

Allelopathic Plants 34: *Eucalyptus* (Myrtaceae)

F.Y. Zhang, X.L. Li, Q. Deng, R.H. Xu and L.X. Chang*

Yunnan University of Traditional Chinese Medicine, Kunming 650500, China

E. Mail : 18825186351@163.com

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ABSTRACT

Eucalyptus provides various timber, firewood, landscaping and pulp for paper. *Eucalyptus* species have been introduced in many countries due to their fast growth, easy management and environmental tolerance. Allelopathy is major cause of biodiversity reduction in *Eucalyptus* plantations. However, no systematic work has been done on this allelopathic plant and its allelopathic effects on other recipient plants. In this review, allelopathic effects of 75-*Eucalyptus* species [7-Major *Eucalyptus* spp: (*E. camaldulensis*, *E. citriodora*, *E. globulus*, *E. grandis*, *E. grandis* x *E. urophylla*, *E. tereticornis* and *E. urophylla*) and 68-minor investigated species] are reported. The allelopathic effects of *Eucalyptus* sp. on acceptors (e.g., plants, crops and microorganisms) have been summarized and the recent progresses in the allelopathic research and future research prospects are discussed. It provides a quick reference to the *Eucalyptus* spp, their

*Correspondence author

allelopathic effects and uses. It also provides beneficial informations on use of *Eucalyptus* sp., in medicine and agriculture, and suggests how to best manage a forest ecosystem by avoiding allelopathic inhibitory effects on other plants.

Keywords: Agriculture, allelochemicals, allelopathic effects, *Eucalyptus* species, medicinal plant, Phytochemicals, secondary metabolites

1. INTRODUCTION

The genus *Eucalyptus* (Myrtaceae) is native to Australia, containing > 800 species, growing in all tropical and sub-tropical areas and is the second largest genera after *Acacia* (112). *Eucalyptus* planting in long-term monocultures causes substantial negative ecological impacts through soil degradation, productivity decline and the reduction in understory biodiversity. *Eucalyptus* spp. are allelopathic trees, and allelopathy is considered to be the main reason for the biodiversity reduction underneath the *Eucalyptus* plantations (128). More than 2000 plants species from 39 families, have allelopathic effects on target species (79), including *Eucalyptus* species. For example, in South China, fewer plant species can grow under *Eucalyptus* canopy than under indigenous trees (78). The allelopathic effects of *Eucalyptus* have been studied extensively (2,19,100), however, systematic studies on its allelopathic effects are lacking. This Review aimed to extend the knowledge about the distribution, function and allelopathic effects of *Eucalyptus* spp. using the relevant literature sources, and thus provide a basic references to the related research and use of allelopathic effects of *Eucalyptus* plants.

2. MORPHOLOGY AND SPECIES

The genus *Eucalyptus* (Myrtaceae) is tall tree (usually up to 10.0 m) or shrub. It is fast-growing tree of good form, such as *E. maculata* with long bole and small terminal crown, or *E. kumarlensis* with short bole and large spreading crown (32). The *Eucalyptus* bark may be smooth, rough, tessellated and minniritchi. The shape of primitive cotyledon is reniform. The leaves are petiolate and pendulous (32). *Eucalyptus* plants have well-developed root system that can quickly absorb water and soil nutrients.

Eucalypts plants (including *Angophora*, *Corymbia* and *Eucalyptus*; family Myrtaceae) comprise more than 900 species (129). *Eucalyptus* genus alone has over 800 different species (22). They include the most valuable timber species [*E. saligna* Smith, *E. resinifera* Smith, *E. pilularis* Smith, *E. capitellata* Smith and *E. paniculata* Smith]. Some species are used in oil production e.g. *E. camaldulensis*, which is widely distributed (32), *E. globulus* Labill., a tall, erect forest tree with smooth bark, is most widely cultivated specie around the world. *E. polybractea* R. Baker. is used in Australia for essential oil (EOs) production (32). As for the allelopathy research, the most studied species includes *E. globulus*, *E. camaldulensis* Dehn., *E. citriodora* Hook., *E. urophylla* S. T. Blake., *E. grandis* Hill., *E. grandis* x *E. urophylla*, *E. tereticornis* Sm.

