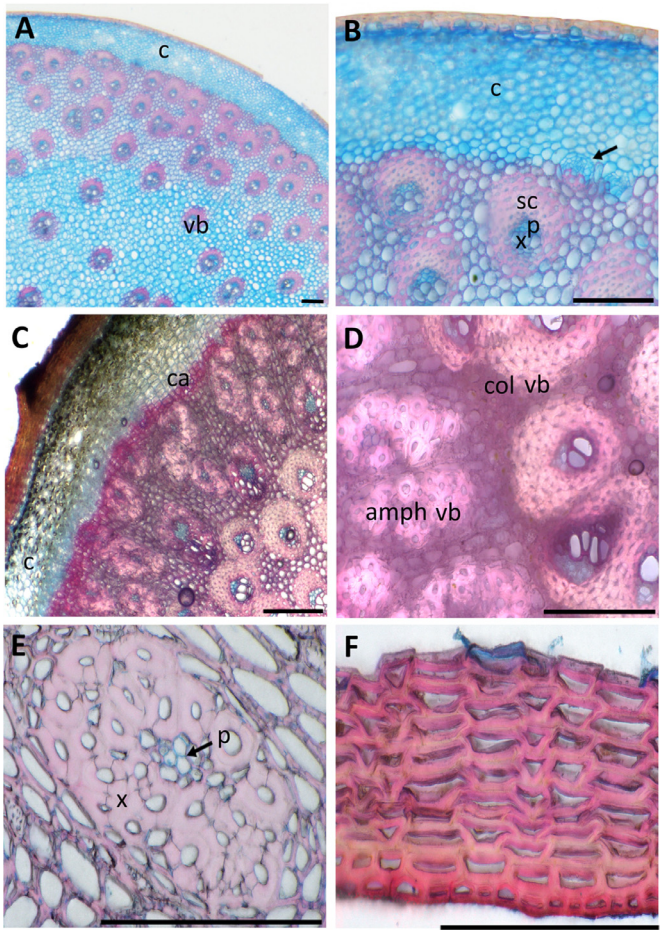

Fig. 5. *Dracaena camerooniana,* stem cross section, stained with astrablue-safranin. **A** primary stem with collateral vascular bundles, **B** detail of A, the arrow points to a young vascular bundle at the border to the cortex, **C** cross section of the secondary stem showing the cortex and the boundary between the primary vascular tissue (collateral bundles on the right of picture) and secondary vascular tissue (amphivasal bundles on the left), **D** detail of C, **E** amphivasal bundle, **F** storied cork cells (periderm) of the secondary stem. **amph vb** amphivasal vascular bundle, **c** cortex, **ca** cambium, **col vb** collateral vascular bundle, **ph** phloem, **sc** sclerenchyma, **vb** vascular bundle, **x** xylem. Scale bar 200 μm.

