SHST
Horticulture and Forestry Society of Transylvania

Ben Rabeh S *et al.* (2023)
Notulae Scientia Biologicae
Volume 15, Issue 2, Article number 11502
DOI:10.15835/nsb15211502
Review Article

NSB
Notulae Scientia Biologicae

Environmental stress tolerance, hydro-distilled essential oils characteristics and biological activities of *Eucalyptus torquata* Luehm.

Sonia Ben RABEH[1,2]*, Kaouther Ben YAHIA[3], Samir DHAHRI[4],
Souda BELAÏD[1,2], Imen CHEMLALI[1,2], Chokri Ben ROMDHANE[4],
Mehrez ROMDHANE[2], Ezzeddine SAADAOUI[4]

[1]*University of Gabes, Faculty of Science Gabes, Gabes, Tunisia; soniabenrabeh.a@gmail.com (*corresponding author); belaidsouda95@gmail.com; chemlali.imen@gmail.com*
[2]*University of Gabes, National Engineering School of Gabes, Laboratory of Energy, Water, Environment and Processes, Gabes, Tunisia; mehrez.romdhane@univgb.tn*
[3]*University of Carthage, I National Institute for Rural Engineering, Water and Forestry (INRGREF), LEF, Tunisia; kaoutherbenyahia01@gmail.com*
[4]*University of Carthage, National Institute for Rural Engineering, Water and Forestry (INRGREF), LGVRF, Tunisia; dhahri.samir@iresa.agrinet.tn; benromdhanechokri@gmail.com; saad_ezz@yahoo.fr*

Abstract

Eucalyptus has become one of the most widely planted genera in the world because of its tolerance to a wide range of soil types and climates, as well as for its many industrial, commercial and medicinal uses. *Eucalyptus torquata* Luehm. is a plantation species frequently planted in semi-arid and arid regions for its ecological, forestry, ornamental and melliferous interests. Based on literature, drought tolerance of this species was mostly directed to adaptation mechanisms. Physiological investigations reveal the importance of stomatal closure and increased solute contents suggesting that osmotic adjustment is one of the main responses to drought in *E. torquata*. On the other hand, it showed low sensitivity to salt stress. This paper also highlights the immense benefits of *E. torquata* which contains essential oils with variable chemical composition and rich essentially in 1,8-cineole, torquatone, α-pinene, trans-myrtanol, α-eudesmol, β-eudesmol, globulol, trans-pinocarveol and aromadendrene. These oils, as well as the methanol and aqueous extracts possess a wide variety of bioactivities of great importance which are particularly valuable as antibacterial and antifungal agents also have a strong toxicity against insects and mites in addition to antiproliferative and cytotoxic effects against different types of cancer cells.

Keywords: biological activities; chemical composition; coral gum; essential oil; *Eucalyptus*

Introduction

Eucalypts (*Eucalyptus* spp.) are endemic to Australia; however, its few species are indigenous to neighboring countries. The genus *Eucalyptus* comprises more than 800 species and hybrids, which includes

Received: 00 Xxx 2022. Received in revised form: 00 Xxx 2023. Accepted: 08 Jun 2023. Published online: 19 Jun 2023.
From Volume 13, Issue 1, 2021, Notulae Scientia Biologicae journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

shrubs and flowering trees. It is the most valuable genus and it is found in almost all parts of the world due to human introduction (Chemlali *et al.*, 2022). It has been broadly cultivated in many countries to utilize as wood for a diverse range of products and grow across a large range of climatic environments and soil types. Eucalypts are known for their adaptation to arid conditions and are considered drought, salt and heat tolerant compared to other trees (Teulières *et al.*, 2007). The mild climate is the most preferred for most species of *Eucalyptus*, they are highly distributed where there are warm summers, temperate winters, moderate rainfall, dry atmosphere and plenty of sunlight (Najum Rasheed *et al.*, 2005).The distribution of *Eucalyptus* all over the world also the dominance in Australia means ecological importance of this genus which provide food and habitat resources for a diverse range of fauna (Vuong *et al.*, 2015). Eucalypts are one of the most bio-economic plant species with high potential to grow in salt-affected soil with arid climatic condition also capable of providing an economic return in the future, it used for ornamental purposes, afforestation, providing feedstock for the pulp and paper industries or to obtain timber and gum, also a nectar resources for honey and known by cosmetic and medicinal values (Saadaoui *et al.*, 2022). In some countries dried *Eucalyptus* leaves are used as tobacco and smoked for asthma (Sefidkon *et al.*, 2008), aqueous extracts are used for aching joints, bacterial dysentery, ringworms, tuberculosis, etc. (Sefidkon *et al.*, 2010). Also, hot water extracts of dried leaves are traditionally used as analgesic, anti-inflammatory, and antipyretic remedies for the symptoms of respiratory infections, such as cold, flue and sinus (Silva *et al.*, 2003).

Eucalyptus has been prized as a rich source of essential oils that's more useful as it is easily extractable and has advantages as its superior quality and is regarded as safe and non-toxic by the United States Food and Drug Authority (FDA). *Eucalyptus* oils are volatile organic compounds found in fruits, flowers, bark, seeds, wood and roots, while, these compounds are mainly extracted from foliage (Boland *et al.*, 1991) because in the leaves that oils were most plentiful and more than 300 species of this genus contain volatile oils in their leaves (Pino *et al.*, 2002). *Eucalyptus* essential oils contain terpenoids, phenolic, flavonoids and alkaloids that possess many bioactivities that could be grouped into three classes viz: perfumery, industrial and medicinal (Abiri *et al.*, 2021). In fact, essential oils rich in 1,8-cineole are utilized as pharmaceuticals, whereas those rich in citronellal, citral and geranyl acetate are used in perfumery (Dhakad *et al.*, 2018). Under natural conditions, essential oils from the leaves of *Eucalyptus* known to provide allelopathic property to this plant (May and Ash, 1990) and defense to *Eucalyptus* leaves against attack by harmful insects, and thus acts as a natural pesticide (Batish *et al.*, 2008; Üstüner *et al.*, 2018; Gallon *et al.*, 2020; Sadraoui-Ajmi *et al.*, 2022). In fact, many researchers reviewed the biological properties of *Eucalyptus* essential oils including anti-microbial, fungicidal, antiviral, insecticidal/insect repellent, herbicidal, acaricidal and nematicidal also the anti-tumour and cytotoxic activities (Zhang *et al.*, 2010; Vuong *et al.*, 2015; Barbosa *et al.*, 2016; Dhakad *et al.*, 2018; Salehi *et al.*, 2019; Abiri *et al.*, 2021; Chandorkar *et al.*, 2021). The importance and the commercial uses of essential oils of *Eucalyptus* have increased the research on their extraction, exploring their chemical compositions and bioactivities.

In fact, *Eucalyptus torquata* Luehm. commonly known as coral gum or coolgardie gum is an attractive tree with a small to medium size growing to 6-8 m and a spread of some 5 m, presenting a single trunk, a greyish green foliage and the blade has a lanceolate shape. The length of leaves around 90-120 mm and wide of 15-20 mm, the profuse flowers are reddish-pink or coral colored and hang decoratively on reddish stems. Flowering is very conspicuous and occurs in spring to summer (Al-Snafi, 2017). It is a fast-growing tree known for tolerance to drought, often hybridising in cultivation with another commonly grown arid zone species, *E. woodwardii* to give a hybrid *E. torwood*. It recommends planting *E. torquata* in protected areas as an ornamental tree in the public and private gardens due to its beautiful flowers and its medium size (El-Juhany and Al Al-Shaikh, 2015). The researchers were also exploring the potency of *E. torquata* by valuing their extracts and essential oils which show different biological activities such as antibacterial, antifungal (Ashour, 2008), cytotoxic (Ashour, 2008; Bardaweel *et al.*, 2014; Lahmadi *et al.*, 2021) and pesticidal activity (Ebadollahi *et al.*, 2017; El Finti *et al.*, 2022; Ebadollahi *et al.*, 2022). Also, *E. torquata* considered an important sources of nectar and pollen for honeybees as showing an abundant flowering of long period and good quality of pollen and nectar for the nutrition of bee; for these reasons, it is frequently planted in arid regions (Eisikowitch *et al.*, 2012; Saadaoui *et al.*,2022).

The purpose of this study is to provide the readers with information concerning the tolerance and behavior of *E. torquata* under drought and salt stress, also, exploring the potency and diversity of extracts and essential oils of this species in terms of chemical composition and biological activities.

Evaluation of the tolerance of *E. torquata* to drought and salt stress

Drought and the salinization of soil are a widespread environmental problems and an important factors determining plant productivity and distribution (Teulières, 2010).For landscape applications like reclamation of dry and arid saline lands, *Eucalyptus* is a good choice, it's a versatile woody species that develops an extensive deep root system and presents the challenge of finding a good compromise between adaptation to specific environmental conditions and productivity (Teulières *et al.*, 2007).