3. CLIMATIC CONDITIONS AND DISTRIBUTION

Eucalyptus trees can grow in a wide range of climatic and edaphic conditions, from rainforest to alpine to desert (32). A few species have been introduced in temperate regions ([https://baike.baidu.com/item/ *Eucalyptus* L. Herit](https://baike.baidu.com/item/Eucalyptus)). Many *Eucalyptus* species are adaptable to differing habitats, hence, widely planted in other countries, for their fast growth, hard timber and excellent fuel (32).

Its remarkable adaptability coupled with fast growth and superior wood properties lead to its rapid adoption in plantation forestry in > 100 countries (99). The *Eucalyptus* species are widely distributed in subtropical and tropical regions worldwide (Fig 1,143), in following countries: Australia, Brazil, India, China, Tasmania, New Guinea, Philippines, Iran, Angola, Argentina, Ethiopia, Kenya, South Africa, Tanzania, Uganda, Uruguay, Zambia, Zimbabwe, Morocco, USA, Bangladesh, Egypt, Congo, Sri Lanka, Pakistan, Kenya, Jordan, Portugal, Spain, Brazil, Chile, South Africa and Japan, etc.

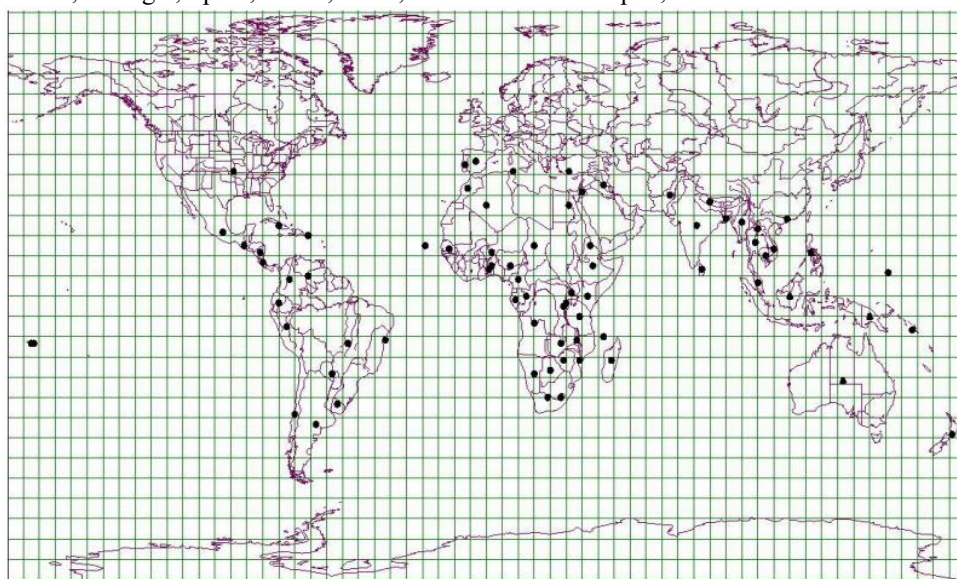


Figure 1. Main distribution of *Eucalyptus* species in different countries and regions (143)

In the 18th century, *E. tereticornis* was introduced in India (97) and *E. maidenii* in Portugal in the 19th century (39). It was introduced to China in 1890, and currently has about 300 species (135), among them major spp. are : *E. camaldulensis*, *E. dunnii*, *E. globulus*, *E. grandis*, *E. maidenii*, *E. saligna*, *E. tereticornis*, *E. urophylla* and their hybrids/clones (109). It was introduced to Tunisia in 1957, now its 117 species are cultivated for folk medicine (24). It was introduced to Ethiopia in 1890, and has largest area (894,240 ha) of *Eucalyptus* plantations in 2011 in East Africa (38,76). Therefore, *Eucalyptus* has become one of the world's most widely planted genera (5). Currently, India, Brazil, China and Australia together make > 50% of global *Eucalyptus* plantations (70).

