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Wood and leaf remains of palms with affinities to Sabal Adans., from the middle Eocene of Turkey

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Abstract: Two new fossil species based on the study of wood remains and leaf imprints from the middle Eocene Çekerek Formation (central-northern part of Turkey) are assigned to the palm family Arecaceae. Standard thin sections from the two samples of fossil wood were investigated and identified as Palmoxylon sabaloides Greguss 1969, with close xylotomical affinities to the modern genus Sabal Adans. The leaf imprints are weakly costapalmate and correspond to the genus Sabal as well. Based on the short petiole extension (costa), the leaves resemble the fossil-species Sabal lamanonis (Brong.) Heer, 1855. This fossil-species was abundant in Paleogene strata of western and southwestern Europe but has only rarely been described from Cenozoic strata of the Eastern Mediterranean region. The presence of this species, in combination with previously reported pollen records of mangrove palms, indicate warm (sub)tropical conditions in the middle Eocene of north-central Turkey and may reflect the Middle Eocene Climate Optimum (MECO).

Key words: Palmoxylon, fossil-species, Sabal, leaf imprint, fossil palm wood

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1. Introduction

During the recent decades, intensive studies of fossil wood remains have considerably improved our understanding of Cenozoic woody plant species throughout Turkey, and more than 40 fossil wood species were identified from Turkey [e.g., Özgüven-Ertan, 1971, 1977, 1981 (1983); Aytuğ and Şanlı, 1974; Eroskay and Aytuğ, 1982; Şanlı, 1982; Selmiyer, 1990, 2001; Kayacık et al., 1995; Akkemik et al., 2005, 2009, 2016, 2017, 2018, 2019a,b, 2020, 2022a,b; Kutluk et al., 2012; Akkemik and Şakinç, 2013; Acarca Bayam et al., 2018; Iamandei et al., 2018; Akkemik, 2019, 2020, 2021a,b; Akkemik and Acarca Bayam, 2019; Güngör et al., 2019; Polat et al., 2019; Çevik Üner et al., 2020]. Among these findings, several fossil woods of Arecaceae (the palm family) were identified to genus level by Akkemik et al. (2016) and Güngör et al. (2019).

Iamandei et al. (2018) described three fossil species of palms as Palmoxylon coryphoides Ambwani & Mehrrotra from Gökçeada and Palmoxylon cf. Trachycarpus from Hoçä village of Seben (Bolu) and Palmoxylon cf. borassus L. from Erkili in Edirne.

The investigation of Cenozoic leaf fossils in Turkey focused mainly on the Miocene epoch (e.g., Güner et al., 2017 for southwestern Anatolia; Denk et al., 2017 for central Anatolia).

The findings of different types of palm fossils indicated the presence of warm, humid, subtropical conditions during the Miocene (Iamandei et al., 2018). However, although the Paleogene leaf record of palms is rich and spectacular for western and southwestern Europe (e.g., Ettingshausen, 1853; Heer, 1855; Saporta, 1865), records from the Eastern Mediterranean region are largely based on dispersed pollen. Typically, fossil pollen taxa are compared to taxa thriving in mangrove vegetation (Nypa) and brackish back-mangrove vegetation (e.g. Akkiraz et al., 2007). In this study, we present new fossil palm woods and fossil leaf imprints from middle Eocene strata of Çekerek (Yozgat), north-central Turkey. Palm fossil woods and leaf imprints are investigated morphologically and their taxonomic affinities to modern palms are established. In addition, the biogeographic relevance of the new finds and their implications for palaecoclimate reconstructions are discussed.

