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ENDOCARP MORPHOLOGY OF AFRICAN CELTIS (CELTIDACEAE/ULMACEAE)

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SUMMARY

Endocarp morphology of 14 species of mainly African *Celtis* was examined using light and scanning electron microscopy. Macro- and micro-morphological characters included endocarp shape, colour, size, surrounding rim and SEM examination of the outer layer of the endocarp. Different classes of shape and sculpture were recognised. A key for the identification of the investigated taxa based on endocarp characters is provided.

Key words: *Celtis*, Africa, endocarp, sculpture, shape.

INTRODUCTION

Celtidaceae (formerly Ulmaceae–Celtidoideae) (Elias, 1970; Grudzinskaya, 1976; Omori & Terabayashi, 1993; Judd et al., 1994; Ueda et al., 1997) comprise c. 150 species classified in 9 genera, distributed in the Northern Hemisphere and in Africa, up to southern Africa. Some species of the family are ornamental; some are used for timber and reforestation.

In the flora of Africa, Celtidaceae is a small family with the main genus *Celtis*, at present represented by 12 species. The habitat of *Celtis* species reaches from North Africa (Algeria, Libya and Morocco) to South Africa and Madagascar. Several tree species are found in the rain forest (*Celtis tessmannii* Rendle, *C. mildbraedii* Engl.) or in semi-deciduous forest (*Celtis adolfi-friderici* Engl., *C. prantlii* Engl., *C. zenkeri* Engl.). Other *Celtis* species are shrubs or small trees of rain forest undergrowth (*C. gomphophylla* Baker), or found on the forest/savannah boundary, sometimes in montane forest (*C. africana* Burm.f.). One species (*C. toka* Forssk.) is a fairly large tree with a compact crown, living beside streams or planted in villages in the Sudano-Sahelian zone.

The fruits in Ulmaceae and Celtidaceae families are of two general types: dry and variously winged samaras or fleshy drupes. A wide variety of dry winged fruits occurs in the Ulmaceae and, along with endocarp features, are useful in distinguishing genera. Endocarps in the Ulmaceae are generally thin and soft except for *Zelkova* and *Hemiptelea*. Drupes characterize all genera of the Celtidaceae except for *Pteroceltis*, which has a winged drupe. Size ranges from approximately 1–2 mm in diameter in *Lozanella*, *Parasponia*, and *Trema* to up to 23 mm broad in *Ampelocera glabra*. Endocarps in the Celtidaceae are usually globose (except for *Ampelocera*, which can be ellipsoid, and *Gironniera* and *Lozanella*, which are lenticular), thick-walled and hard

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due to calcium carbonate in *Celtis* and sclereids in *Aphananthe* (Manchester, 1989). Reticulate surface sculpturing is found in *Celtis*, *Peteroceltis*, *Trema*, and *Parasponia*. *Pteroceltis* has spherical endocarps very similar to *Celtis* except for a pair of prominent rounded wings.

The cotyledons are usually folded in the Celtidaceae. *Celtis* is distinguished by its broad contorted cotyledons (Killip & Morton, 1931). Seed coat (testa) features vary among the genera. *Celtis*, *Chaetachme*, and *Pteroceltis* have the most elaborate seed surface sculpturing in the family with many holes. *Lozanella*, *Parasponia*, and *Trema* have a lineate seed coat surface (Takaso & Tobe, 1990).

The drupaceous fruits of the Celtidaceae vary in colour from bright yellow to orange, deep red, and purple and are primarily bird-dispersed. *Celtis philippensis* var. *wightii*, which grows in coastal forests in Melanesia, has been suggested to be water-dispersed (Soepadmo, 1977).

Most systematists agree that data concerning the macro- and microstructure of fruits and seeds are very significant for the classification of Angiosperm taxa. Heywood (1971) drew attention to the importance and impact of scanning electron microscopic (SEM) imaging in the study of systematic problems, as very valuable information has been provided by this technique. During the last decades, scholars have applied scanning electron microscopy to morphological studies of seeds and small fruits. Micro morphology and ultra-structural data have contributed useful information for evolution and classification of seed and fruit plants and play an important role in the modern synthetic systems of Angiosperms.