Responses to drought

Drought is the second productivity-limiting stress after cold to find subsequently biotic and abiotic stresses, it was suggested that the availability of water is the important determining factor for the distribution of *Eucalyptus* (Li and Wang, 2003). In fact, among 117 *Eucalyptus* species introduced in Tunisia, *E. torquata* is considered a drought-resistant species (Khouja *et al.*, 2001; Saadaoui *et al.*, 2017). Australian Native Plants Nursery (2015) mentioned that *E. torquata* is tolerant of extended dry periods (El-juhany *et al.*, 2008), also, in Saudi Arabia it was classified among the high tolerating species to drought (El-juhany and Al Al-Shaikh, 2015). In the Mediterranean arid regions, *E. torquata* showed a high tolerance level and flower abundance also in the southern provinces of North Africa (Chemlali *et al.*, 2022). Mechanisms employed for drought resilience of *E. torquata* were investigated by Souden *et al.* (2020) which reported physiological and biochemical responses of this species subjecting to a dehydration period followed by rehydration. It reported that *E. torquata* was less resilient to drought than *E. camaldulensis*. Nevertheless, common responses were shown during the dehydration phase including lowering cell water potential from -1MPa to -4.9MPa after 28 days and to -7.1MPa after 45 days of no irrigation which was restored with 88% after rewatering. In the face of water stress, lowering the water potential of the cells by the plant, help to maintain the water content of the cells and, consequently, the turgor (White *et al.*, 2000). Other physiological responses for *E. torquata* are observed including the early closure of stomata which starting from -3.5MPa to prevent water loss, the net photosynthesis was decreased to achieve less than 2 $\mu mol.m^{-2}.s^{-1}$. The chlorophyll fluorescence parameters *Fv/Fm* (maximum photochemical efficiency of PSII) was decreased and after 30 days of re-watering, *E. torquata* restored the structural and functional integrity of its photosynthetic machinery. Changes in xylem conductivity under water deficit also showed which conducted to minimal xylem embolism for *E. torquata* and the value of Ψ xylem which induced 50% PLC (Ψ50) is-4.6MPa, obviously, the level of xylem cavitation decreased after rehydration (Souden *et al.*, 2020). It has been shown also that in case of drought and/or salinity, osmotic adjustment is the key to the adaptation of plants at the cellular level this by the accumulation of organic and inorganic solutes which helps to reduce the water potential without reducing the actual water content (Sanders and Arndt, 2012). For *E. torquata*, water stress induced accumulation of soluble sugars (glucose and fructose) and cyclitols (pinitol, myo-inositol) for its osmotic adjustment (Souden *et al.*, 2020). These adaptive traits are the key factor in the determination of *E. torquate* drought resistance.

Responses to salinity

Another major stress for plants is the salinity of soils. In fact, the exposure to salt stress triggers many common reactions in *Eucalyptus* species which have developed several strategies to cope with these challenges (Assareh, 2016). However, three strategies for achieving greater salt tolerance: damage prevention, homeostasis establishment and growth regulation (Zhu, 2001). How *E. torquata* deal with and respond to salinity stress has been reported by Balti *et al.* (2021) and the study showed that *E. torquata* was the salt-sensitive even at lower salt concentrations (80 mM NaCl) among other species such as *E. gomphocephala* and *E. loxophleba*. Salt stress induces certain biochemical and physiological changes in *E. torquata,* also visible symptoms mainly by the development of necrotic spots in leaves after exposure to 170 mM of NaCl for 30 days which indicates salt-induced damage at cellular level. Slower growth was not observed for *E. torquata* indicating the inability of growth modulating under salt stress. Changes in photosynthesis also observed, salt stress majorly affect optimal protein function in the photosynthetic electron transport chain (pETC). The chlorophyll fluorescence-based PSII-related parameters calculated showed lower values, in addition to that, a decline in chlorophyll and carotenoids contents in leaves has been observed. The K^+/Na^+ ratio for *E. torquata* declined significantly than other species mainly for *E. loxophleba* which have the ability to selectively increase K^+ amounts over Na^+ (Balti *et al*., 2021). Moreover, NaCl salinity causes a significant effect on Na^+, K^+ and Cl^- uptake and their distribution, in this, higher levels of external Na^+ interfere with K^+ acquisition limiting plant K uptake. Therefore, one of the important physiological mechanisms for salinity tolerance is the K^+ selective absorbance (Nasim *et al*., 2008). Germination also is strongly influenced by osmotic pressure caused by salts in the soil solution (Madsen and Mulligan, 2006). Mechergui *et al.* (2019) reported that seeds of *E. torquata* were not able to germinate at up to 9, 12 and 15 $g.L^{-1}$ NaCl that means that the salinity levels influenced significantly the percentage of germination. For the responses of *E. torquata* to salt stress in relation to growth, it reported that this species showed low survival percentages and volume growth to age 20 years under salt water irrigation (El-Juhany and Al Al-Shaikh, 2015). All these results suggest a good drought tolerance of this forest species; however, it shows a relative sensitivity to the presence of NaCl in the growing medium and soils.

Yields of *E. torquata* on essential oils

The essential oils of *E. torquata* may be obtained from different plant parts; however, as observed in Table1, the highest was found in the leaves whose production was much higher than that in the trunk bark. Hydro distillated leaves of *E. torquata* ranged 1.15-3% of essential oil. Similar essential oils yield (1.21-3.1%) has been reported for *E. globulus*, as the principal source of *Eucalyptus* oil in the world (Derwich *et al*., 2009; Mossi *et al*., 2011; Mulyaningsih *et al*., 2011; Harkat-Madouri *et al*., 2015). The geographical origin also highly affects this production; in this, good extraction yields were observed for plants from Tunisia. In fact, several studies reviewed the parameters that can influence the total essential oil content of plant including part of plant (Silva *et al*., 2011), geographic origin (Gilles *et al*., 2010; Almas *et al*., 2018), the seasonal variations (Silva *et al*., 2011), the phenological stage (Salem *et al*., 2018), method of extraction (Ben Hassine *et al*., 2010; Herzi *et al*., 2013; Chamali *et al*., 2021), rainfall and harvesting regime (Gilles *et al*., 2010).

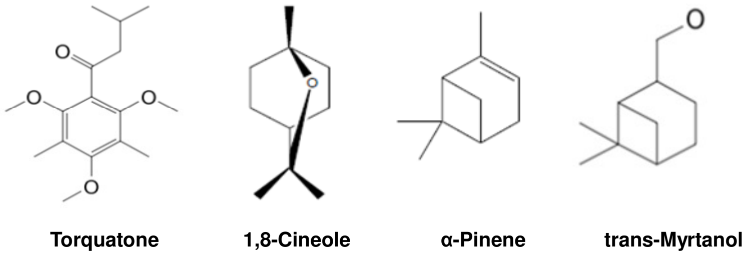
Table 1. Essential oil yields in *E. torquata* obtained by hydro distillation in Tunisia, Iran, Morocco and Cyprus

Origin	**Part used**	**Harvest period/sample crushed or not**	**Essential oils yields (%)**	**References**
Tunisia	Trunk bark	February 2019/Dry sample ground into a fine powder	0.006	(Lahmadi *et al.*, 2021)
	Leaves	January 2005/Dry leaves boorishly crushed	3.2	(Elaissi *et al.*, 2010)
		January 2007/Dry leaves medially crushed	1.86	(Ben Hassine*et al.*, 2010)
Iran		Dry leaf powder	1.15	(Ebadollahi *et al.*, 2017)
Morocco		April 1991	1.17	(Zrira *et al.*, 1994)
Cyprus		March 2021/ Dry leaves crushed into tiny pieces	1.6	(Yiğit Hanoğlu *et al.*,2022)

Chemical profiling of *E. torquata* essential oils

Essential oils obtained from *Eucalyptus* are usually rich in monoterpenes and in some cases sesquiterpenes. Nevertheless, the chemical profile and main components of oils from *Eucalyptus* varied significantly between species. Mostly, the main components were the oxygenated monoterpenes 1,8-cineole and the monoterpene hydrocarbons α-pinene with various percentages dependent on the specific species (Goldbeck *et al.*, 2014; Ishnava *et al.*, 2013). Other compounds also are detected as major component in *Eucalyptus* oils as example; limonene in *E. crebra* oils, citronellal in *E. citriodora* oils (Ghaffar *et al.*, 2015) and p-cymene in *E. oleosa* (Chamali *et al.*, 2019). In Tunisia, most of *Eucalyptus* species oils showed that the oxygenated monoterpenes constituted the major fraction as the 1,8-cineole was the major component (Elaissi *et al.*, 2010; Elaissi *et al.*, 2011a, 2011b, Elaissi *et al.*, 2011; Elaissi *et al.*, 2012, Elaissi *et al.*, 2012; Sebei *et al.*, 2015; Limam *et al.*, 2020; Ameur *et al.*, 2021).

