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Eucalypt in the Tunisian arid region: Diversity and valorization for honey production

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Abstract
For four years (2016 - 2019), we studied *Eucalyptus* in the arid region of Tunisia. This tree is frequently introduced in the region from the sixties of the twentieth century, with the installation of three arboreta in 1959/1960 and several plantations; these arboreta are the only ones planted in the arid region. Fifteen species and one hybrid have been identified, with a very variable presence, the most dominant species are: *E. camaldulensis*, *E. torquate*, *E. microtheca*, *E. occidentalis* and *E. gomphocephala*. In 2017 and 2018, each month, we have followed the flowering of all *Eucalyptus* species, identified those that have an importance and abundance of flowering, and qualified as interesting in beekeeping. These are: *E. camaldulensis*, *E. torquata*, *E. microtheca*, *E. occidentalis*, *E. oleosa*, *E. diversifolia*, *E. flocktoniae* and *E. torwood* (hybrid). Besides, other species are present and show no interest for beekeepers, mainly *E. gracilis*, *E. astringens*, *E. brockwayii* and *E. gomphocephala*, the latter is very common in Mediterranean region, Tunisia and the area of this study (Gabes).

Keywords: *Eucalyptus* sp., flowering, beekeeping, dry region, Tunisia

Introduction
Eucalyptus sp. (Myrtaceae) is represented by 747 species. It is native to Australia, with a few native species from Papua New Guinea, Indonesia and the Philippines (Leicach *et al*., 2012) [14]. Tunisia is one of the North African countries that has frequently planted eucalypt. This tree accounts for 6% of the national forest cover (DGF, 2010) [6]. Indeed, 117 species have been introduced and tested in 30 arboreta and several regions of Tunisia (Khouja *et al*., 2001) [13]. This tree is essentially characterized by rapid growth and drought tolerance. It is used for wood, firewood, poles, building materials, pulp and paper. It is also a raw material for many industries including medicine and honey production (FAO, 2011) [10]; all of these benefits could improve the incomes of rural people. Indeed, *Eucalyptus* is a honey tree of great importance; it is an important source of nectar and pollen for the honeybees (Simeão *et al*., 2015) [19]. In Australia, most honeys are palynologically dominated by *Eucalyptus*. In fact, about 70% of Australian honey comes from *Eucalyptus* species (Sniderman *et al*., 2018) [20]. Thus, in the east Mediterranean region, *Eucalyptus* honey is frequent in northern Africa and southern Europe. *Eucalyptus* honey is commercialized worldwide and much desired by consumers for its medicinal properties (Bobis *et al*., 2020) [3]. It is known for its relevant beneficial effects, mainly its antibacterial properties. The mechanisms of action reside in honey sugars, which exert pressure on bacterial cells through osmotic effect (Proano *et al*., 2021). In Tunisia, there are 12000 beekeepers and 310000 beehives. The average national production is 1800T of honey in 2015, with 120T in the south and 45T for the region of Gabes our study area. *Euaclyptus camaldulensis* and *E. gomphocephala* are the two species frequently planted in the country and used for honey productuion (Ben Brahim & Nsaibya, 2016) [1]. Thus, the production of *Eucalyptus* honey is frequent even in the south of Tunisia.
In this study, we aim to identify the *Eucalyptus* species present in the region of Gabes in the arid of Tunisia, their flowering period and their interest for beekeepers. Thus, we analyzed the pollen and nectar qualities of these species. This work is a step for the analysis and valorization of eucalypt in beekeeping in presaharian and saharian regions.

Materials and methods
1. Description of the study area
Prospecting and study were carried out in the Gabes area between latitudes 33° 18' 09.69"N and 34° 16' 43.13"N and longitudes 9° 31' 44.09"E and 10° 26' 29.26"E (Figure 1). This region covers 7166 km² and is characterized by an arid bioclimate, the average annual rainfall is 190 mm. Average annual Potential Evapo-Transpiration (PET) is about 1762 mm. Maximum and minimum temperatures are 24.3°C and 16.2°C, respectively (Masmoudi & Habaieb 2017).