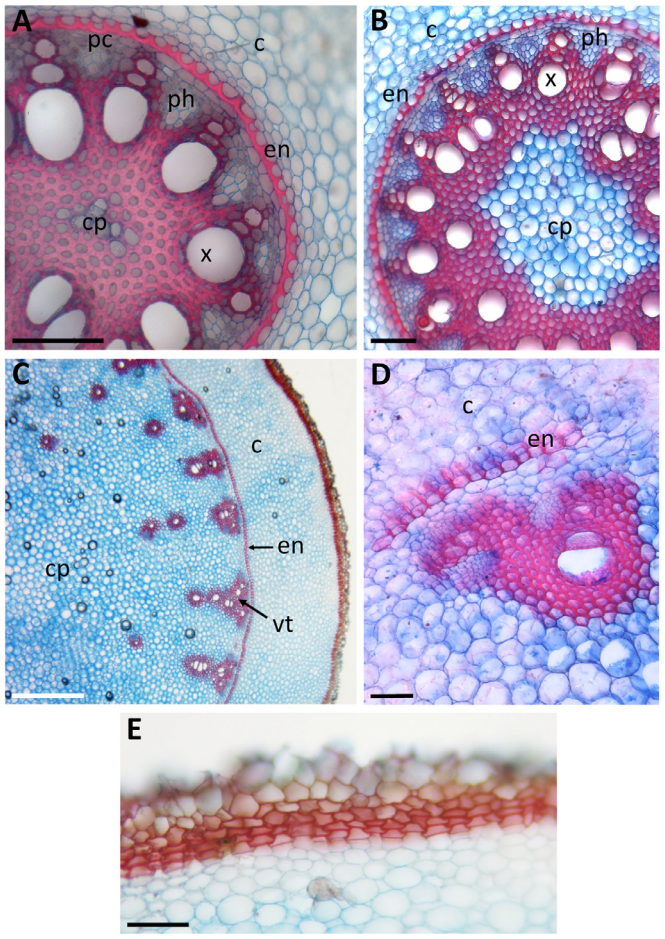

Fig. 6. Cross section of the *Dracaena camerooniana* root, stained with astrablue-safranin. **A** vascular cylinder of young root (phase B Fig. 7), **B** enlarging central pith (phase C Fig. 7), **C** tuber of 1 cm diameter with still intact endodermis, **D** disrupted endodermis and fragmented vascular tissue (phase E Fig. 7), **E** storied cork layers in secondary dermal tissue. **c** cortex, **en** endodermis, **cp** central pith, **pc** pericycle, **pe** periderm, **ph** phloem, **vt** vascular tissue, **x** xylem. Black scale bar 100 μm, white scale bar 1 mm.

the size varies from 2.1 *2.7* 3.4 μm (section A Fig. 3) to 1.2 *1.4* 1.8 μm (section B) and 0.9 *1.0* 1.3 μm (section C). The values at the abaxial side even differ from 2.2 *2.8* 3.4 μm (section A) and 0.9 *1.2* 1.7 μm (section B) to 0.6 *0.8* 1.0 μm. Furthermore, the abaxial cuticle shows randomly distributed cuticular bumps (Fig. 4A).

The tissue distribution in *Dracaena camerooniana* stem cross sections varies depending on age and thickness. Nevertheless, several basic characteristics can be observed (Fig. 5). The primary vascular bundles of the stem are collateral with all xylem poles orientated inwardly (Figs. 5A and B). The bundles are surrounded by sclerenchyma forming a broader sheath near the phloem parts. The number of vascular bundles increases towards the stem periphery. The cortex forms the outer part of the stem, showing chloroplasts in its periphery. In the primary stem, this cortex is 400 μm broad. The protective tissue outwards is formed by a single layered epidermis and a single layered sclerenchymatic hypodermis (together 50 μm) (Fig. 5B). The soon starting remeristematization of the cortical parenchyma leads to a cork cambium that produces storied cork cells (Fig. 5F), identified via Sudan III staining.

For the secondary growth, monocotyledons develop a cambium ring between the cortex and the primary vascular tissue (Fig. 5C). This secondary thickening meristem, also called monocot meristem, continually produces secondary amphivasal vascular bundles that are radially elongated. In *Dracaena camerooniana*, its radial size varies from 150 to 250 μm; its tangential size varies from 100 to 175 μm. These bundles only show a central phloem surrounded by a ring of mature tracheids with cell walls 10.3 $\pm$ 2.20 μm thick (7.3 *10.3* 14.7 μm) (Fig. 5E), the latter rather contribute to stiffness than to water transport. While Fig. 5B shows a young vascular bundle at the border to the cortex of a primary stem, Fig. 5D shows the boundary between the primary and the secondary vascular tissue.

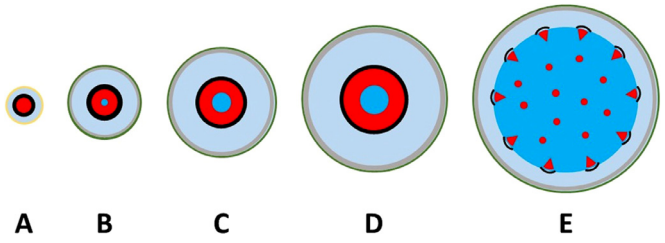

Fig. 7. Development of the *Dracaena camerooniana* roots according to phases A-E in Table 1. **A** young root with rhizodermis and vascular tissue inside the endodermis, the pith is nearly invisible, **B** beginning parenchymatous pith development inside the vascular cylinder and initiation of cambial activity underneath the exodermis, **C, D** the pith diameter increases contemporaneous with the number of endodermis cells, **E** tuberous root of 2 cm diameter with ruptured endodermis and fragmented vascular tissue. **Colours:** red: vascular tissue, black: endodermis, dark blue: parenchymatous pith, light blue: parenchymatous cortex, yellow: rhizodermis, green: exodermis, grey: cambial activity, here called periderm.