2. Geological setting

The fossil site from which the wood and leaf remains described in the present study originate belongs to the
middle Eocene Çekerek Formation (Özcan et al. 1980). As described by Koçbulut et al. (2015) and Akkemik et al. (2021), the age of Çekerek Formation was established as Lutetian based on the abundant macro- and microfossil fauna. The Çekerek Formation comprises three members namely from bottom to top, Kuzluca, Kuzalan limestone, and Göynücek agglomerate (Figure 1:1). A number of studies dealt with the stratigraphy of the area (Akyazi and Tunç 1992; Akpinar et al. 2003; Koçbulut et al. 2015). The basement is formed by Permo-Triassic Turhal metamorphics. The Late Jurassic-Early Cretaceous Carcurum Formation is widely exposed in the area and rests on the Turhal metamorphics with an angular unconformity. Regionally, the Çekerek Formation lies on the Maastrichtian aged Artova Ophiolitic Melange (Özcan et al., 1980; Öksüz & Okuyucu, 2014) and is overlain by the Çerkeş Formation of Mio-Pliocene age consisting of an alternation of conglomerate, sandstone, and claystone (Figure 1:2).

During the middle Eocene (Lutetian), the Central Pontides were shallow marine environments. At the end of the middle Eocene, in the middle Pontides, the entire orogen was lifted above sea level (Okay et al., 2018). The upper parts of the Çekerek Formation are represented by the Göynücek Agglomerate Member mainly composed of a matrix of volcanic materials and basalt and andesite pebbles-blocks. Silicified wood, metamorphic rock fragments, recrystallized limestone, limestone blocks, mudstone and claystone lumps, and coal seams are also commonly observed in this member (Koçbulut et al., 2015).

The Çekerek Formation was deposited in a shallow marine environment during the middle Eocene transgression; and the Göynücek Agglomerate Member was covered by sediments transitional to continental conditions resulting from intense volcanism in different phases (Akyazi and Tunç 1992; Kaydu Akbulak et al. 2021).

Recently, Akkemik et al. (2021) published a study of fossil wood from the middle Eocene, corresponding to the time of the Middle Eocene Climate Optimum (MECO, see Westerhold et al., 2020) as Actinodaphn oxyylon zileensis Akkemik & Mantzouka, and Pinuxylon cl. tarnoczienense (Tuzson) Greguss.

### 3. Materials and methods

The fossil site is located in Sarıkaya village of Çekerek district in the province of Yozgat (Figure 1). Two fossil woods of palms were collected from the Çekerek Formation and some fossil leaf imprints were discovered at the fossil site. The sedimentary rock was too friable to recover the leaf fossils; hence, they were photographed in situ. The fossil woods and their thin sections are stored at the fossil wood collection of ISTO Herbarium in the Department of Forest Botany, Faculty of Forestry, Istanbul University-Cerrahpaşa, with the numbers ISTO-FW-00252 and ISTO-FW-00253.

Three standard thin sections, in transverse, tangential, and radial directions of the fossil woods were made and the anatomical structure of the palm-stem was studied under a LEICA microscope with transmitted light. In addition, numerous photos with characteristic anatomical details were taken to support the xylotomical description and identification of these two fossil woods. For identification, we used the terminology of Mahabalé (1958) and Kaul (1960 - quoting Mohl, 1845–1850), Tomlinson (1961, 1990), Tomlinson et al. (2011), and Thomas & De Franceschi (2012, 2013).

The fossil leaf imprints were identified and described based on the digital images taken in the field.

### 4. Systematic paleobotany

#### 4.1. Identification of the fossil wood

**Order** Arecales Bromhead 1840 (in Reveal, 2004)

**Family** Arecaceae Bercht. & Presl, 1820 (nom. cons.)

**Subfamily** Coryphoideae Burnett, 1835

**Genus** Palmoxylon Schenk, 1882

**Species** Palmoxylon sabaloides Greguss, 1969

**Figure 2:** 1-9.

**Material:** ISTO-FW-00252 and ISTO-FW-00253

**Locality:** Sarıkaya Village, Çekerek (Yozgat, Turkey)

**Formation:** Çekerek Formation

**Age:** Middle Eocene

**Origin of the stem remains:** Probably stem wood

**Storage:** The Herbarium of Istanbul University-Cerrahpaşa, Faculty of Forestry, Department of Forest Botany. (ISTO)

**Microscopic description:** Studying standard thin sections of fragments of petrified palm stem we observed the presence of the subdermal zone and, partially, the central zone (in some cross sections).