2. Temperature and rainfall
The values of the average temperature and rainfall recorded in the city of Gabes per month during 2017 and 2018 are the following from January (1) to December (12) (Table 1):

Table 1: Temperature and rainfall during 2017 and 2018 in Gabes (Data from the National Institute of Meteorology, Tunisia)

Year	Parameter	1	2	3	4	5	6	7	8	9	10	11	12	Total	Average
2017	Average temperature (°C)	12	16	18	20	24	28	30	31	28	24	19	14	-	22
	Rainfall (mm)	2	4	25	12	21	4	1	0	2	10	38	19	138	-
2018	Average temperature (°C)	15	15	20	21	22	27	31	30	29	25	20	16	-	22,58
	Rainfall (mm)	1	15	6	2	8	1	1	9	5	9	10	1	68	-

1 to 12 are the months of the year, from January to December

Table 2: Presence of species in the region, flowering abundance and honey interests

Species	Presence (+, +/-, -)	Flowering abundance (+, +/-, -)	Quality of pollen and nectar for bees (N, P, NP ou NU)	References
E. camaldulensis,	+	+	NP	(Birtchnell & Gibson, 2008), Johannsmeier, 2016
E. torquata,	+	+	NP	Eisikowitch *et al*., 2012)
E. occidentalis	+	+	NP	Coleman, 1962
E. microtheca,	+	+	NP	Somerville & Nicol, 2006, Johannsmeier, 2016
E. torwood	-	+	NP	Eisikowitch *et al*., 2012
E. gracilis	-	-	Np	(Birtchnell & Gibson, 2008), Coleman, 1962
E. brokwayii	-	-	NU	
E. gomphocephala,	+	-	Np	Coleman, 1962
E. salmonophloia	-	-	Np	Coleman, 1962
E. astringens	-	+/-	NP	Coleman, 1962
E. lesouefii	-	+/-	NU	
E. oleosa	+/-	+	Np	Birtchnell & Gibson, 2008)
E. salubris	+/-	+	NP	Coleman, 1962
E. diversifolia	+/-	+	NP	Birtchnell & Gibson, 2008)
E. flocktoniea	-	+	NU	
E. sargentii	-	+	**NU**	

(+: high, +/-: medium, -: low, N: rich in nectar, P: rich in Pollen, p: less pollen, NU: data unavailable).

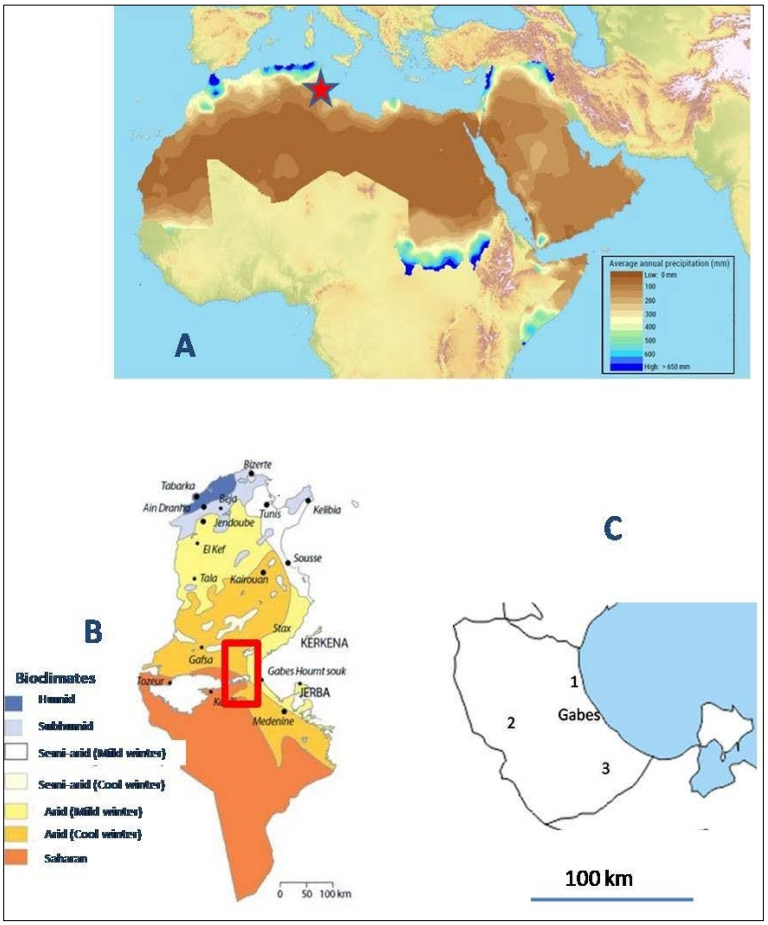

Fig 1: Situation of the study area in the Mediterranean basin (A) and the study region in the South of Tunisia (B) and the limits of the study region and the three arboreta: (1): Metouia, (2): Hamma and (3): Zrig Barrania.