A wide number of terpenes have been identified in the leaves essential oil of *E. torquata*, using analyses by GC-FID, GC or GC-MS (Table 2). In spite of current variations of the origin of the analyzed plants, there is consistence that 1,8-cineole and α-pinene are a characteristic compound of this species. 1,8-cineole was isolated in concentrations between 11 and 70% also the α-pinene obtained with concentration between 10 and 20%. Other compounds detected such as trans-pinocarveol, α-terpineol and borneol from chemical class of oxygenated monoterepenes. The oils also contain considerable amount of the monoterpene hydrocarbons p-cymene, also the aromadendrene and alloaromadendrenefrom chemical class of sesquiterepene hydrocarbons. α-eudesmol, β-eudesmol, γ-eudesmol and globulol are the main oxygenated sesquiterpenes. A high percentage of torquatone also was detected. This last compound forms a member of acylphloroglucinols which was a class of specialized metabolites with relatively high content in *Eucalyptus* with diverse structures and bioactivities (Singh *et al.*, 2009; Yao *et al.*, 2021). Torquatone was first isolated from *E. torquata* and *E. caesia* Benth growing in Australia with 25 and 50% of the essential oil fraction respectively (Bowyer and Jefferies, 1959). It derivative also from the essential oils of number of *Eucalyptus* species and absent in others and present with relative high concentration in *E. torquata* (Ghisalberti, 1996; Bignell *et al.*, 1997a, 1997b; Elaissi *et al.*, 2010; Yiğit Hanoğlu *et al.*, 2022). The chemical formula of torquatone is $C_{16}H_{24}O_4$; there is 4,6-trimethoxy-3,5-dimethyl-1-(3-methylbutyroyl)-benzene (Menut *et al.*, 1999; Figure 1). When the composition of twelve *Eucalyptus* essential oils (*E. torquata* Luehm, *E. woodwardi* Maiden, *E. stricklandii* Maiden, *E. occidentalis* Endl, *E. brockwayi* C. A. Gardn, *E. salmonophloia* F. Muell, *E. gillii* Maiden, *E. oldfieldii* F. Muell, *E. largiflorens* F. Muell, *E. loxophleba* Benth, *E. sargentii* Maiden, *E. gracilis* F. Muell,) are compared, the high percentage of torquatone is recorded for *E. torquata* with 42% also the low percentage of sesquiterpenes hydrocarbons and oxygenated monoterpene with a low quantity of 1,8-cineole (12%) and a relative high amounts of α-pinene (10.5%), α-eudesmol (2.9%), β-eudesmol (10.1%) and γ-eudesmol (1.3%). *Eucalyptus woodwardii* oil had resembling chemical characteristics to *E. torquata* oil essentially in major compounds detected (Elaissi *et al.*, 2010; Ben Amor, 2021).



Torquatone **1,8-Cineole** **α-Pinene** **trans-Myrtanol**

Figure 1. Chemical structure of major elements of essential oil of *E. torquata*

Plants cultivated in different countries produce essential oils with variable composition as can be seen from Table 2. Torquatone is detected as a major component of *E. torquata* leaves essential oils from Tunisia (42%), Australia (42%) and Cyprus (29%) while totally absent in oils from Iran and Morocco. The same for α-eudesmol, β-eudesmol and γ-eudesmol that are not detected in Iranian species. An intra-specific variation is also recorded and explained by geographical, environmental and climatic variations which affect the chemical composition of essential oils. Also, it was proven that essential oils of different plant parts have different chemical composition (Table 2). The trunk bark essential oil of *E. torquata* growing in Tunisia has a completely distinct chemical profile compared to the leaf essential oils. The 1,8-cineole was totally absent and the major constituents being the oxygenated monoterpenes (84.7%), with trans-myrtanol (73.4%) and myrtenol (4.7%) as the main components. The apocarotene cis-β-ionone and the fatty acid nonanoic acid also identified in significant percentages of 3.9% and 2.4% respectively, the sesquiterpene hydrocarbons were represented with only 2% with γ-maaliene as the main component (1.3%) (Lahmadi *et al.*, 2021). Therefore, there are notable quantitative and qualitative differences in *E. torquata* essential oils compositions; it is mentioned in literature that these differences are attributed to several exogenous factors: harvest time, seasonal factors, soil composition, geographical position and the method of drying of plants. Endogenous factors are involved including genetic makeup and the ontogenetic development stage (Marzoug *et al.*, 2011; Zandi-Sohani and Ramezani, 2015).

Since the chemical composition of the *Eucalyptus* essential oils is directly associated with their biological activities, the following discussion will be focused on such activities of *E. torquata*. The specific and different composition in *E. torquata* can only act on these activities.

Table 2. Major components of *E. Torquata* essential oils obtained by hydro distillation from Tunisia, Iran, Australia, Morocco and Cyprus

Origin	Part used	Major Components (%)	Identification method	References
Tunisia	Trunk bark	trans-Myrtanol (73.4), myrtenol (4.7), (E)-β-ionone (3.9), nonanoic acid (2.4), α-terpineol (1.9), decanoic acid (0.9), γ-maaliene (1.3), cis-myrtanol (1.2), β-cyclocitral (0.8), geranylacetone (0.8), (E)-ocimenol (0.7)	(GC-EI-MS)	(Lahmadi *et al.*, 2021)
	Leaves	Torquatone (42), 1,8-cineole (12), α-pinene (10.5), β-eudesmol (10.1) trans-pinocarveol (5.1), α-eudesmol (2.9), p-cymene (2), globulol (2), γ -eudesmol (1.3), aromadendrene (1.1), δ-cadinol (0.9)	(GC (RI) and GC/MS)	(Elaissi *etal.*, 2010)
Iran		1,8-Cineole (69.6), α-pinene (9.5), terpinen-4-ol (0.8), α-terpineol (1.1), alloaromadendrene (7.8), aromadendrene (4.5), limonene (1.5), p-cymene (0.7)	GC-FID and GC-Mass	(Nikbakht et *al.,*2015)
		1,8-Cineole (66.9), α-pinene (13.9), trans-pincarveol (6.3), p-cymene (4.2)	(GC and GC/MS)	(Sefidkon *et al.*, 2010)
		1,8-Cineole (28.57), α-pinene (15.74), globulol (13.11), alloaromadendrene (7.26) α-terpineol (2.64), epiglobulol (2.50), p-cymene (2.46), trans-pinocarveol (2.09), viridiflorol (1.86), endo-borneol (1.72), neoalloocimene (1.53), terpineol-4 (1.51), ledene (1.39), α-gurjunene (1.25), δ-selinene (1.04)	(GC-MS)	(Ebadollahi *et al.*, 2017)
		1,8-Cineole (24.2), α-pinene (20) globulol (8.4), aromadendrene (7.8), α-terpineol (2.5), cubeban-11-ol (2.4), trans-sabinol (2), alloaromadendrene (1.8)	(GC-MS)	(Ebadollahi *et al.*, 2022)
Australia		Torquatone (42), 1,8-cineole (11.2), α-pinene (10.2), α-eudesmol (10.2), β-eudesmol (11.1), γ-eudesmol (4.8)	(GC-FID and GC-MS)	(Baranska *et al.*, 2005)
Morocco		1,8-cineole (46,9), α-pinene (16,7), bornéol (10.8), 4-terpinéol (3,2), globulol (1.6), p-cymene (1.3)	(GC-FID)	(Zrira *et al.*, 1994)
Cyprus		Torquatone (29.2), 1,8-cineole (18.8), α-pinène (18.6), β-eudesmol (10.3), α-eudesmol (6.8)	(GC and GC-MS)	(Yiğit Hanoğlu *et al.*, 2022

Biological activities

Antimicrobial activity of E. torquata essential oils

Eucalyptus essential oils endowed antimicrobial action against a large spectrum of bacteria and fungi which consist to its therapeutic properties as a promising alternative to drugs for several diseases and disorders (Zhang *et al*., 2010; Barbosa *el al*., 2016; Dhakad *et al*., 2018). Additionally, the possible interactions of *Eucalyptus* essential oils with conventional antimicrobial agents was studied that could lead to new treatment strategies involving reduced antibiotic doses and for higher therapeutic efficacy (Knezevic *et al*., 2016; Scazzocchio *et al*., 2016; Al-Qaysi *el al*., 2020). The bioactivity of *Eucalyptus* essential oils may be due to their monoterpene components; in fact, antimicrobial activity could be attributed to the presence of compounds such as 1,8-cineole, α-pinene, β-pinene and limonene (Dhakad *et al*., 2018). However, the interactions of different constituents may be responsible for the total bioactivity of *Eucalyptus* essential oils that can potentially lead to additive, synergistic, or antagonistic effects (Mulyaningsih *et al*., 2010).

Eucalyptus torquata essential oils marked antimicrobial activities against a large spectrum of bacteria based on agar diffusion method and the microdilution method (Table 3) the bioassays confirm that Gram-positive bacteria are more sensitive compared to Gram-negative ones. Indeed, leaves, stems and flowers essential oils of *E. torquata* exhibited a moderate to high antibacterial activity against *Staphylococcus aureus, Staphylococcus epidermidis, Enterococcus faecalis and Bacillus subtilis* with inhibition zones in the range of 10 and 22 mm of diameter and against the two bacteria *Klebsiella pneumoniae* and *Proteus mirabilis* with inhibition zones in the range of 8 and 10 mm of diameter while not active against *salmonella typhi*. Also, *E. torquata* flowers essential oil demonstrated antibacterial action against *Pseudomonas aeruginosa* with inhibition zone of 11mm (Ashour, 2008; Bardaweel *et al*., 2014) this last bacteria was resistant to essential oils obtained from several *Eucalyptus* species and from other plants (Elaissi *et al*., 2011; Wilkinson and Cavanagh, 2005). In other hand*, Pseudomonas aeruginosa* with *Escherichia coli* are resistant to leaves essential oils of *E. torquata* grown in Egypt while susceptible to that grown in Jordan with inhibition zones of 11 and 9 mm respectively (Ashour, 2008; Bardaweel *et al*., 2014). Minimum inhibitory concentration (MIC) of leaves essential oils of *E. torquata* from Jordan was calculated by the microdilution method, Norfloxacin 1 mg/ml was used as reference controls for antibacterial activity. The MIC values for *Bacillus subtilis*, *Staphylococcus aureus*, *Staphylococcus epidermidis, Escherichia coli* and *Pseudomonas aeuriginosa* are 198, 201, 197, 204 and 217 µg/ml respectively (Bardaweel *et al*., 2014).