The fibrovascular bundles (FVB) are of the open-collateral type and appear, in cross section, more congested, suggesting the subdermal zone. They appear with the vascular part oriented to the center and the fibrous part to the outside (Figure 2: 1). FVB are variably orientated suggesting the presence of the central zone in some sections (Figure 2: 2-3). They show sclerenchyma caps of the Reniformia type (sensu Stenzel, 1904) which do not display an obvious centrifugal differentiation of the fibrous part. The size of FVB varies, the radial /tangential diameter (r/tg. d.) is (300) 600–1000/200–600 μm; the phloematic sclerenchyma cap has r/tg. d. of 80–250/200–300 μm and the f/v ratio (the ratio between areas occupied by the sclerenchyma and the vascular part in cross section) = 1.6/1 – 3/1. The bundle density within this zone is about 180 bundles/cm². In the central zone, the size values are
Figure 1. The study site. 1) Location of the study area; 2) local geological map showing the fossil site (modified from the MTA Geological Map of Turkey).
**Figure 2.** *Palmoxylon sabaloides* Greguss 1969. 1) Cross-section – fibrovascular bundles with sclerenchyma caps of reniform type, oriented towards the external stem part, usually with two metaxylem vessels and ground tissue and fibrous bundles within the subdermal zone. 2-3) Cross section – fibrovascular bundles variably oriented with reniform sclerenchyma caps, with nonspecific lacunae as 1-2 islands (i.e. divided or undivided phloem) and with two metaxylem vessels rounded by intrafascicular parenchyma of tabular type; also, nonoriented and fibrous bundles are present, suggesting the central zone. 4-9) Longitudinal sections – with the fibrous sheath of FVB, intrafascicular parenchyma, and scalariform pitted protoxylem vessels (4); metaxylem vessels with scalariform perforations. (5 and 8) and with spiral thickenings and scalariform pitting (6-9).
The investigation of \( P. \) coryphoides

from Mexico, Cuba, and the Bahamas. It is a salt-tolerant palm tropical regions of the southeastern United States, Mexico, Cuba, and the Bahamas. It is a salt-tolerant palm genus and commonly lives near the Atlantic coast, and it can cope with short periods of low temperatures as low as -14°C (Tomlinson 1961; Wikipedia, accessed 19.07.2017). Fossil remains of \( Sabal \) are found commonly in Europe, far from the present distribution area of the genus. In Europe, Rásky (1964) described fossil leaf imprints of \( Sabal \) from the Cenozoic of Hungary and made a review of the fossil leaf imprints described from the European Cenozoic.

For fossil wood of palms, the valid genus is \( Palmoxylon \), which was erected by Schenk (1882) and was proposed to be conserved by Doweld (2017). Considering other published species of \( Palmoxylon \) Schenk 1882, we restricted our comparison to species with fibrovascular bundles with fibrous sheaths of the reniform type, which are, usually, attributed more or less explicitly to the “sabaloid palms”. Presently, this group of palms belongs to the subfamily Coryphoideae (Dransfield et al. 2005).

Thus, we compared the synthetic description of our specimens with the species described by Schenk (1882), Berry (1924), Chiarrugi (1933), Rao & Menon (1964a,b), Menon (1965), Trivedi & Verma (1971a, b), Prakash (1962), Grambast (1957, 1964), Greguss (1954, 1959, 1969), Prive-Gill & Pelletier (1981), Gottwald (1992), Nambudiri & Tidwell (1998), Kahlert et al. (2005), Iamandei & Iamandei (2006), Iamandei et al. (2018), and Velitzelos et al. (2019), and we observed that most of them differ from our specimen but also share some similarities.

Fossil palm woods, similar to the extant \( Sabal palmetto \) Lidd., Eams & McDaniels (see Tomlinson, 1961), were described from the Cenozoic of Hungary as \( Palmoxylon sabal \), \( P. \) sabaloides, and \( P. \) dorogense (Greguss, 1954, 1968, 1969) and are very similar to our specimens by the aspect and arrangement of the fibrovascular bundles, and/or interfascicular parenchyma.