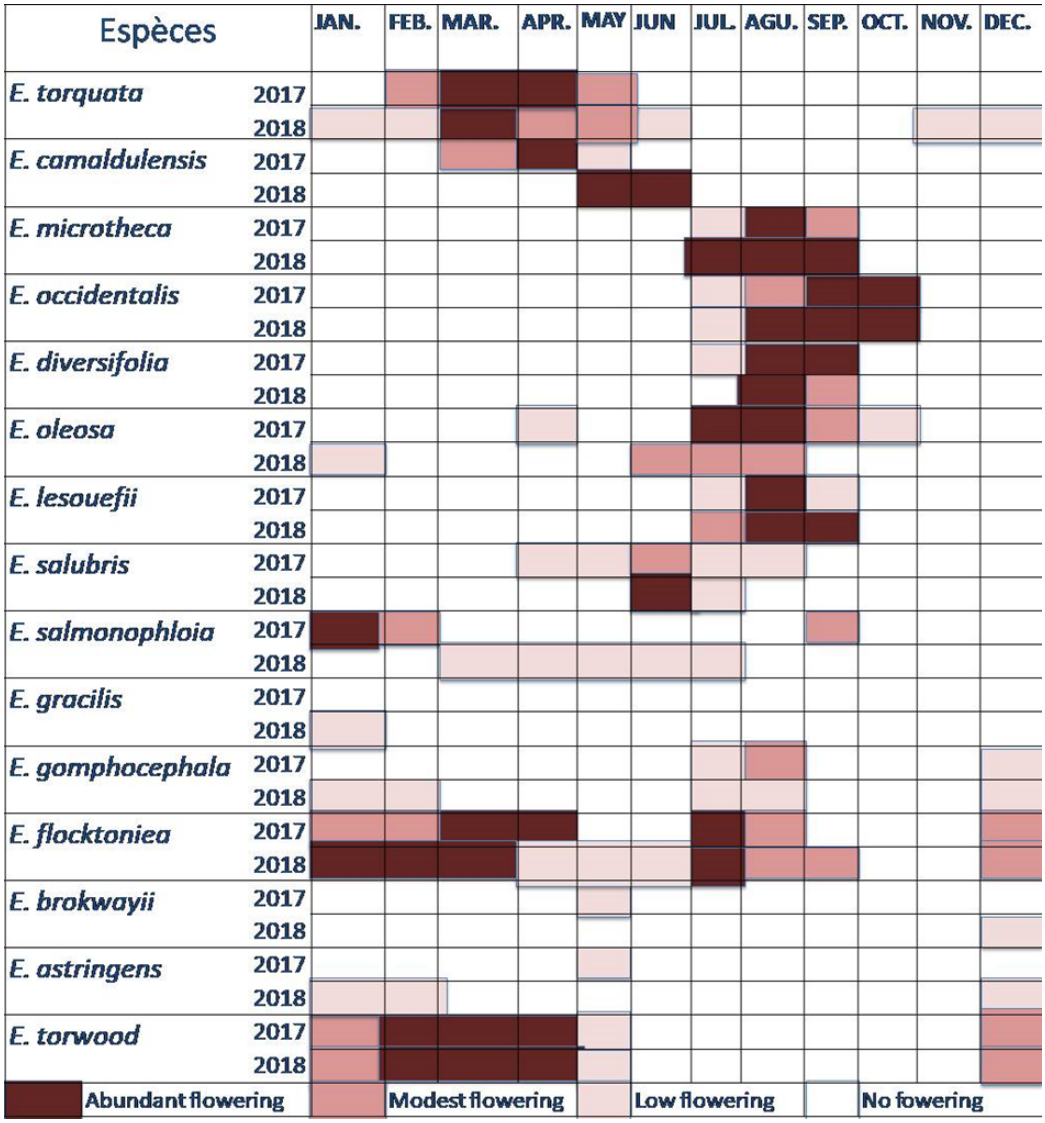

Fig 2: Flowering cycle of each species in the region of Gabes in 2017 and 2018

3. Plant material and methodology

The plant material concerned by our study is the *Eucalyptus* species existing in the great region of Gabes. We carried out prospecting throughout the study area. We listed and identified the species present and followed their flowering cycle during two years (2017 and 2018), by a monthly estimation of flowering level for each species (high, medium, low, nil). The studied species are present in three arboreta or planted in several other areas. The identification was made based on the existing herbarium at INRGREF and the archives of each arboretum's *eucalyptus* collection.