Most of the following studies focused on intrageneric seed coat variation in various structures (see Aniszewski et al., 2001); for the colours of seeds refer to Dahlgren & Clifford (1982). In Celtidaceae, external seed morphology and germination were studied by Metcalfe & Chalk (1950), Polhill (1964), Whiffin & Tomb (1972), Corner (1976), Canne (1980), and Barthlott (1981). These studies were focused on germination, extraction, nursery practice, germinative energy, and germinative capacity, while investigations on seed and not so much on endocarp morphology, and sculpture of endocarp are lacking. The present study set out to fill some of the gaps in our knowledge, focusing on the micro- and macro-morphological (Binocular and SEM) characters of endocarp of (mainly) African *Celtis* spp. to decide on the importance of endocarp characters as a criterion for separating species within this genus.

MATERIAL AND METHODS

Most of the endocarp material was taken from herbarium vouchers, especially from the herbarium at Wageningen (WAG), but also from sheets on loan from other herbaria (B, BR, K, L, P, W), see Table 1.

In general endocarps of *Celtis* can be inspected easily. Mature fruits were taken from the specimens, as far as available. The dried fruits were boiled in water for 10 min. and brushed clean, then rinsed in water with bleach for 10 min. to obtain clean endocarps. These were first examined by binocular (B) or light microscope (LM). Subsequently endocarps were mounted on stubs with double adhesive tape. The stubs were sputter-coated with gold-palladium for 2–3 min. in a Polaron Equipment Ltd. SEM coating unit E5100. After coating, the specimens were examined with a Joel 5200 scanning electron

Table 1. List of specimens used in (B/SEM) endocarp studies. B = binocular, SEM = electron microscope.

Taxon	Collector	Country of origin
C. adolfi-friederici Engl.	*Mildbraed 825*	Cameroon (K)
C. africana Burm.f.	*Dahlstrand 579*	South Africa (C)
C. australiensis Sattarian	*Chesterfield, E.A. 389*	Australia (L, PERTH)
C. australis L.	*Sattarian 03BG15801*	Italy (Bot. Gdn WAG)
C. bifida Leroy	*O'Connor 44*	Madagascar (K)
C. gomphophylla Baker	*Chapman 9361*	Malawi (MO)
C. malagasica Sattarian	*Phillip, P.B. 2938*	Madagascar (MO)
C. mildbraedii Engl.	*Leeuwenberg 4078*	Ivory Coast (WAG)
C. philippensis Blanco	*Soepadmo 7225*	Malaysia (L)
C. prantlii Priemer ex Engl.	*Le Testu 1479*	Gabon (WAG, P)
C. tessmannii Rendle	*Liben 2254*	D.R. Congo (BM)
C. toka Forssk.	*De Wilde, W.J.J.O. 5287*	Cameroon (WAG)
C. wightii Planch.	*Ludanga 782*	Tanzania (C)
C. zenkeri Engl.	*Leeuwenberg 6227*	Cameroon (WAG)

microscope. All photomicrographs were taken at the Department of Plant Cytology and Morphology, SEM Laboratory, Wageningen University, The Netherlands.

RESULTS

Endocarp characters prove to be important to distinguish species of African *Celtis* in Ulmaceae/Celtidaceae. The endocarp shape varies from elliptic to ovoid, lenticular, or ovoid-beaked. The size of the endocarp ranges from small (4 by 3 by 2 mm) to large (11 by 10 by 8 mm) and is very useful in terms of identification of species. The endocarp colour varies from white, cream, and grey to brown and helps to separate species. The endocarp shape varies from globular to polygonal. The outer layers of the endocarp differ; they curve and are raised from the bottom to the top but in different directions. The apex of the endocarp is round or beaked. The ridges of the endocarp are another character; from a faint ridge to 1–3 clear ridges can be seen among African *Celtis*. Outer layers of the endocarp (sculpture) vary from smooth with different size of holes, to a prominent rough surface, and membranous platelets can be present. The ratio of D/L endocarp length also varies from 3/4 to 6/8, for more details of the species see Table 2.