\( Privé-Gill \) & \( Pelletier \) (1981) described a \( Palmoxylon \) sp., also with FVB of the Reniformia type, a xylotomical feature similar to our specimens.

Iamandei & Iamandei (2006) described \( Palmoxylon techerense \) from Late Cretaceous strata in the Carpathians, which is close to the extant genus \( Sabal \), having similar fibrovascular bundles in the central cylinder, surrounded by parenchyma of tabular type. These features are also present in our specimens.

More recently, Iamandei et al. (2018) described three fossil species of \( Palmoxylon \) (\( P. \) coryphoides Ambwani & Mehrotra, \( P. \) sp. cf. \( Trachycarpus \) H. Wendl. and \( P. \) sp. cf. \( Borrassus \) L.) from Turkey, which are slightly different from our specimens in the aspect and arrangement of the fibrovascular bundles and of interfascicular parenchyma.

In addition, more species of fossil palms were described from Greece by Velitzelos et al. (2019) as...

Thus, based on the foregoing discussion and compared with previous studies (Greguss, 1969; Tomlinson, 1961, 1990; Iamandei et al., 2006, 2018; Tomlinson et al., 2011; Thomas, 2011a,b, 2013; Thomas & DeFranceschi, 2012, 2013; Velitzelos et al., 2019), we found high similarities with the Coryphoideae of the *Sabal*-type in the features of the fibrovascular and fibrous bundles and their composition, and also, the arrangement of intra- and interfascicular parenchyma. Consequently, using the diagnoses of Greguss (1969) and Velitzelos et al. (2019), we assigned our studied fossil wood to the species *Palmoxylon sabaloides* Greguss, 1969.

### 4.2. Identification of the fossil leaf imprints

**Family** Arecaceae Bercht. & J.Presl, 1820 (nom. cons.)

**Subfamily** Coryphoideae Burnett, 1835

**Genus** Sabal Adams., 1763

*Sabal* sp.

Figure 3: 1–3

**Description:** This species is represented by two specimens (Figure 3: 1–3). One of the specimens preserves sufficient morphological characters to allow a generic assignment. Leaves are weakly costapalmate with long, stout, and unarmed petioles, 6-cm-long (preserved part), 2-cm-wide, with a 1.5-cm-long costa (Figure 3:2). Sixteen leaf segments radiate from the costa, leaf segments about 0.5-cm-wide (average), the longest one 20 cm in length (preserved part), each with a firm midrib arching away from the costa (Figure 3).

**Remarks:** This type of palm leaves have been referred to as *Flabellaria* (Sternberg, 1822), *Palmacites* (Brongniart, 1822), and *Sabalites* (Saporta, 1865). Heer (1855) considered them to belong to the modern genus *Sabal*. Using a fossil-genus name, *Sabalites* is a younger synonym of *Palmacites*. The name *Flabellaria* used by Sternberg (1822) is invalid, as the genus *Flabellaria* (Malpighiaceae) had been described earlier (Cavanilles, 1790). For simplicity, we follow the concept of Heer (1855) and refer the leaf remains to the modern genus *Sabal*.

Similar leaves are found, for example, in the modern *Sabal minor* (Jacq.) Pers. (Figure 3: 4). Fossil leaves of the *Sabal* type are common in Paleogene strata of western Europe (Heer, 1855) but have only rarely been reported from Cenozoic strata of the Eastern Mediterranean region (Velitzelos et al., 2014; Denk et al., 2017, 2019). From Oligocene strata of northeastern Turkey, Kayseri Özer et al. (2017) described dispersed leaf segments belonging to a palm.

The leaves reported here closely resemble leaves described from the early Oligocene of Thrace (Evros, as *Sabal lamanonis* (Bronn.) Heer, 1855; Velitzelos et al., 2014), which are fairly common in Eocene to Oligocene deposits of western and southwestern Europe (e.g. Heer, 1855; Saporta, 1865).