E. torquata essential oils also cause growth inhibition of some fungal species, oils from flowers, stems and leaves of *E. torquata* from Egypt and Jordan exhibited a moderate to high antifungal activities against mycelial fungi *Aspergillus flavus* and *Aspergillus niger*also against the yeast *Candida albicans*. Flowers essential oil from Egypt showed the maximum zone inhibition against *Aspergillus flavus* and *Candida albicans* with inhibition zones of 17 and 15 mm respectively, while the leaves essential oil is active with inhibition zones of 10 and 14 mm respectively. Nevertheless, essential oils from Jordan are active against *Aspergillus flavus* and *Candida albicans* with inhibition zones of 10 mm and with MIC values of 198 and 192 µg/ml respectively (Ashour, 2008; Bardaweel *et al*., 2014).

As a result, the difference in the chemical composition of *E. torquata* essential oils shown previously could be the cause of the difference in their biological and therapeutic activities.

Antimicrobial activities of E. torquata extracts

Hence, there is an urgent need to find alternative antimicrobial agents for the treatment of resistant pathogenic microorganisms. The use of plant-based antimicrobials has several advantages over synthetic chemicals since the lower incidence of numerous side effects, low toxicity for mammals and high degradability

(Raja, 2014). *Eucalyptus* species are known to be a rich source of bioactive compounds, including phenolic, flavonoid, terpenoids, tannins, phloroglucinol and cardiac glycosides, which had potential antimicrobial activities (Luís *etal*., 2016; Elansary *et al*., 2017; Bhuyan *et al*., 2017; Sabo and Knezevic, 2019). Indeed, phenolic compounds are those which contribute significantly to the antioxidant activities of plant extracts (Siramon and Ohtani, 2007; Ghaffar *et al*., 2015). Two studies conducted in Morocco revealed that aqueous extracts of powdered waste from *E. torquata* (leaves, stems, twigs and other parts) contained total polyphenols amounts of 73.48 and 76.68 mg GAE/g DW and flavonoids content of approximately 58 mg RE/g DW in which significant antioxidant capacity has been investigated for these extracts (Bouhlali *et al*., 2020; Bouhlali *et al*., 2021). Additionally, methanol and aqueous extracts from leaves, stems and flowers of *E. torquata* showed antibacterial action against different medically bacteria such as *Staphylococcus aureus, Staphylococcus epidermidis, Enterococcus faecalis, Bacillus subtilis and Escherichia coli* with different inhibition zones in the range of 7 and 25 mm, also, it marked an antifungal activity against the yeast *Candida albicans* with inhibition zones in the range of 9 and 14 mm of diameter (Ashour, 2008).

In another way, the growing interest in the use of natural plant products in the biological control of plant disease through the use of biological methods has been a great challenge for agriculture for a long time. In fact, *Eucalyptus* species possess fungicidal properties against large spectrum of phytopathogenic fungi (Zhou *et al*., 2016; Gakuubi *et al*., 2017; Abdelkhalek *et al*., 2020). Also, aqueous extracts from *E. torquata* waste (leaves, branches, twigs) showed an antifungal activity against two fungal pathogens *Fusarium oxysporum* f. sp. *albedinis* and *Mauginiella scaettae* in a dose dependent manner and more stronger than extracts from other plants such as *Acacia cyanophylla*, *Cupressus atlantica, Nerium oleander* and *Schinus molle* (Bouhlali *et al*., 2020; Bouhlali *et al*., 2021). These soil-borne fungal pathogens caused a serious threat to date palm (*Phoenix dactylifera* L.) in Morocco. “Bayoud” disease and inflorescence rot are the principal enemy of palm trees caused by these pathogens and researchers suggest the use of this plant to control these diseases. It reported that at every concentration tested, *E. torquata* extract showed the strongest inhibition activity on fungal mycelia growth of pathogens. At a dose of 4% of extract, the spore germination of *Fusarium oxysporum* inhibited with 79.21% after 7 days of incubation and strong sporulation reductions is shown with 44.97% of extract after 10 days of incubation (Bouhlali *et al*., 2020). 100% inhibition of spore germination of *Mauginiella scaettae* at a low concentration of 1% of *E. torquata* extracts after 24h of incubation and a great reduction in sporulation by 88.05% at a dose of 4%. The inhibitory effect of these extracts is related to their composition; moreover, content in polyphenols and flavonoids in aqueous extracts of *E. torquata* are found to be correlated with this antifungal activity as well as their antioxidant properties (Bouhlali *et al*., 2021).

Table 3. Biological properties of *E. torquata* essential oils and extracts

***E. torquata* effects**	**Plant part (extract or oil)**	**Tested organism and /or cell line**	**Effects and/or related mechanisms [a]**	**References**
Antimicrobial activity	Leaves essential oil from Jordan	*B. subtilis,* *S. aureus* *S. epidermidis* *P. aeuriginosa* *E. coli* *C. albicans*, *A. flavus*	Growth inhibition IZD MIC 11 198 12 201 10 197 9 204 11 217 10 192,198	(Bardaweel *et al.*, 2014)
	Leaves, stems and flowers essential oils from Egypt	*B. subtilis* *S. aureus* *S. epidermidis* *E. faecalis* *K. pnemounia* *P. mirabilis* *C. albicans* *A. flavus* *A. niger*	11-15 10-16 19-22 12-19 8-10 8-9 10-15 14-17 12-15	(Ashour, 2008)
	Flowers essential oil from Egypt	*P. aeuriginosa*	11	
	Leaves, stems and flowers methanolic extract from Egypt	*S. aureus* *S. epidermidis* *E. faecalis* *B. subtilis, E. coli* *C. albicans*	16-17 10-16 13-19 13-15 10-11	
	Leaves, stems and flowers aqueous extract from Egypt	*S. aureus* *S. epidermidis* *E. faecalis* *B. subtilis* *C. albicans*	10-13 9-13 18-24 11-14 9-10	
Anticancer activity	Stems and leaves essential oils from Egypt	MCF7 Human breast adenocarcinoma cells	Notable cytotoxic effect with IC50 values of 1.34(stem oil) and 5.22 µg/mL (leaf oil)	
	Leaves essential oil from Jordan	Nine mammalian cell line (MCF-7, HeLa, Caco, T47D, BJAB, Raji, A498, PC3 and Caki)	Cytotoxic effect with IC50 values ranging from 33 and 115 µg/mL after exposure time of 48 h Probably involved cell death by apoptosis	(Bardaweel *et al.*, 2014)
	Trunk bark essential oil from Tunisia	Two human cell lines MDA-MB-231 and SW620	Inhibitory effect on cell proliferation with IC50 values of	(Lahmadi *et al.*, 202)

			40.66 and 26.71 µg/mL after 48h	
Insecticidal activity	Aqueous extract of leaves from Morocco	*D. opuntiae*	65% mortality in the population of adults females and 50% of nymphal stage after three application of extract (60%)	(El Finti *et al.*, 2022)
	Leaves essential oil from Iran	*R. dominica*	Fumigant toxicity after 72h with LC50 and LC90 values of 31.567 and 105.017 µL/L of Air respectively	Ebadollahi *et al.*, 2022)
Acaricidal activity	Leaves essential oil from Iran	*T. urticae*	Strong fumigant toxicity against female adults (LC50 = 3.59 (µl/l air after 24h)	(Ebadollahi *et al.* (2017)

[a]**IZD** – Inhibitory zone diameter (mm), **MIC**- minimal inhibitory concentration (µg/ml), **IC50**- 50% inhibitory concentration, **LC50**-50% lethal concentration, **LC90** - 90% lethal concentration.

Anticancer activity

The cytotoxic effect of extracts and components isolated from different species of *Eucalyptus* has been studied by several researchers. Anti-tumor properties of phenolics, terpenoids (monoterpenes, sesquiterpenes, diterpenoids and triterpenoids) derived from *Eucalyptus* plants have been discussed by Abiri *et al.* (2021) which explain the broad spectrum of toxicity, antitumor properties, and mechanisms against cancerous cell lines of *Eucalyptus*-derived essential oil which can be a promising green anti-cancer drugs. Also, Bardaweel *et al.* (2014) demonstrated the cytotoxic effect of essential oils from *E. torquata* gorwn in Jordan which reported that it was varied and highly cell line dependent; in fact, various cytotoxicity levels have been observed on the cancer cell lines treated with essential oil after exposure time of 48 h at 37 °C based on MTT assay. It reported that the EBV-negative Burkitt's lymphoma BJAB cell and the human Burkitt's lymphoma Raji cell line are the most sensitive cell lines with IC50 values of 33 and 39 µg/ml respectively. Although, cytotoxic proprieties also observed against the human breast adenocarcinoma MCF7 cell line (IC50 values of 115 µg/mL), the human ductal breast epithelial tumor cell line T47D (IC50 values of 82 µg/mL), the human clear cell renal cell carcinoma Caki cell (IC50 values of 94 µg/mL), the human kidney carcinoma cell line A498 line (IC50 values of 87 µg/mL), the human prostate cancer PC3 cell line (IC50 values of 108 µg/mL), the human colon adenocarcinoma Caco-2 cell line (IC50 values of 108 µg/mL) and the human epithelial carcinoma HeLa cell line (IC50 values of 91 µg/mL). Also, the Lactate dehydrogenase (LDH) activity and the decrease in DNA content of cell line treated indicated that the cytotoxic activity of *E. torquata* essential oils probably mediated through induction of cell death by apoptosis (Bardaweel *et al.*, 2014).