ENDOCARP CHARACTERS

Endocarp shape

The shape of the endocarp showed variation among the African *Celtis*. Most of the endocarps vary from ovoid-acuminate to ovoid. They are ovoid-acuminate in *C. australis*, *C. bifida*, *C. philippensis*, *C. prantlii*, *C. toka*, *C. wightii*, and *C. zenkeri* (Table 2), lenticular-ovoid in *C. africana* and *C. tessmannii*, angular-ovoid in *C. gomphophylla*, and globose to ellipsoid in *C. adolfi-friederici*.

Table 2. Endocarp morphology of African *Celtis* spp., *C. philippensis* s.s. and *C. australiensis*.

Taxon	Size (mm)	Colour	Shape and texture	Ratio diam./ length	Ridges	Shape	Outer layer of the endocarp
C. adolfi-friederici	10 by 9 by 8	white	globose to ellipsoid, acuminate, reticulate, (rough)	9/10	a few prominent longitudinal ridges	polygonal, not isodiametric	raised different boundaries in different directions
C. africana	4 by 3 by 2	grey	lenticular-ovoid, reticulate, (rough)	3/4	one prominent ridge	polygonal, not isodiametric	curvy boundaries not raised much; tip beaked
C. australiensis	6 by 4 by 4	white	ovoid-acuminate, (smooth)	4/6	two ridges	polygonal, not isodiametric	boundaries curvy, not raised
C. australis	6 by 6 by 5	greyish white	ovoid, acuminate reticulate, (rough)	6/6	two prominent longitudinal ridges	polygonal, not isodiametric	raised boundaries at different directions
C. bifida	6 by 5 by 4	white	ovoid, acuminate reticulate, (rough)	5/6	two prominent ridges	polygonal, not isodiametric	raised boundaries at different sides
C. gomphophylla	4 by 3 by 2.5	dark brown	angular-ovoid, (rough)	3/4	one ridge muricate surface	not polygonal, different boundaries from the bottom	few boundaries from the bottom middle, one side flat, apex beaked
C. malagasica	10 by 8 by 9	cream	globose to elliptic, (smooth)	8/10	two ridges (prominent) longitudinal	polygonal, not isodiametric	boundaries curvy, semi raised
C. mildbraedii	6 by 5 by 3	grey	rhomboid, reticulate, (rough)	5/6	one ridge	polygonal, not isodiametric	boundaries curvey and raised
C. philippensis s.s.	6 by 5 by 5	grey	ovoid, (smooth)	5/5	one ridge	not polygonal	faint boundaries, smooth
C. prantlii	8 by 6 by 5	white	ovoid-, acuminate, reticulate, (smooth)	6/8	one ridge	polygonal, not isodiametric	different boundaries but not raised so much
C. tessmannii	11 by 10 by 8	brown	lenticular, (rough)	10/11	a few ridges	polygonal, isodiametric	raised boundaries, curvy
C. toka	7 by 6 by 6	grey	ovoid-acuminate, (smooth)	6/7	one ridge	polygonal	boundaries curvy
C. wightii	8 by 6 by 5	white	ovoid-acuminate, (smooth)	6/8	one ridge	polygonal	faint boundaries
C. zenkeri	5 by 4 by 4	cream	ovoid- acuminate, reticulate, (rough)	4/5	one ridge and transverse connecting ridges	polygonal, not isodiametric	boundaries curvy and raised not much

Two classes of endocarp epidermis surface can be distinguished: smooth and rough. *Celtis philippensis* has a smooth epidermis, and *C. adolfi-friederici*, *C. africana*, *C. bifida*, *C. gomphophylla*, *C. mildbraedii*, *C. tessmannii*, and *C. zenkeri* have a rough epidermis.

Endocarp size

The size of the endocarp also varies. The range is from the smallest one (4 by 3 by 2 mm) in *C. gomphophylla* and *C. africana* to the largest one (11 by 10 by 8 mm) in *C. tessmannii*, but the majority of the endocarps measure about 6 by 5 by 5 mm in *C. australis*, *C. bifida*, *C. mildbraedii*, *C. philippensis*, *C. toka*, *C. wightii*, and *C. zenkeri*.