Species of *Eucalyptus* in the region of Gabes

1. Arboreta of *Eucalyptus* in dry Tunisian region

There are only three arboreta in the south of Tunisia, the driest region of the country. They were planted by the National Forest Research Institute (INRF) in 1959/1960. These arboreta and their geographical coordinates are as follows: Metouia (Latitude 33° 57' 50.68''N, longitude 9° 59' 07.33" E and altitude 31m), Hamma (33° 54' 41.87'' N, longitude 9° 39' 40.92"E and altitude 40 m) and Zrig Barania (33° 43' 56.12''N, longitude 10° 09' 34.387"E, 43 m) (Figure 1). In these arboreta, there are 11 species and one hybrid. They are *Eucalyptus torquata* Luehm., *Eucalyptus oleosa* F.Muell. ex Miq., *Eucalyptus flocktoniae* (Maiden) Maiden, *Eucalyptus salubris* F.Muell, *Eucalyptus gracilis* F.Muell., *Eucalyptus astringens* (Maiden) Maiden, *Eucalyptus salmonophloia* F.Muell., *Eucalyptus occidentalis* Endl., *Eucalyptus microtheca* F.Muell., *Eucalyptus brockwayii* C.Gardner, *Eucalyptus lesouefii* Maiden and *Eucalyptus torwood* (hybrid, *E. woodwardii* x *E. torquata*). The first seven species on the list exist in all three arboreta at the same time. The state of growth and development is variable between species and between arboreta.

2. Species of *Eucalyptus* in the region of Gabes

In addition to the species mentioned in the three arboreta, there are other species planted in the region like *Eucalyptus camaldulensis*, *Eucalyptus gomphocephala*., *Eucalyptus diversifolia* Bonpl and *Eucalyptus sargentii* Maiden. In total, fifteen species and one hybrid have been identified in the Gabes region. They are *E. camaldulensis*, *E. gomphocephala*, *E. torquata*, *E. microtheca*, *E. occidentalis*, *E. oleosa*, *E. lesouefii*,

E. salubris, *E. salmonophloia*, *E. gracilis*, *E. flocktoniae*, *E. brockwayii*, *E. astringens*, *E. sargentii* and *E. diversifolia*, and the hybrid *Eucalyptus torwood*. Five species are frequent in this region. They are *E. camaldulensis*, *E. gomphocephala*, *E. torquata*, *E. microtheca* and *E. occidentalis*.

Flowering cycle

Figures 2 shows the flowering periods of each species identified in the arid region of Tunisia, as well as the importance of their flowering. Eight species presented an abundant flowering in 2017. These periods are one month for *E. camaldulensis* and *E microtheca*, two months pour *E. torquata*, *E. occidentalis*, *E. diversifolia* and *E. oleosa* and three months for *E. flocktonia*e and *E. torwood*. The period of abundant flowering varies little in 2018; it was extended by one month for *E. camaldulensis* and *E. flocktoniae* and two months for *E. microtheca*. However, it has shrunk a month to *E. torquata* and *E. diversifolia* and it has not happened for *E. camaldulensis. E torwood ke*pt the same flowering period. The low variation in the flowering period observed between 2017 and 2018 is probably due to the variation in climatic factors between the two years. Indeed, the temperature is higher in 2018 and the rainfall in 2017 (table 1). Thus, the period of an abundant flowering is changed by a modest flowering; just less abundant.

Among these species, those that are common in the region and frequently used by beekeepers as a source of nectar are, *E. camaldulensis*, *E. torquata*, *E. microtheca*, *E. occidentalis*. On the other hand, *E. gracilis* and *E. brockwayii* are characterized by low flowering spread over a short period. Flowering is totally absent in 2017 for *E. gracilis*. The flowering period is longer for *E. gomphocephala*, *E. salmonophloia* and *E. astringens*, but their flowering is less abundant. These species are renowned for their abundant flowering in the humid, subhumid and semi-arid regions of Tunisia (Ben Brahim & Nsaibya, 2016) [1]. We can deduce that the species showing an abundant flowering of long period are: *E. camaldulensis*, *E. torquata*, *E. occidentalis*, *E. microtheca*, *E. flocktoniea*, *E. oleosa* and *E. torwood*. The majority of these species produce pollen and nectar with good quality for bee nutrition (Coleman, 1962; Birtchnell & Gibson, 2008, Johannsmeier, 2016) [4, 2, 12]. Moreover, their flowering is in winter or summer, in a critical period of the year, characterized by the absence of flowering in the majority of the spontaneous and cultivated plants. *E. torwood*, for example, showed abundant flowering for six months, from December to May. This result is obtained by Eisikowitch *et al*. (2012) [8] for this same hybrid from October to May, and reflects the importance of this hybrid for beekeepers. Other than these seven species, showing flowering abundance for the monitoring done in 2017 and 2018 (Tables 1 and 2), one other was identified later, in 2019, it's *Eucalyptus sargentii*, species represented by well-developed individuals, which frequently flowered between December 2019 and June 2020.