The trunk bark essential oil of *E. torquata* grown in Tunisia displayed significant antiproliferative effect against two human cancer cell lines: breast carcinoma cell lines MDA-MB-231 and colorectal cancer cell lines SW620 which demonstrated inhibitory effect on the tested cell lines proliferation in a dose-dependent manner after 48 h of incubation using Crystal Violet Staining (CVS) assay, the highest cytotoxic activity of essential oil is observed at 100µg/mL and it's shown that colon carcinoma cells are more sensitive against essential oils (with IC50 values of 26.71 µg/mL) than breast MDA-MB-231 (with IC50 values of 40.66 µg/mL) (Lahmadi *et al.*, 2021). According to the protein-staining sulphorhodamine B (SRB) assay for cell growth, essential oils of *E. torquata* from Egypt (extracted from stem with IC50 value of 1.34 µg/mL and leaves with IC50 value of 5.22

µg/mL) have a cytotoxic effect on the Human breast adenocarcinoma cell line (MCF7) and failed to exert a considerable effect on Human hepatocellular carcinoma cell line (HEPG2) (Ashour, 2008). These studies increase the attention in exploring this species and improving the therapeutic opportunities against cancer.

E. torquata as pesticide

Attacks and infection by pests (especially weeds, pathogens and animal pests) are the largest competitor of agricultural crops that severely reduce crop productivity (Oerke, 2006). However, the excessive use of synthetic pesticide residue in food, accumulated in the environment and increasing health hazards to humans in addition to the increasing risk of pesticide resistance (Pimentel *et al*., 1992), is thus pertinent to explore the pesticidal activities of natural products. *Eucalyptus* species are known to be a rich source of bioactive compounds that allow it to act directly as natural pesticide (Radwan *et al*., 2000; Shukla *et al*., 2002; Batish *et al*. 2008; Anita *et al*., 2012; Barbosa *et al*., 2016; Adak *et al*., 2020). Absolutely, *E. torquata* has been shown insecticidal properties against the Cochineal, *Dactylopius opuntiae*, an insect that highly damaging the cactus plants in Morocco, it found that three applications of aqueous extract (60%) of *E. torquata* leaves are needed to reduce mealybug populations also caused the death of 65% of females and 50% of nymphal stages of *Dactylopius* spp. after 72 h after spraying with *E. torquata* extract which could be an alternative for the control of wild cochineal (El Finti *et al*., 2022). Also, *E. torquata* essential oils showed a great insecticidal potential on the adults of *Rhyzopertha dominica,* an insect pest of stored products, in which significant fumigant toxicity against insect which was augmented by increasing the concentration of *E. torquata* essential oils and the exposure time. The LC50 value decreased with increasing exposure time from 37.728 (µL/L of Air) after 24 h to 31.567 (µL/L of Air) after 72 h of exposure with essential oil. In fact, sublethal biochemical disruption has been shown in treated insects, including the reduction of energy content resulting from the significant decrease of the protein and glycogen contents. In other hand, an inhibition of digestive amylase and protease enzyme activities, also, a significant decreases in the relative growth rate of insects (Ebadollahi *et al*., 2022) which confirm that *E. torquata* extract and essential oils can be used to control insect pests. Also, it found that possess acaricidal properties as reported by Ebadollahi *et al.* (2017) which demonstrated that *E. torquata* leaves essential oils have strong toxicity against the adult females of *Tetranychus urticae* Koch and the observed LC50 values in the fumigation test was 3.59 µL/L air after 24 h.

Conclusions

With many *Eucalyptus* species adapted to arid conditions, *E. torquata* is considered drought tolerant. The corresponding tolerance mechanisms developed by this species were demonstrated in this review. To assume, drought resistance of *E. torquata* was manifested by stomatal closure to prevent water loss. Osmotic adjustment was a coping strategy to water stress by increasing the accumulation of solutes, including soluble sugars (glucose and fructose) and cyclitols (pinitol and myo-inositol) in addition to that, the resilience to xylem embolism. However, salt stress may have a negative impact on *E. torquata* which appears sensitive to the presence of NaCl that acts in particular on photosynthesis. This paper showed also the large variability in yields and chemical composition that exists among *E. torquata* hydro distillated essential oils from several origins. The majority of oils produced are rich in 1,8-cineole, α-pinene and torquatone. It can be concluded that *E. torquata* derived essential oils are a rich resource of active phytochemicals which can possess a wide range of biological activities; From the present review, it is clear that possess potent antimicrobial capacity and exhibit an advances anticancer and biocidal effects.

Authors' Contributions

Writing-original draft: SBR; drafting guidance: KBY, SD, IC, SB, CBR; Supervision: ES, MR. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This work was by the INRGREF (Agricultural Experimentation Unit of Gabes).

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Abdelkhalek A, Salem MZM, Kordy AM, Salem AZM, Behiry SI (2020). Antiviral, antifungal, and insecticidal activities of *Eucalyptus* bark extract: HPLC analysis of polyphenolic compounds. Microbial Pathogenesis 147:104383. *https://doi.org/10.1016/j.micpath.2020.104383*

Abiri R, Atabaki N, Sanusi R, Malik S, Abiri R, Safa P, … Abdul-Hamid H (2021). New insights into the biological properties of *Eucalyptus*-Derived essential oil: A promising green anti-cancer drug. Food Reviews International 1-36. *https://doi.org/10.1080/87559129.2021.1877300*

Adak T, Barik N, Patil NB, Govindharaj GPP, Gadratagi BG, Annamalai M, … Rath PC (2020). Nanoemulsion of *Eucalyptus* oil: An alternative to synthetic pesticides against two major storage insects *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst) of rice. Industrial Crops and Products 143:111849. *https://doi.org/10.1016/j.indcrop.2019.111849*

Al-Qaysi AMK, Al-Ouqaili MTS, Al-Meani SAL (2020). Ciprofloxacin-and gentamicin-mediated inhibition of *Pseudomonas aeruginosa* biofilms is enhanced when combined the volatile oil from *Eucalyptus camaldulensis*. Systematic Reviews in Pharmacy 11:98-105. *https://doi.org/10.31838/srp.2020.7.16*

Al-Snafi PDAE (2017). The pharmacological and therapeutic importance of *Eucalyptus* species grown in Iraq. IOSR Journal of Pharmacy 7(3):72-91. *https://doi.org/10.9790/3013-0703017291*

Aleksic Sabo V, Knezevic P (2019). Antimicrobial activity of *Eucalyptus camaldulensis* Dehn. plant extracts and essential oils: A review. Industrial Crops and Products 132:413-29. *https://doi.org/10.1016/j.indcrop.2019.02.051*

Almas I, Innocent E, Machumi F, Kisinza W (2018). Effect of geographical location on yield and chemical composition of essential oils from three *Eucalyptus* species growing in Tanzania. Asian Journal of Traditional Medicines 14(1):1-12. *http://asianjtm.syphu.edu.cn/EN/*

Ameur E, Sarra M, Yosra D, Mariem K, Nabil A, Lynen F, Larbi KM (2021). Chemical composition of essential oils of eight tunisian *Eucalyptus* species and their antibacterial activity against strains responsible for otitis. BMC Complementary Medicine and Therapies 21(1):1-16. *https://doi.org/10.1186/s12906-021-03412-0*

Ashour HM (2008). Antibacterial, antifungal, and anticancer activities of volatile oils and extracts from stems, leaves, and flowers of *Eucalyptus sideroxylon* and *Eucalyptus torquata*. Cancer Biology & Therapy 7(3):399-403. *https://doi.org/10.4161/cbt.7.3.5367*

Balti H, Abassi M, Dietz KJ, Kumar V (2021). Differences in ionic, enzymatic, and photosynthetic features characterize distinct salt tolerance in *Eucalyptus* species. Plants 10(7):1401. *https://doi.org/10.3390/plants10071401*

Baranska M, Schulz H, Reitzenstein S, Uhlemann U, Strehle MA, Krüger H, … Popp J (2005). Vibrational spectroscopic studies to acquire a quality control method of *Eucalyptus* essential oils. Biopolymers: Original Research on Biomolecules 78(5):237-248. *https://doi.org/10.1002/bip.20284*

Barbosa LCA, Filomeno CA, Teixeira RR (2016). Chemical variability and biological activities of *Eucalyptus* Spp. essential oils. Molecules 21(12):1671. *https://doi.org/10.3390/molecules21121671*

Bardaweel S, Hudaib M, Tawaha K (2014). Evaluation of antibacterial, antifungal, and anticancer activities of essential oils from six species of *Eucalyptus*. Journal of Essential Oil Bearing Plants 17(6):1165-74. *https://doi.org/10.1080/0972060X.2014.963169*

Bardaweel SK, Hudaib MM, Tawaha KA, Bashatwah RM, Material AP (2015). Antimicrobial, antioxidant and Free Radical Scavenging activities of essential oils extracted from six *Eucalyptus* species. International Journal of Biotechnology and Bioengineering 9(1):66-69. *https://doi.org/10.5281/zenodo.1099314*

Batish DR, Singh HP, Kohli RK, Kaur S (2008). *Eucalyptus* essential oil as a natural pesticide. Forest Ecology and Management 256(12):2166-74. *https://doi.org/10.1016/j.foreco.2008.08.008*

Ben Hassine D, Ben Ismail H, Jribi C, Khouja ML, Abderrabba M (2010). Chemical composition of some Tunisian *Eucalyptus* essential oils as obtained by hydrodistillation using Clevenger type apparatus. Biosciences Biotechnology Research Asia 7(2):647-665.