The endocarp size is a good character, useful to separate *C. adolfi-friederici* and *C. tessmannii* from the rest of African *Celtis*.

Endocarp colour

The colours of the endocarp are diagnostic and of systematic interest among African *Celtis*. A white endocarp is seen in *C. adolfi-friederici*, *C. bifida*, *C. prantlii*, and *C. wightii*, while a grey colour is seen in *C. africana*, *C. australis*, and *C. mildbraedii*. *Celtis gomphophylla* has a dark brown endocarp; it is light brown in *C. tessmannii*, while *C. zenkeri* has a cream-coloured endocarp.

Ridges

The presence/absence of a ridge on the endocarp is a significant character in African *Celtis*. There are no ridges in *C. philippensis*, there is one main ridge in *C. africana*, *C. gomphophylla*, *C. mildbraedii*, *C. prantlii*, *C. toka*, *C. zenkeri*, *C. wightii* and a few ridges can be seen in *C. tessmannii* and *C. adolfi-friederici* (Table 2).

Endocarp sculpture (ornamentation)

African *Celtis* species often have a polygonal sculpture. This structure is formed by the ridges and cross-connection between the edges. Polygonal sculpture is found in *C. adolfi-friederici*, *C. africana*, *C. australis*, *C. bifida*, *C. mildbraedii*, *C. tessmannii*, and *C. toka*, and normally the surface is rough, especially in *C. tessmannii* and *C. adolfi-friederici*, and the polygons are curved. A non-polygonal shape is found in *C. gomphophylla*, but there are some prominent edges from the bottom. *Celtis philippensis* has also a non-polygonal shape and smooth surface.

Table 3. Description of endocarp surface (shape of outer layer of the endocarp) of selected species (SEM photographs).

Taxon	Description SEM
C. adolfi-friederici	Rough layers with different size of holes, prominent surface sculpturing, membranous platelets present
C. africana	Smooth layers and fissured layers
C. australis	Rough surface, with a few holes, membranous platelets present
C. mildbraedii	Smooth layers and crusts, continuous coverings usually without very prominent surface
C. tessmannii	Rough layers with holes, prominent surface sculpturing, membranous platelets present
C. wightii	Rough layers with different holes, prominent surface sculpturing