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The primary roots of *Dracaena cameroonianа* show a polyarch stele that is characteristic for monocots. The numerous vascular xylem and phloem poles are embedded in a sclerenchyma sheath. The vascular cylinder has a single layered pericycle and is sur rounded by the tertiary endodermis with thickened radial and inner periclinal walls (Fig. 6A).

With increasing root diameter, the central pith enlarges consider ably. To that effect, the cells of the endodermis start to divide (num ber increasing from 38 to 206) and simultaneously stretch in tangential size more than threefold (from 10 *14.3* 17 μm to 32.9 *45.2* 72.9 μm) after developing the U shaped cell wall thicken ings, with the result that the inner periclinal wall is thinned to half of the original thickness (from 3 *5.0* 6.1 μm to 2 *2.6* 3.4 μm). During tuber formation, the parenchyma of the pith markedly increases eventually (Fig. 6B/C) causing disruption of the endodermis (Fig. 6D/7E).

In the outer part of the root, cortical parenchyma is well devel oped (Fig. 6C). Raphides are present. At the beginning, the rhizoder mis is still present but soon peeled away. The cambial activity underneath the exodermis of the roots produces several storied cork layers (Fig. 6E), again identified via Sudan III staining. In a tuber of 2 cm thickness, the cork layer is 100 μm thick.

3.3. *Analysis of major nutrients in* D. camerooniana *roots*

The content of the major nutrients, protein, fat, and carbohydrates were determined in two *Dracaena cameroonianа* root samples (Table 2), as well as the amino acid composition (Table 3).

Water (77%) and protein content in dry matter (5.3% d.m.) were in the same range as described for comparable edible roots like cassava (water content: 56 79%; protein: 3.3 3.4% d.m.) (Yeoh and Truong 1996; FAO 2020) and potatoes (water content: 78%; protein: 9.2% d. m.) (Souci *et al.*, 2016). The fat content was found to be lower (0.2% d. m.) but still in a similar range as reported for cassava (0.8 1.0% d.m.; (FAO 2020)) and potatoes (0.5% d.m.; (Souci *et al.*, 2016)). Minerals, analysed via the ashes, account for 0.8% d.m in *D. cameroonianа* roots while three to sixfold higher contents are given for cassava (2.6 2.9% d.m.; (FAO 2020)) and potatoes (4.6% d.m.; (Souci *et al.*, 2016)).

Total carbohydrates were calculated as difference from the sum of protein, fat and ash to 100% of dry matter. The amount (93.7% d.m.) is comparable to that of cassava (79 89% d.m.; (Ketiku and Oyenuga 1972). Lower amounts are given for available carbohydrates in pota toes (66.7% d.m.; (Souci *et al.*, 2016)). This excludes non digestible carbohydrates like inulin or cellulose. Therefore, the sum of total car bohydrates would be higher than the noted amount. Analyses of indi vidual sugars point to remarkably high contents of fructose in the roots of *D. cameroonianа* (2.8% d.m.) compared to cassava (0.3 0.8% d. m.; (Ketiku and Oyenuga 1972)) and potatoes (0.8% dry matter; (Souci *et al.*, 2016)). Sucrose contents of *D. cameroonianа* and cassava are found to be in the same range (1.6 3.0% d.m. and 2.1 4.4% d.m.; (Ketiku and Oyenuga 1972)), while the content of glucose in cassava exceeds that found for *D. cameroonianа* (0.1 0.4 % d.m. vs. 0.5 1.7 % d. m.; (Ketiku and Oyenuga 1972)). Potatoes are reported to contain less sucrose (1.4% d.m.) but more glucose (1.1% d.m.) compared to *D. cameroonianа* (Souci *et al.*, 2016).