Bhuyan DJ, Vuong QV, Chalmers AC, Van Altena IA, Bowyer MC, Scarlett CJ (2017). Phytochemical, antibacterial and antifungal properties of an aqueous extract of *Eucalyptus microcorys* leaves. South African Journal of Botany 112:180-85. *https://doi.org/10.1016/j.sajb.2017.05.030*

Bignell CM, Dunlop PJ, Brophy JJ (1997a). Volatile leaf oils of some Queensland and Northern Australian species of the genus *Eucalyptus*. (Series Ii). Part i. Subgenus Symphyomyrtus, Section Adnataria:(A) Series Oliganthae,(b) Series Ochrophloiae,(c) Series Moluccanae,(d) Series Polyanthemae,(e) Se. Flavour and Fragrance Journal 12(1):19-27. *https://doi.org/10.1002/(SICI)1099-1026(199701)12:1<19::AID-FFJ597>3.0.CO;2-F*

Bignell CM, Dunlop PJ, Brophy JJ (1997b). Volatile leaf oils of some Queensland and Northern Australian species of the genus Eucalyptus (Series II). Part II. Subgenera (a) Blakella,(b) Corymbia,(c) Unnamed,(d) Idiogenes,(e) Monocalyptus and (f) Symphyomyrtus. Flavour and Fragrance Journal 12(4):277-84. *https://doi.org/10.1002/(SICI)1099-1026(199707)12:4<277::AID-FFJ642>3.0.CO;2-B*

Boland DJ, Brophy JJ, House APN (1991). *Eucalyptus* leaf oils: use, chemistry, distillation and marketing. Phytochemistry 31(6):2193. *https://doi.org/10.1016/0031-9422(92)80403-2*

Bouhlali EDT, Derouich M, Ben-Amar H, Meziani R, Essarioui A (2020). Exploring the potential of using bioactive plant products in the management of *Fusarium oxysporum* f. Sp. Albedinis: The causal agent of Bayoud disease on Date Palm (*Phoenix dactylifera* L.). Beni-Suef University Journal of Basic and Applied Sciences 9(1):1-9. *https://doi.org/10.1186/s43088-020-00071-x*

Bouhlali EDT, Derouich M, Meziani R, Essarioui A (2021). Antifungal potential of phytochemicals against *Mauginiella scaettae*, the plant pathogen causing inflorescence rot of Date Palm. Scientifica 2021:1896015. *https://doi.org/10.1155/2021/1896015*

Bowyer BC, Jefferies PR (1959). Studies in plant chemistry: The Essential oils of *Eucalyptus caesia* Benth. and *E. torquata* Luehm. and the structure of Torquatone. Australian Journal of Chemistry 12(3):442-446. *https://doi.org/10.1071/CH9590442*

Chamali S, Ben Daoud H, Saadaoui E, Elfalleh W, Romdhane M (2019). A new process for the green extraction of essential oil from *Eucalyptus oleosa*: Microwave-assisted hydrodistillation. Arabian Journal of Medicinal and Aromatic Plants 5(3):35-46. *https://doi.org/10.48347/IMIST.PRSM/ajmapv5i3.18666*

Chamali S, Bouajila J, Ben Daoud H, Camy S, Saadaoui E, Condoret JS, Romdhane M (2021). Variation in chemical composition and biological properties of two Tunisian *Eucalyptus* essential oils under three eco-friendly extraction techniques. Journal of Essential Oil Research 34(1):36-53. *https://doi.org/10.1080/10412905.2021.2008029*

Chandorkar N, Tambe S, Amin P, Madankar C (2021). A systematic and comprehensive review on current understanding of the pharmacological actions, molecular mechanisms, and clinical implications of the genus *Eucalyptus*. Phytomedicine Plus 1(4):100089. *https://doi.org/10.1016/j.phyplu.2021.100089*

Chen H, Jiang JG (2010). Osmotic adjustment and plant adaptation to environmental changes related to drought and salinity. Environmental Reviews 18(NA):309-319. *https://doi.org/10.1139/A10-014*

Yiğit Hanoğlu D, Hanoğlu A, Adediran SB, Baser KHC, Özkum Yavuz D (2022). The essential oil compositions of two *Eucalyptus* sp. (*E. camaldulensis* Dehnh. and *E. torquata* Luehm.) naturalized to Cyprus. Journal of Essential Oil Research. *https://doi.org/10.1080/10412905.2022.2147592*

Derwich E, Benziane Z, Boukir A (2009). GC/MS analysis of volatile constituents and antibacterial activity of the essential oil of the leaves of *Eucalyptus globulus* in Atlas median from Morocco. Advances in Natural and Applied Sciences 3(3):305-314. *http://www.insipub.com/aensi/anas/2009/305-313.pdf*

Dhakad AK, Pandey VV, Beg S, Rawat JM, Singh A (2018). Biological, medicinal and toxicological significance of *Eucalyptus* leaf essential oil: A review. Journal of the Science of Food and Agriculture 98(3):833-848. *https://doi.org/10.1002/jsfa.8600*

Ebadollahi A, Naseri B, Abedi Z, Setzer WN, Changbunjong T (2022). Promising insecticidal efficiency of essential oils isolated from four cultivated *Eucalyptus* species in Iran against the lesser grain borer, *Rhyzopertha dominica* (F.). Insects 13(6):517. *https://doi.org/10.3390/insects13060517*

Ebadollahi A, Sendi JJ, Maroufpoor M, Rahimi-Nasrabadi M (2017). Acaricidal potentials of the terpene-rich essential oils of two Iranian *Eucalyptus* Species against *Tetranychus urticae* Koch. Journal of Oleo Science 66(3):307-314. *https://doi.org/10.5650/jos.ess15258*

Eisikowitch D, Dag A, Samocha Y (2012). Two Eucalypts and one hybrid as a potential source of pollen and nectar in Israel. American Bee Journal 152(6):607-609.

El-Juhany L, Al Al-Shaikh AM (2015). Evaluation of the growth and adaptability of some exotic *Acacia* and *Eucalyptus* species to Riyadh Region, Saudi Arabia. Research Journal of Agriculture 2:1-12.

El-juhany LI, Aref IM, Ahmed AIM (2008). Response of *Eucalyptus camaldulensis*, *Eucalyptus microtheca* and *Eucalyptus intertexta* seedlings to irrigation with saline water. World Journal of Agricultural Sciences 4:825-834. *https://www.idosi.org/wjas/wjas4(s)/5.pdf*

Elaissi A, Medini H, Simmonds M, Lynen F, Farhat F, Chemli R, … Khouja ML (2010). Variation in volatile leaf oils of twelve *Eucalyptus* species harvested from Hajeb Layoun arboreta (Tunisia). Chemistry & Biodiversity 7(3):705-716. *https://doi.org/10.1002/cbdv.201000103*

Elaissi A, Medini H, Simmonds M, Lynen F, Farhat F, Chemli R, … Khouja ML (2011a). Variation in volatile leaf oils of five *Eucalyptus* species harvested from Jbel Abderrahman arboreta (Tunisia). Chemistry & Biodiversity 8(2):352-361. *https://doi.org/10.1002/cbdv.201000103*

Elaissi A, Medini H, Simmonds M, Lynen F, Farhat F, Chemli R, … Khouja ML (2011b). Variation in volatile leaf oils of seven *Eucalyptus* species harvested from Zerniza arboreta (Tunisia). Chemistry & Biodiversity 8(2):362-372. *https://doi.org/10.1002/cbdv.201000103*

Elaissi A, Rouis Z, Mabrouk S, Bel Haj Salah K, Aouni M, Khouja ML, … Harzallah-Skhiri F. (2012). Correlation between chemical composition and antibacterial activity of essential oils from fifteen *Eucalyptus* species growing in the Korbous and Jbel Abderrahman arboreta (North East Tunisia). Molecules 17(3):3044-3057. *https://doi.org/10.1002/cbdv.201000103*

Elaissi A, Rouis Z, Salem NAB, Mabrouk S, Ben Salem Y, Salah KBH, … Khouja ML (2012). Chemical composition of eight *Eucalyptus* species essential oils and the evaluation of their antibacterial, antifungal and antiviral activities. BMC Complementary and Alternative Medicine 12(1):1-15. *https://doi.org/10.1186/1472-6882-12-81*

Elaissi A, Salah KH, Mabrouk S, Larbi KM, Chemli R, Harzallah-Skhiri F (2011). Antibacterial activity and chemical composition of twenty *Eucalyptus* species essential oils. Food Chemistry 129(4):1427-1434. *https://doi.org/10.1016/j.foodchem.2011.05.100*

Elansary HO, Salem MZM, Ashmawy NA, Yessoufou K, El-Settawy AAA (2017). *In vitro* antibacterial, antifungal and antioxidant activities of *Eucalyptus* Spp. leaf extracts related to phenolic composition. Natural Product Research 31(24):2927-2930. *https://doi.org/10.1080/14786419.2017.1303698*