### 4.3. Paleogeographic and paleoclimatic significance

Today the genus *Sabal* comprises 17 species (Báñki et al., 2022). Today’s *Sabal* species grow mainly under tropical and subtropical conditions, occurring in swamp, riparian, and lowland areas, and most of the species are understory trees (Zona, 1990). The distribution of *Sabal* is mainly from the Gulf Coasts to Venezuela (including Mexico, Central America, and Colombia) (see Zona, 1990).

Many fossils of palm trees, including both macro- and microfossils have been identified and described from different parts of the world (Dransfield, 2008). The global palm fossil record is considered the richest among fossilized monocots (Harley, 2006; Song, 2022) and ranges from the Lower Cretaceous to the Holocene. In the middle Eocene, it reaches its broadest geographical distribution (Dransfield, 2008) reflecting high global temperatures during the Paleogene (Westerhold et al., 2020). Palms are mainly represented by two leaf types, pinnate and palmate; palmate leaves are additionally split into two subgroups, one having a costa and one lacking a costa (Dransfield, 2008; Wenjun, 2013). Read and Hickey (1972) affiliated costapalmate leaves “with a definite costa or extension of the petiole into the blade” with *Sabalites* (junior synonym of *Palmacites*; here treated as *Sabal* in accordance with Heer, 1855).

According to Denk et al. (2017) and Güngör et al. (2019), vegetation units of palm leaf imprints were evaluated as VU0 (subtropical) and VU4 (riparian). Interestingly, previous records of palms from Eocene strata of Turkey based on dispersed pollen grains, provided evidence of palms belonging to mangrove vegetation and hence representing coastal conditions (riparian in a wider sense). The present records of fossil wood and foliage morphologically corresponding to *Sabal* adds a new component to Eocene plant communities in Turkey. Although commonly being part of riparian communities, *Sabal* also occurs in well-drained subtropical settings. During the middle Eocene of north-central Anatolia, such conditions were present.

Furthermore, palynological data (e.g., Akgün, 2002; Akkiraz et al., 2007) revealed valuable paleoclimate evidence for the middle Eocene of central Anatolia. Akkiraz et al. (2007) described middle-? late Eocene mangrove communities in the Yozgat-Sorgun area including back-
mangrove elements such as palms. These mangroves indicate warm (sub)tropical lowland environments. The annual temperature, these authors suggested, was about 25 °C in coastal areas, and 16.5–23.1 °C in the montane region, hence corresponding to the megathermal zone. From another site (Çorum-Amasya), which is near our sampling area, Akgün (2002) suggested the presence of mangroves and other typical elements of the present Atlantic and Indo-Pacific mangrove communities including palms.

As another proxy record, the record of *Actinodaphnoxyylon zileensis* Akkemik & Mantzouka (Lauraceae) from the middle Eocene of Zile (Akkemik et al., 2021), which is near the sampling area, indicated the presence of warm (sub)tropical climate conditions. Indeed, an indistinct growth ring boundary is one of the evidences of tropical conditions (IAWA Committee, 1989). Due to the absence of growth ring boundaries in *Actinodaphne* and being a subtropical and tropical genus,
the paleoclimatic conditions around Zile were suggested as tropical or paratropical.

Based on this discussion, we suggest that the presence of *Sabal*-type palm species may be regarded as new evidence of tropical (paratropical) conditions in the middle Eocene of north-central Anatolia. Furthermore, this record provides further paleoclimatological evidence for the presence of paratropical conditions in this region during the middle Eocene as previously suggested by Akkemik et al. (2021).

5. Conclusion

Records of palm remains from the middle Eocene of north-central Anatolia include petrified wood fragments and leaf imprints with morphologies corresponding to the extant genus *Sabal*. At present, all species of this genus grow in subtropical and tropical conditions of the Caribbean Basin. We suggest that similar conditions occurred in the middle Eocene of north-central Anatolia and that these conditions reflect the Middle Eocene Climate Optimum (MECO) in Turkey.

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