The nutritional value of the protein fraction depends on its amino acid composition, mainly the essential amino acids. Thus, the con tents of threonine, valine, leucine, isoleucine, phenylalanine and lysine are given and compared to those in cassava and potatoes in Table 3. *Dracaena cameroonianа* as well as cassava provide much lower amounts of these essential amino acids when compared with potatoes. For *D. cameroonianа*, between 12% (isoleucine) and 27% (valine) of the corresponding values in potato protein was found, while the range for cassava runs from a minimum of 38% (phenylala nine) to a maximum of 50% (lysine).

3.4. *Analyses of minor nutrients in* D. camerooniana *leaves*

The analyses focused on vitamins and ashes (as a hallmark for total amount of minerals) in raw and traditionally cooked leaves. The content of ashes served as sum parameter for minerals. In addition, amounts of vitamins C (ascorbic acid), B_1 (thiamine) and B_2 (ribofla vin) were investigated (see Table 3). Data for cassava and *Gnetum africanum*, which are frequently consumed as leafy vegetable in Angola and neighbouring countries as well, served as comparative values (Table 4).

Vitamin contents analysed in raw *D. cameroonianа* leaves are in the same order of magnitude but lower than those reported for *G. africanum*. In comparison, we found that raw *D. cameroonianа* leaves contain 61 to 74% of the thiamine and riboflavine (52 μg vs. 70 μg for B1; 97 μg vs. 160 μg for B2), while ascorbic acid accounts only for about 10% of the amount reported for *G. africanum* (3 mg vs. 44 mg) (FAO 2020). Up to five fold higher amounts of vitamins B1

Table 2
Major nutrients in *Dracaena cameroonianа* root; data based on 100 g dry matter (d.m.); [1]: (FAO 2020); [2] (Yeoh and Truong 1996); [3] (Souci *et al.*, 2016); [4] (Ketiku and Oyenuga 1972); *calculated as difference from the sum of protein, fat and ash to 100% of dry matter; ** available carbohydrates.

	D. cameroonianа	Cassava	Potato
Water content [g/ 100 g]	76.8	56-79[1], [2]	77.8[3]
Dry matter [g/ 100 g]	23.2	21-44[1]	22.2[3]
Protein [g/100 g]	5.3	3.3-3.4[1]	9.2[3]
Fat [g/ 100 g]	0.2	0.8-1.0[1]	0.5[3]
Carbohydrates [g/ 100 g]	93.7*	79.0-83.4[1]** 79-89[4]	66.7[3]**
Sucrose [g/ 100 g]	2.3	2.1-4.4[4]	1.4[3]
Glucose [g/ 100 g]	0.3	0.5-1.7 [4]	1.1[3]
Fructose [g/ 100 g]	2.8	0.3-0.8[4]	0.8[3]
Ashes [g/ 100 g]	0.8	2.6-2.9[1]	4.6[3]

Table 3
Amino acids in *D. cameroonianа* root, data based on 100 g protein; [3] (Souci *et al.*, 2016); [5] calculated from ("FoodData Central").

	D. cameroonianа [g/100 g Prot]	Cassava[5] [g/ 100 g Prot]	Potato[3] [g/100 g Prot]
Threonine	0.99	2.01	4.50
Valine	1.76	2.57	6.50
Isoleucin	0.60	1.99	5.00
Leucine	0.91	2.87	7.00
Phenylalanine	0.96	1.91	5.00
Lysine	1.35	3.24	6.50

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Table 4
Micronutrients in raw and processed *D. camerooniana* leaves, data based on 100 g fresh weight; [6]: (FAO 2020).