El Finti A, El Boullani R, Zahidi A, El Mousadik A (2022). Management of the Prickly Pear Mealy Bug, *Dactylopius opuntiae* using bio-insecticide in Morocco. Advances in Entomology 10(4):267-74. *https://doi.org/10.4236/ae.2022.104019*

Gakuubi MM, Maina AW, Wagacha JM (2017). Antifungal activity of essential oil of *Eucalyptus camaldulensis* Dehnh. against selected *Fusarium* Spp. International Journal of Microbiology 2017:8761610. *https://doi.org/10.1155/2017/8761610*

Gallon C, Martello RH, Cozzer G, Rezende CAL, Calisto JFF, Floss PA, … Albeny-Simões D (2020). Chemistry matters: Biological activity of *Eucalyptus* essential oils on Mosquito larval mortality. Entomologia Experimentalis et Applicata 168(5):407-415. *https://doi.org/10.1111/eea.12908*

Ghaffar A, Yameen M, Kiran S, Kamal S, Jalal F, Munir B, … Jabbar A (2015). Chemical composition and in-vitro evaluation of the antimicrobial and antioxidant activities of essential oils extracted from seven *Eucalyptus* species. Molecules 20(11):20487-20498. *https://doi.org/10.3390/molecules201119706*

Ghisalberti EL (1996). Bioactive Acylphloroglucinol derivatives from *Eucalyptus* species. Phytochemistry 41(1):7-22. *https://doi.org/10.1016/0031-9422(95)00484-X*

Gilles M, Zhao J, An M, Agboola S (2010). Chemical composition and antimicrobial properties of essential oils of three Australian *Eucalyptus* species. Food Chemistry 119(2):731-737. *https://doi.org/10.1016/j.foodchem.2009.07.021*

Goldbeck JC, do Nascimento JE, Jacob RG, Fiorentini ÂM, da Silva WP (2014). Bioactivity of essential oils from *Eucalyptus globulus* and *Eucalyptus urograndis* against planktonic cells and biofilms of *Streptococcus mutans*. Industrial Crops and Products 60:304-309. *https://doi.org/10.1016/j.indcrop.2014.05.030*

Harkat-Madouri L, Asma B, Madani K, Bey-Ould Si Said Z, Rigou P, Grenier D, … Boulekbache-Makhlouf L (2015). Chemical composition, antibacterial and antioxidant activities of essential oil of *Eucalyptus globulus* from Algeria. Industrial Crops and Products 78:148-153. *https://doi.org/10.1016/j.indcrop.2015.10.015*

Ben Hassine D, Ben Ismail H, Jribi C, Khouja ML, Abderrabba M (2016). Chemical composition of some Tunisian *Eucalyptus* essential oils as obtained by hydrodistillation using Clevenger type apparatus. Biosciences Biotechnology Research Asia 7(2):647-656. *https://www.biotech-asia.org/?p=8997*

Herzi N, Bouajila J, Camy S, Cazaux S, Romdhane M, Condoret JS (2013). Comparison between Supercritical CO2 extraction and hydrodistillation for two species of *Eucalyptus*: Yield, chemical composition, and antioxidant activity. Journal of Food Science 78(5):67-72. *https://doi.org/10.1111/1750-3841.12113*

Ishnava KB, Chauhan JB, Barad MB (2013). Anticariogenic and phytochemical evaluation of *Eucalyptus globules* Labill. Saudi Journal of Biological Sciences 20(1):69-74. *https://doi.org/10.1016/j.sjbs.2012.11.003*

Khouja ML, Khaldi A, Rejeb MN (2001). Results of the *Eucalyptus* introduction trials inTunisia. Proceeding of the international conference on *Eucalyptus* in the Mediterranean basin: Perspectives and new utilization. Centro Promozione Pubblicità, Florence, Taormina-Italy: pp 163-168.

Knezevic P, Aleksic V, Simin N, Svircev E, Petrovic A, Mimica-Dukic N (2016). Antimicrobial activity of *Eucalyptus camaldulensis* essential oils and their interactions with conventional antimicrobial agents against multi-drug resistant *Acinetobacter baumannii*. Journal of Ethnopharmacology 178:125-136. *https://doi.org/10.1016/j.jep.2015.12.008*

Lahmadi G, Lahmar A, Znati M, Elaieb MT, Khouja ML, Ascrizzi R, … Jannet HB (2021). Chemical composition and cytotoxic activity of *Eucalyptus torquata* Luehm. and *Eucalyptus salmonophloia* F. Muell. Tru. Chemistry & Biodiversity 18(11):2100315. *https://doi.org/10.1016/j.jep.2015.12.008*

Li C, Wang K (2003). Differences in drought responses of three contrasting *Eucalyptus microtheca* F. Muell. populations. Forest Ecology and Management 179(1-3):377-385. *https://doi.org/10.1016/S0378-1127(02)00552-2*

Limam H, Ben Jemaa M, Tammar S, Ksibi N, Khammassi S, Jallouli S, … Msaada K (2020). Variation in chemical profile of leaves essential oils from thirteen Tunisian *Eucalyptus* species and evaluation of their antioxidant and antibacterial properties. Industrial Crops and Products 158:112964. *https://doi.org/10.1016/j.indcrop.2020.112964*

Luís Â, Duarte A, Gominho J, Domingues F, Duarte AP (2016). Chemical composition, antioxidant, antibacterial and Anti-Quorum sensing activities of *Eucalyptus globulus* and *Eucalyptus radiata* essential oils. Industrial Crops and Products 79:274-282. *https://doi.org/10.1016/j.indcrop.2015.10.055*

Madsen PA, Mulligan DR (2006). Effect of NaCl on emergence and growth of a range of provenances of *Eucalyptus citriodora*, *Eucalyptus populnea*, *Eucalyptus camaldulensis* and *Acacia salicina*. Forest Ecology and Management 228(1-3):152-159. *https://doi.org/10.1016/j.foreco.2006.02.044*

Marzoug HNB, Romdhane M, Lebrihi A, Lebrihi F, Couderc F, Abderraba M, … Bouajila J (2011). *Eucalyptus oleosa* essential oils: Chemical composition and antimicrobial and antioxidant activities of the oils from different plant parts (stems, leaves, flowers and fruits). Molecules 16(2):1695-1709. *https://doi.org/10.3390/molecules16021695*

May FE, Ash JE (1990). An assessment of the allelopathic potential of *Eucalyptus*. Australian Journal of Botany 38(3):245-254 .*https://doi.org/10.1071/BT9900245*

Mechergui K, Jaouadi W, Naghmouchi S, Alsubeie M, Khouja ML (2019). Micromorphological observation of *Eucalyptus* seeds, multivariate statistical analyses and modeling of their germination under salt stress and osmotic constraint. Cerne 25:156-171. *https://doi.org/10.1590/01047760201925022635*

Mossi AJ, Astolfi V, Kubiak G, Lerin L, Zanella C, Toniazzo G, … Restello R (2011). Insecticidal and repellency activity of essential oil of *Eucalyptus* Sp. against *Sitophilus zeamais* Motschulsky (Coleoptera, Curculionidae). Journal of the Science of Food and Agriculture 91(2): 273-277. *https://doi.org/10.1002/jsfa.4181*

Mulyaningsih S, Sporer F, Reichling J, Wink M (2011). Antibacterial activity of essential oils from *Eucalyptus* and of selected components against multidrug-resistant bacterial pathogens. Pharmaceutical Biology 49(9):893-899. *https://doi.org/10.3109/13880209.2011.553625*

Mulyaningsih S, Sporer F, Zimmermann S, Reichling J, Wink M (2010). Synergistic properties of the terpenoids Aromadendrene and 1,8-Cineole from the essential oil of *Eucalyptus globulus* against antibiotic-susceptible and antibiotic-resistant pathogens. Phytomedicine 17(13):1061-1066. *https://doi.org/10.1016/j.phymed.2010.06.018*

Najum Rasheed A, Muhammad Asif N, Umer R (2005). Chemical compositional and intra provenance variation for content of essential oil in *Eucalyptus crebra*. Asian Journal of Plant Sciences 4(5):519-523. *https://doi.org/10.3923/ajps.2005.519.523*

Nasim M, Qureshi RH, Aziz T, Saqib M, Nawaz S, Sahi ST, Pervaiz S (2008). Growth and ionic composition of salt stressed *Eucalyptus camaldulensis* and *Eucalyptus teretcornis*. Pakistan Journal of Botany 40(2):799-805. *http://173.208.131.244:9060/xmlui/handle/123456789/17120*

Nikbakht MR, Rahimi-Nasrabadi M, Ahmadi F, Gandomi H, Abbaszadeh S, Batooli H (2015). The chemical composition and in vitro antifungal activities of essential oils of five *Eucalyptus* species. Journal of Essential Oil Bearing Plants 8(3):666-677. *https://doi.org/10.1080/0972060X.2014.935061*

Oerke EC (2006). Crop losses to pests. The Journal of Agricultural Science 144(1):31-43. *https://doi.org/10.1017/S0021859605005708*

Ogunwande IA, Olawore NO, Adeleke KA, Konig WA (2003). Chemical composition of the essential oils from the leaves of three *Eucalyptus* species growing in Nigeria. Journal of Essential Oil Research 15(5):297-301. *https://doi.org/10.1080/10412905.2003.9698595*