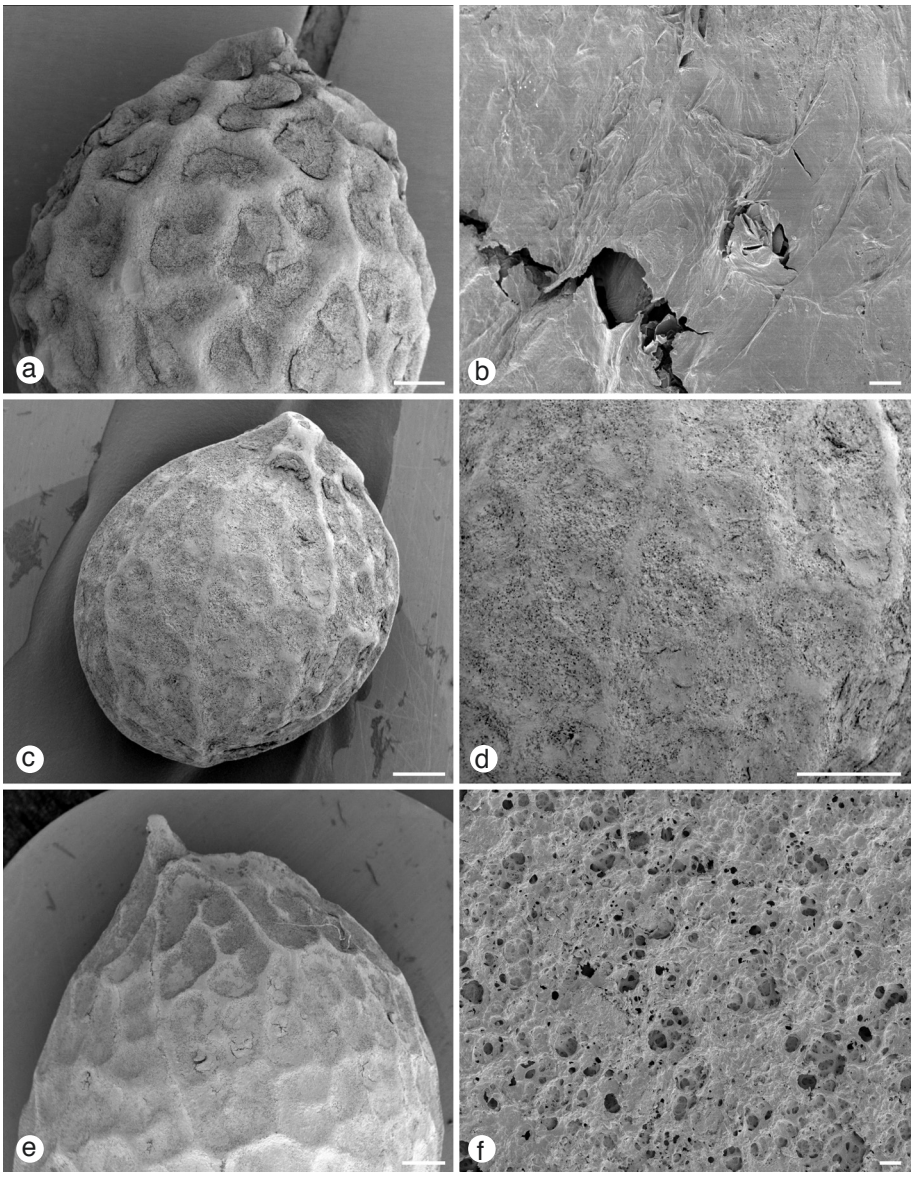


Plate 1. SEM micrographs of *Celtis* species. a, b. *C. adolfi-friederici* Engl.; c, d. *C. australis* L.; e, f. *C. tessmannii* Rendle. — Scale bars: a, c, e = 1 mm; b, d, f = 10 μm.