		Vitamin C [mg/ 100g]	Vitamin B1 [μg/ 100g]	Vitamin B2 [μg/ 100g]	Ashes [g/ 100g]
D. camerooniana	raw	3.14	52.1	97.4	1.97
	Cooked	n.n.	15.8	32.8	0.79
G. africanum[6]	raw	44	70	160	2.6
	Cooked	18	50	100	2.6
Cassava[6]	raw	33	250	460	2.1
	Cooked	13	170	300	2.2

and B2 compared to *D. camerooniana* are reported for cassava leaves (250 μg and 460 μg, respectively) (FAO 2020). In this study, cooking resulted in a complete loss of vitamin C in *D. camerooniana*, whereas the content in the *G. africanum* and cassava is lowered by 60% only (FAO 2020). For thiamine and riboflavin the preparation of *D. camer ooniana* leaves leads to a loss of ~70%. Losses in boiled *G. africanum* and cassava account for only 30 to 40% (FAO 2020).

Our findings are in accordance with a reported decrease in vita min B2 content of 20% 67% in different traditionally prepared and cooked African leafy vegetables (Schonfeldt and Pretorius, 2011).

Minerals were analysed by the content of ashes in the leaves. Amounts found for *D. camerooniana* are similar to those reported for cassava and *G. africanum* (2.0 g/100 g vs. 2.1 g/100 g and 2.6 g/100 g, respectively) (FAO 2020). The content decreases by 60% when the leaves are cooked. This is in contrast to data reported for *G. africanum* and cassava, were no loss of minerals was found.

4. Discussion

4.1. Anatomy

4.1.1. Leaf

The majority of dragon tree species has a different appearance than *D. camerooniana*, particularly observable in anatomical details. Most of the few investigated species (*D. cinnabari, D. jayniana, D. ombet, D. serrulata, D. tamaranae*) exhibit amphistomatic leaves with slightly or deeply sunken tetracytic stomata that are, in some species, arranged in bands (Klimko *et al.,* 2018). Here, we neither observed sunken tetracytic stomata nor their arrangement in bands. The adax ial leaf surface shows only very few anomocytic stomata. Still, *D. kaweesakii*, a newly described species from the higher mountains in Thailand (Wilkin *et al.,* 2013), shows a similar tissue distribution, both with anomocytic stomata at the same level of the epidermis cells, and thin leaves of 0.2 0.4 mm (*D. camerooniana*) and 0.4 0.45 mm (*D. kaweesakii*), respectively. A comparison with the phylo genically closer species *D. surculosa* and *D. ovata* (Bos 1984) are not possible due to missing anatomical data. On the other side, sunken stomata are adaptations to reduce the rate of transpiration, typically for xerophytes. The above mentioned *Dracaena* species showing sunken tetracytic stomata are growing in dry habitats such as in Socotra (*D. cinnabari*), in NE Africa (*D. ombet*), on limestone karsts in Thailand (*D. jayniana*), in the Arabian Peninsula (*D. serrulata*) or on cliffs in Gran Canaria (*D. tamaranae*) (Marrero et al., 1998, POWO).

According to Rudall et al., 2017, the anomocytic stomata type (without subsidiary cells) is the common type in Asparagaceae. This observation probably confirms the statement of Bos (1984) that *Dra caena* is a comparatively ancient group in Liliaceae, the family of which *Dracaena* was formerly part of. Anomocytic stomata probably represent an ancestral character (Florin 1950). However, it is under debate, whether the ancestral state of stomata in monocots is anomo cytic or paracytic (Rudall et al., 2017).

The reduced number of palisade layers, defined as chlorenchyma with vertically elongated, is another similarity to *D. kaweesakii* (Klimko *et al.,* 2018). While *D. draco, D. tamaranae, D. jayniana, D. ombet, D. serrulata* and *D. cinnabari* exhibit 2 to 5 palisade layers, *D. kaweesakii* shows only 1 to 2 layers while it lacks in *D. camerooniana* or at maximum consists of one layer. The reduction of palisade cell layers could be explained by the fact that *D. camerooniana* is an understory plant in rainforests where only diffuse light reaches the forest floor. As palisade cells help to facilitate more equal distribution of collimated light to chloroplasts within the leaf (Vogelmann and Martin 1993), they might not be essential in undergrowth vegetation. Further studies should be conducted comparing leaves after different light exposure. The reduced leaf thickness (0.3 0.6 mm) again con firms the adaptation to wet conditions compared to the xeromorphic leaves of other *Dracaena* species that even contain water storage tis sue in their central mesophyll region (Klimko *et al.,* 2018).