Characteristics of pollen and nectar

Eucalyptus plantations are frequently used for the establishment of bee yards. This choice is profitable because *Eucalyptus* produces massive quantities of flowers with a large number of anthers, producing a large amount of pollen (Simeão *et al*., 2015) [19]. Indeed, *Eucalyptus* species are generally characterized by a great interest in beekeeping because their nectar is rich in carbohydrates and their pollen contains proteins, fatty acids, vitamins and minerals. These elements are essential for the nutrition and health of bees (Eliyahu, 2020) [9].

The nectar from *Eucalyptus* is the basic raw material for the nutrition of bee and the production of honey (Bobis *et al*., 2020) [3]. In fact, in South Asia, South America, Africa and the Mediterranean basin, *Eucalyptus* species are important and dominant sources of nectar for beekeeping (Sniderman *et al*., 2018) [20]. The nutritional quality and the volume of nectar per flower varies greatly between species. In *E. erythrocoris*, Lupo & Eisikowitch (1990) obtained a volume of 4 ml of nectar per flower in four days of flowering, with a total of 0.5 g of sugar. However,the volume of nectar is estimated to be 0.18 ml in *E. spathulata* by Power *et al*. (2018). Davis (1997) studied three *Eucalyptus* species, *E. cosmophylla*, E. grandis and *E. pulverulenta* and revealed a difference in nectar quantity and quality. Nectar yields and sugar levels per flower obtained are highest in *E. cosmophylla*, intermediate in *E. pulverulenta* and lowest in *E. grandis*. In addition, the nectars of *E. cosmophylla* and *E. grandis* are rich in hexose, while those of *E. pulverulenta* are rich in sucrose. At the same time, the sugar concentration of the nectar varies from 37.3 g/100 mL for *E. cosmophylla*, 49.6 g/100 mL for *E. pulverulenta* and 68.2 g/100 mL for *E. grandis*.

Eucalyptus pollen contains on average of 23.8% of crude protein (Somerville and Nicol, 2006). Invernizzi *et al*., (2011) noted that *E. grandis* pollen has 30% crude protein, but these values gradually decreased to 20% at the end of the flowering period. Frequently, isoleucine is the most limited amino acid in the composition of *Eucalyptus* pollen, for that reason, an exclusive supply of *Eucalyptus* pollen is not suitable for bees (Somerville & Nicol, 2006). In addition to the good quality of the nectar and pollen, the diversity of eucalypt adapted and planted in our arid regions allows us to obtain a long flowering period, which essentially covers the dry seasons of the year. This objective can be achieved, if in future afforestation programs, we avoid monoculture with a single species of *Eucalyptus*, and test and introduce other species and hybrids, known for their melliferous interests. For example, Eliyahu *et al*. (2020) [9] selected and propagated two honey *Eucalyptus* species for the arid region: *Eucalyptus* × *trabutii* and *E. brachyphylla*, two trees with high flowering intensity and high nectar production, and *E. erythrocoris*, recommended by Lupo & Eisikowitch (1990) and considered an excellent honey *Eucalyptus*. The diversification of *Eucalyptus* species used for afforestation and the selection of melliferous trees help to achieve the two main objectives of afforestation in this dry region: protection against desertification and improvement of the quality and quantity of pollen and nectar available for bees. The ultimate objective of this strategy is to contribute to the improvement of the rural population's income.

Conclusion

In the dry region, in addition to its ecological interests, *Eucalyptus* is a necessary tree for beekeepers. Thus, its flowering is possible in dry conditions, with a long period of the year and a good quality of pollen and nectar for the nutrition of bees. Moreover, it is characterized by a high diversity and elevated number of species.

In such situation, the choice of species is crucial for the success of the plantations and the best beekeeping performance. A germplasm was installed in December 2017 in the region and the

main objective of this study is to analyze the physiological behavior and the level of adaptation of these species.

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