Palá-Paúl J, Pérez-Alonso MJ, Velasco-Negueruela A, Sanz J (2002). Study of essential oils of *Eucalyptus resinifera* Smith, *E. tereticornis* Smith and *Corymbia Maculata* (Hook.) grown in Cuba. Flavour and Fragrance Journal 17(1):1-4. *https://doi.org/10.1002/ffj.1026*

Pimentel D, Acquay H, Biltonen M, Rice P, Silva M, Nelson J, … D'Amore M (1992). Environmental and economic costs of pesticide use. BioScience 42(10):750-760. *https://doi.org/10.2307/1311994*

Radwan SM, Zidan ZH, El-Hammady A, Aly MM (2000). Field performance of tested *Eucalyptus* plant extracts, biocides and conventional pesticides against key pests infesting cotton in Egypt. Annals of Agricultural Science (Cairo) 45(2): 777-791. *https://www.cabdirect.org/cabdirect/abstract/20013015331*

Raja N (2014). Botanicals: Sources for eco-friendly biopesticides. Journal of Biofertilizers and Biopesticides 5(1):1. *https://doi.org/10.4172/2155-6202.1000e122*

Saadaoui E, Ben Yahia K, Dhahri S, Ben Jamaa ML, Khouja ML (2017). An overview of adaptative responses to drought stress in *Eucalyptus* spp. Forestry Studies 67(1):86. *https://doi.org/10.1515/fsmu-2017-0014*

Saadaoui E, Ben Yahia K, Chemlali I, Belaïd S, Ben Romdhane C (2022). Eucalypt in the Tunisian arid region: Diversity and valorization for honey production. International Journal of Agriculture and Nutrition 4(1):1-5.

Sadraoui-Ajmi I, Benali N, Soltani A, Chaib S, Limem E, Jallouli S, … Mediouni-Ben Jemâa J (2022). Usage of agricultural DAP-Fertilizer and *Eucalyptus* essential oils as potential attractants against the Mediterranean fruit fly *Ceratitis capitata* (Tephritidae). Journal of Asia-Pacific Entomology 25(1):101857. *https://doi.org/10.1016/j.aspen.2021.101857*

Salehi B, Sharifi-Rad J, Quispe C, Llaique H, Villalobos M, Smeriglio A, … Martins N (2019). Insights into Eucalyptus genus chemical constituents, biological activities and health-promoting effects. Trends in Food Science & Technology 91:609-624. *https://doi.org/10.1016/j.tifs.2019.08.003*

Salem N, Kefi S, Tabben O, Ayed A, Jallouli S, Feres N, … Elkahoui S (2018). Variation in chemical composition of *Eucalyptus globulus* essential oil under phenological stages and evidence synergism with antimicrobial standards. Industrial Crops and Products 124:115-125. *https://doi.org/10.1016/j.indcrop.2018.07.051*

Sanders GJ, Arndt SK (2012). Osmotic adjustment under drought conditions: Plant responses to drought stress: from morphological to molecular features. Springer, Berlin Heidelberg pp 199-229. *https://doi.org/10.1007/978-3-642-32653-0-8*

Scazzocchio F, Garzoli S, Conti C, Leone C, Renaioli C, Pepi F, Angiolella L (2016). Properties and limits of some essential oils: Chemical characterisation, antimicrobial activity, interaction with antibiotics and cytotoxicity. Natural Product Research 30(17):1909-1918. *https://doi.org/10.1080/14786419.2015.1086346*

Sebei K, Sakouhi F, Herchi W, Khouja ML, Boukhchina S (2015). Chemical composition and antibacterial activities of seven *Eucalyptus* species essential oils leaves. Biological Research 48(1):1-5. *https://doi.org/10.1186/0717-6287-48-7*

Sefidkon F, Assareh MH, Abravesh Z, Barazandeh MM (2010). Chemical composition of the essential oils of four cultivated *Eucalyptus* species in iran as medicinal plants (*E. microtheca*, *E. spathulata*, *E. largiflorens* and *E. torquata*). Iranian Journal of Pharmaceutical Research 2:135-140. *https://doi.org/10.22037/ijpr.2010.711*

Sefidkon F, Bahmanzadegan A, Assareh MH (2008). Effect of distillation methods and harvesting times on the essential oil and cineole content of *Eucalyptus dealbata*. Chemistry of Natural Compounds 44(2):250-253. *https://doi.org/10.1080/0972060X.2008.10643626*

shariat A, Assareh MH (2016). Physiological and biochemical responses of eight *Eucalyptus* species to salinity stress. Ecopersia 4(1):1269-1282. *https://doi.org/10.18869/modares.ecopersia.4.1.1269*

Silva J, Abebe W, Sousa SM, Duarte VG, Machado MIL, Matos FJA (2003). Analgesic and anti-inflammatory effects of essential oils of *Eucalyptus*. Journal of Ethnopharmacology 89(2-3):277-283. *https://doi.org/10.1016/j.jep.2003.09.007*

Silva SM, Abe SY, Murakami FS, Frensch G, Marques FA, Nakashima T (2011). Essential oils from different plant parts of *Eucalyptus cinerea* F. Muell. Ex Benth. (Myrtaceae) as a source of 1,8-Cineole and their bioactivities. Pharmaceuticals 4(12):1535-1550. *https://doi.org/10.3390/ph4121535*

Singh IP, Sidana J, Bansal P, Foley WJ (2009). Phloroglucinol compounds of therapeutic interest: Global patent and technology status. Expert Opinion on Therapeutic Patents 19(6):847-866. *https://doi.org/10.1517/13543770902916614*

Siramon P, Ohtani Y (2007). Antioxidative and antiradical activities of *Eucalyptus camaldulensis* leaf oils from Thailand. Journal of Wood Science 53(6):498-504. *https://doi.org/10.1007/s10086-007-0887-7*

Souden S, Ennajeh M, Ouledali S, Massoudi N, Cochard H and Khemira H (2020). Water relations, photosynthesis, xylem embolism and accumulation of carbohydrates and cyclitols in two *Eucalyptus* species (*E. camaldulensis* and *E. torquata*) subjected to dehydration–rehydration cycle. Trees 34(6):1439-1452. *https://doi.org/10.1007/s00468-020-02016-4*

Teulieres C, Bossinger G, Moran G, Marque C (2007). Stress studies in *Eucalyptus*. Plant Stress 1(2):197-215.

Üstüner T, Kordali Ş, Bozhüyük AU, Kesdek M (2018). Investigation of pesticidal activities of essential oil of *Eucalyptus camaldulensis* Dehnh. Records of Natural Products 12(6):557-568. *https://doi.org/10.25135/rnp.64.18.02.088*

Vuong QV, Chalmers AC, Jyoti Bhuyan D, Bowyer MC, Scarlett CJ (2015). Botanical, phytochemical, and anticancer properties of the *Eucalyptus* species. Chemistry & Biodiversity 12(6):907-924. *https://doi.org/10.1002/cbdv.201400327*

White DA, Turner NC, Galbraith JH (2000). Leaf water relations and stomatal behavior of four allopatric *Eucalyptus* species planted in Mediterranean southwestern Australia. Tree Physiology 20(17):1157-1165. *https://doi.org/10.1093/treephys/20.17.1157*

Wilkinson JM, Cavanagh HMA (2005). Antibacterial activity of essential oils from Australian native plants. Phytotherapy Research 19(7):643-646. *https://doi.org/10.1002/ptr.1716*

Yao ZW, Liu H, Zhou R, Feng MY, Wang F, Qin XJ, … Zheng YT (2021). Non-volatile Acylphloroglucinol components from *Eucalyptus robusta* inhibit Zika virus by impairing RdRp activity of NS5. Bioorganic Chemistry 116:105303. *https://doi.org/10.1016/j.bioorg.2021.105303*

Yiğit Hanoğlu D, Hanoğlu A, Adediran SB, Baser KHC, Özkum Yavuz D (2022). The essential oil compositions of two *Eucalyptus* sp. (*E. camaldulensis* Dehnh. and *E. torquata* Luehm.) naturalized to Cyprus. Journal of Essential Oil Research. *https://doi.org/10.1080/10412905.2022.2147592*

Zandi-Sohani N, Ramezani L (2015). Evaluation of five essential oils as botanical acaricides against the strawberry spider mite *Tetranychus turkestani* Ugarov and Nikolskii. International Biodeterioration & Biodegradation 98:101-106. *https://doi.org/10.1016/j.ibiod.2014.12.007*

Zhang J, An M, Wu H, Stanton R, Lemerle D (2010). Chemistry and bioactivity of *Eucalyptus* essential oils. Allelopathy Journal 25(2):313-330.

Zhou LJ, Li FR, Huang LJ, Yang ZR, Yuan S, Bai LH (2016). Antifungal activity of *Eucalyptus* oil against Rice Blast fungi and the possible mechanism of gene expression pattern. Molecules 21(5):621. *https://doi.org/10.3390/molecules21050621*

Zhu JK (2001). Plant salt tolerance. Trends in Plant Science 6(2):66-71. *https://doi.org/10.1016/S1360-1385(00)01838-0*

Zrira S, Khiranr FEL, Benjllalr B (1994). Huiles essentielles de six espèces xérophyles d'*Eucalyptus*: Effet du milieu sur les rendements et la composition chimique [Essential oils of six xerophilic *Eucalyptus* species: effect of location on the yield and the chemical composition]. Revue Marocaine des Sciences Agronomiques et Vétérinaires 14(1):5-9.