The horizontal orientation of the vascular bundles in *Dracaena* (xylem and phloem perpendicular to normal orientation) was already described (Klimko *et al.,* 2018, Tomlinson and Fisher 1971). But nei ther hypodermis nor hypodermal fibre bundles comparable to *D. draco, D. tamaranae, D. jayniana* and *D. kaweesakii* (Jura Morawiec & Marcinkiewicz 2020; Klimko *et al.,* 2018) have been found in the leaves of *D. camerooniana*.

4.1.2. Stem

The tissue distribution as well as the structure of the vascular bun dles in the secondary stems of *D. camerooniana* with collateral bun dles in the primary axis and amphivasal ones in the secondary tissue is comparable to other arborescent monocotyledonous plant species (Rudall 1991) including other *Dracaena* species (Jura Morawiec & Tulik 2015, Jura Morawiec 2015, Tomlinson and Zimmermann 1969). The same refers to the secondary dermal tissue that is responsible for the protection of the inner ones. Although Jura Morawiec et al., (2015) state that monocotyledons do not develop a type of periderm like that of dicotyledons or conifers, other authors do use the term periderm for the description of storied cork tissues produced by the periclinal division of meristematic cells (Kauff *et al.,* 2000, Crang *et al.,* 2018). Regardless the designation, the stem is markedly covered by this secondary cork tissue.

4.1.3. Root

In contrast to other roots of *Dracaena* species like D. *draco* (Jura Morawiec et al., 2020, Tomlinson and Zimmermann 1969) no second ary growth with new vascular bundles produced by a secondary thickening meristem was observed. Instead, the central parenchyma tous pith strongly increases its diameter causing the rupture of the vascular tissue and the endodermis. The adaptation of the endoder mis to growth in girth by cell division and circumferential widening of cells as well as its disruption at some point were already described by Gelder (2013). Its protective role is replaced by a secondary der mal tissue. Furthermore, the primary function of the vascular tissue (water and nutrient absorption and transport) is replaced by the function of storage in these root tubers. In their review on root anat omy of monocotyledons, Kauff *et al.,* (2000) only mention small lat eral root tubers in the genera *Schelhammera* and *Kuntheria* (Colchicaceae) but these have not been investigated anatomically in detail. So far, our anatomical descriptions of *D. camerooniana* root

tubers mainly formed by the enlarged parenchymatous pith are unique. Finally, the question remains why *D. camerooniana* produces such prominent storage tubers. This may be explained by either the evolutionary history since many other *Dracaena* species occur in drier savannah habitats or by its huge distribution area in different types of forests and woodlands, including seasonally dry habitats.

4.2. *Nutritive values of* Dracaena camerooniana

Subsequent to the anatomical characterisation of the plant materials, leaves and tubers were analysed for their nutritive ingredients to provide data concerning its contribution to diets and nutrition in North Angola. The analyses of the major nutrients such as protein, fat, carbohydrates and ashes in the roots of *Dracaena camerooniana* point to all similar contents as reported for cassava, which belongs to commonly eaten roots and is widely grown in tropical and subtropical countries. Contents of fat tend to be slightly lower, whereas higher amounts of carbohydrates were calculated for *D. camerooniana.* Nevertheless, due to smaller contents of essential amino acids in the protein fraction, *D. camerooniana* cannot be considered a source of high protein quality. Furthermore, the sulphur containing essential amino acids methionine and cysteine as well as tryptophan have been neglected in the considerations. Their amounts have not been analysed, as they undergo conversion or decay reactions under the acidic conditions applied here for protein hydrolysis. Amounts of those amino acids might increase the nutritional value of *D. camerooniana* roots.