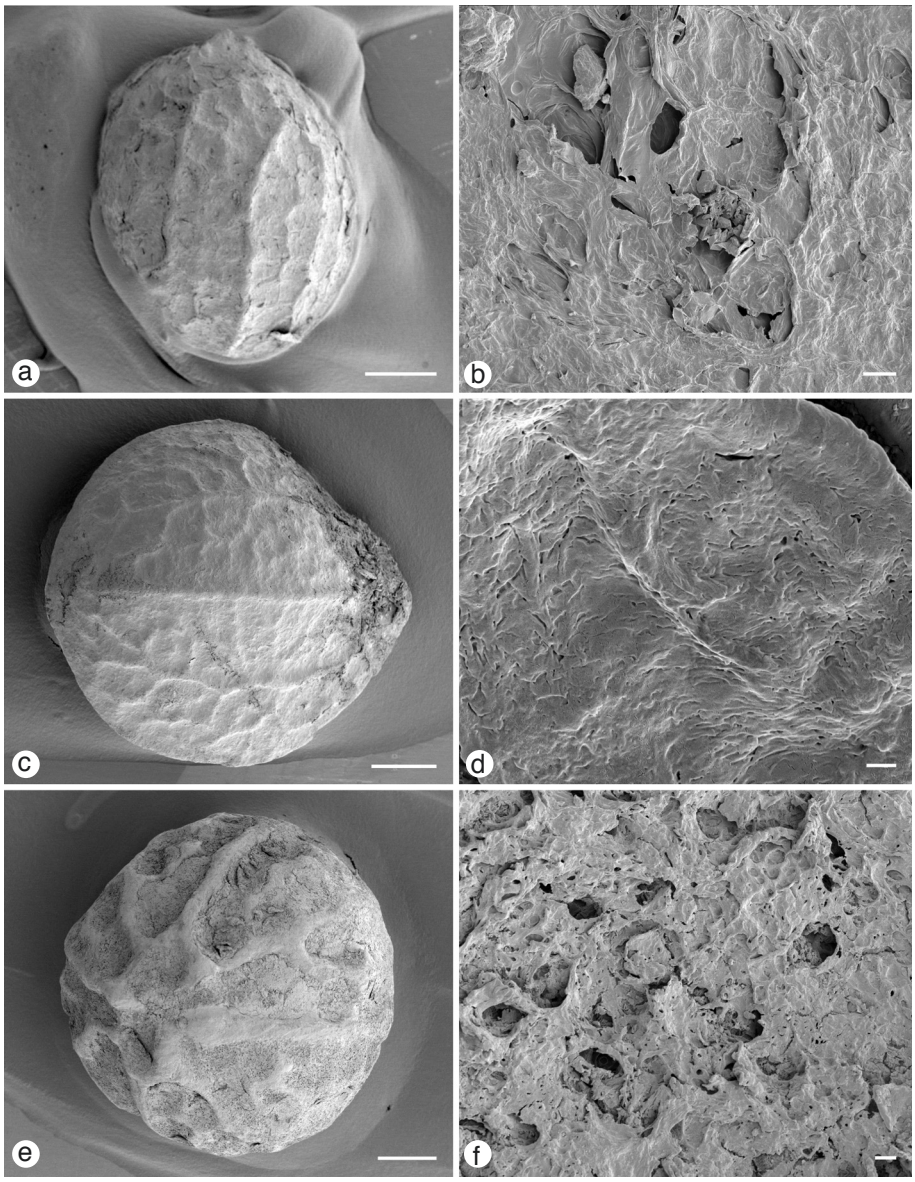


Plate 2. SEM micrographs of *Celtis* species. a, b. *C. africana* Burm.f.; c, d. *C. mildbraedii* Engl.; e, f. *C. wightii* Planch. — Scale bars: a, c, e = 1 mm; b, f = 10 μm; d = 1 μm.

In some species the apex is conspicuously pitted: in *C. adolfi-friederici*, *C. gomphophylla*, and *C. tessmannii* (Plate 1, 2).

With high magnification the outer walls of the endocarp or periclinal walls can be seen to differ. There are two main types. One type of endocarp has rough layers with different sizes of holes, prominent sculpturing, and membranous platelets, while the other one is smooth-layered and fissured, it looks like films in different layers, smooth layers and crusts, and the coverings are usually continuous without very prominent surface sculpturing (Table 3).

KEY TO AFRICAN AND SOME OTHER CELTIS SPECIES BASED ON ENDOCARP CHARACTERS

1a. Endocarp angular-ovoid, dark brown. . . . . **C. gomphophylla**
b. Endocarp ovoid-acuminate, lenticular or globose, other colours. 2
2a. Endocarp lenticular-ovoid or rhomboid, reticulate 12
b. Endocarp ovoid-acuminate, globose, reticulate or smooth 3
3a. Endocarp ovoid, reticulate, smooth or semi rough, various colours 4
b. Endocarp globose to elliptic, quite rough and sunken and raised reticular, white . . . . . **C. adolfi-friederici**
4a. Endocarp smooth, white or cream 5
b. Endocarp reticulate with raised boundaries or lines, grey 8
5a. Endocarp smooth, hardly a few boundaries visible, apex rounded 6
b. Endocarp more or less smooth, apex beaked 7
6a. Endocarp with a few boundaries, these not raised . . . . . **C. malagasica**
b. Endocarp without boundaries . . . . . **C. philippensis**
7a. Endocarp more or less smooth, apex rounded . . . . . **C. prantlii**
b. Endocarp rough, apex beaked . . . . . **C. australiensis**
8a. Endocarp with raised lines and boundaries 9
b. Endocarp polygonal, without raised lines 10
9a. Endocarp grey . . . . . **C. toka**
b. Endocarp white . . . . . **C. bifida**
10a. Endocarp sunken polygonal . . . . . **C. wightii**
b. Endocarp raised polygonal 11
11a. Endocarp white, 6 by 6 by 5 mm . . . . . **C. australis**
b. Endocarp grey, 5 by 4 by 4 mm . . . . . **C. zenkeri**
12a. Endocarp two-sided 13
b. Endocarp four-sided . . . . . **C. mildbraedii**
13a. Endocarp more than 10 mm long, brown, apex beaked . . . . . **C. tessmannii**
b. Endocarp less than 10 mm long, grey, apex rounded . . . . . **C. africana**

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