Remarkable differences have been observed in the composition of the carbohydrate fraction of *D. camerooniana*. Especially the content of fructose (2.8% d.m.) which is more than 3 fold higher than in cassava and potatoes (up to 0.8% d.m., see Table 2). At the same time, the amount of glucose shows the opposite with the lowest contents in *D. camerooniana* (0.3% d.m.) and up to six times higher amounts in potato and cassava (up to 1.7% d.m.). The different proportions of glucose and fructose result in glucose fructose ratios of up to 2 for cassava and 1.4 for potatoes, while in the root of *D. camerooniana* we only detected a ratio of about 0.1. Glucose and fructose in cassava and potatoes might partly result from the degradation of sucrose and starch, which contain the monosaccharides in equimolar proportions or only provide glucose leading do glucose fructose ratios $\geq$1. The inverse ratio in *D. camerooniana* might point to fructose containing polysaccharides like inulin or other fructanes as storage carbohydrates in contrast to starch in the other listed tubers. This would be in good accordance with an only weak positive proof of starch after iodine treatment (data not shown). Inulin is a known prebiotic dietary fibre and therefore could contribute to a healthy digestion and the prevention of gastro intestinal diseases (Kleessen *et al.,* 2001; Kalyani Nair *et al.,* 2010).

The high content of fructose, which is sweeter than sucrose, also matches the fact that the roots of *D. camerooniana* are chewed as a sweet in Angola.

The nutritional value of the leaves of *D. camerooniana* was evaluated based on the contents of vitamins B1, B2 and C and on mineral contents, determined via the ashes. Thiamine and riboflavin were found to be about 61 to 74% of the amount reported for *G. africanum*, which is a commonly cooked leaf vegetable in Angola. Compared to cassava only 20% of the amounts of those vitamins published for cassava leaves (FAO 2020) were found.

For vitamin C, only 10% of the content in *G. africanum* and cassava could be detected (3 vs. 44 and 33 mg/100g fresh weight, respectively) *D. camerooniana*. Further reductions of the water soluble vitamins were observed due to traditional cooking procedures as already reported for other leafy vegetables (Schonfeldt and Pretorius, 2011). For vitamin C, a complete loss was documented, while the loss of B vitamins accounted for about 70%. Similar effects were observed for minerals, which were reduced by 60% due to the preparation. No loss of minerals due to cooking was reported for *G. africanum* and cassava. This might be caused by different preparation techniques. In sum, 100g boiled leaves correspond to 1.3% (thiamine) or 2.5% (riboflavin) of the recommended daily intake of a male adult (FAO 2020). A gentle preparation of the leaves, for example by steaming instead of cooking, would reduce the loss of vitamins (Davidson and Monulu 2018) and might provide a possibility to enhance the nutritional value of the leaves.

In this study, we did not include the analysis of antinutrients. Nevertheless, these could still play an important role in consumption, just as cassava for example cannot be consumed without further processing due to the contained cyanogens (Cardoso *et al.,* 2005; Montagnac *et al.,* 2009). For *Dracaena camerooniana*, that should be checked in further studies.

5. Conclusions

Inspite of its rather average nutritional values, the root of *Dracaena camerooniana* is an valuable addition to the diet of the North Angolan population and may have a high potential for large scale production in a regional horticulture since it is easily propagated via cuttings, as first propagation tests in the Botanical Garden Uíge of the Universidade Kimpa Vita had shown. Further investigations should focus on oligo and polysaccharides as the tubers have a high fructose content, which could indicate inulin as a prebiotic and health promoting ingredient. Another field of interest is the impact of a gentler food preparation to preserve water soluble vitamins and thus to enhance the nutritional value.

Additionally, the anatomical investigation of *D. camerooniana* describes an extraordinary case of secondary growth caused by an increasing central parenchymatous pith that is unique in monocots and worth investigating further.

Declaration of Competing Interest

None.

Declarations

Availability of data and materials: The data mentioned was thoroughly analysed and reported in this work.

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Authors' contributions: Thea Lautenschlager and Christoph Neinhuis carried out the microscopic studies and drafted the manuscript. Mawunu Monizi collected the plant samples. Lara Frommherz provided the analyses of micronutrients in the leaves of *Dracaena camerooniana*. Thomas Henle and Anke Forster were responsible for analyses of major nutrients and amino acid composition in the tubers of *Dracaena camerooniana.*

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