In the last century, *Eucalypts* became one of the most popular fast-growing species in the world for production of pulp, paper industries, firewood, etc. (106). Its 373 *Eucalypts* species have been introduced outside the native range (56). For example, Tasmanian blue gum (*E. globulus*) is most extensively cultivated specie (106), nowadays, it is grown in Europe, Africa, south-east Asia and South America (103). In Spain the eucalyptus plantations, cover 0.64 million ha, including 0.32 million ha of *E. globulus* pure stands (103). In South Africa, *Eucalyptus* species (*Eucalyptus grandis*, *E. dunnii*, *E. nitens*, *E. camaldulensis*, *E. grandis* × *E. nitens*, *E. grandis* × *E. urophylla*, *E. macarthurii* and *E. smithii*) comprised 39.1 % of forest plantations (41). In South Africa and Brazil *E. grandis* is cultivated for industrial purposes (114). In South America, *E. grandis* and *E. urograndis* (*E. grandis* × *E. urophylla*) are planted in 3.75 million ha (39). In India, *E. tereticornis* was introduced in 18th century and has been planted extensively both in forest and in agroforestry systems (97).

4. SECONDARY METABOLITES/ALLELOCHEMICALS RESEARCH

The main compounds obtained from *Eucalyptus* are essential oils (EOs) (126). *Eucalyptus* leaves are rich in EOs, flavonoids and tannins (54). The *Eucalyptus* oil is complex mixture of monoterpenes and sesquiterpenes, and aromatic phenols, oxides, ethers, alcohols, esters, aldehydes and ketones such as 1,8-cineole (Eucalyptol), citronellal, citronellol, citronellyl acetate, p-cymene, eucamalol, limonene, linalool, α -pinene, γ -terpinene, α -terpineol and aromadendrene (23). *E. globulus* leaves contains the flavonoids (hyperoside, rutin, quercitrin, ellagic acid and kaempferol 3-O-glucoside and ellagic acid, hyperoside) (69,101,102). The extracts of *E. camaldulensis* and *E. torelliana* also contains the hydrolysable tannins ellagitannins (1).

The main allelochemicals in *Eucalyptus* plants are phenolic acids and volatile oils, these significantly inhibited the other plants growth (104). The phenolics (Gallic acid, protocatechuic acid, ellagic acid, quercetin, quercetin glycoside, naringenin, catechin, epicatechin, rutin, quercitrin, apigenin, and myricetin) are the secondary metabolites (SMs) in *Eucalyptus* and are phytotoxic to other plant species (15). These have been isolated from *Eucalyptus* extracts (23).

Eucalyptus EOs contains high levels of volatile organic compounds (VOC). EOs are mixtures of volatile compounds, mainly mono- and sesquiterpenoids, phenylpropanoids, etc. containing hundreds of individual chemical constituents, which may have biological activity (112). *Eucalyptus* leaf contains a variety of allelochemicals compounds, with large number of VOCs (α -pinene, β -pinene, α -phellanderene and cineole) (109), which exert significant inhibitory effects on other plants. P-Menth-2-en-1-ols thymol, carvacrol, 1,8-cineole, α -pinene and β -pinene were isolated as allelopathic monoterpenes from *Eucalyptus* species. Other allelopathic terpenes present in *Eucalyptus* were sesquiterpenes : spathulenol and α -, β -, and γ -eudesmol (92). Terpenes are major compounds in *Eucalyptus* leaf samples (111).

5. AGRICULTURAL IMPORTANCE

In agricultural practices, inhibitory effects of allelopathic plants may be exploited for weeds and pest control (74) for the sustainable agricultural management. The greatest weed management challenge is the lack of effective natural products based herbicides (71). The EOs from *Eucalyptus* has strong phytotoxic effects against many weeds [*Parthenium hysterophorus*, *Cassia occidentalis*, *Echinochloa crus-galli*, *Bidens pilosa*, *Amaranthus viridis*, *Rumex nepalensis*, *Leucaena leucocephala*, *Casuarina pusilla* and *Leptospermum myrsinoides* (116,122)]. Setia *et al.* (116) reported that volatile EOs from *E. citriodora* were phytotoxic to *Bidens pilosa*, *Amaranthus viridis*, *Rumex nepalensis* and *Leucaena leucocephala*, the phytotoxicity against weeds had great potential. Many species of genus *Eucalyptus* release phytotoxic VOCs that interfere with the development of weed species (18). The vast repository of allelochemicals from higher plants including *Eucalyptus* plants can serve as bioherbicides or as templates for the synthesis of new herbicides based on their chemistry (127). Many studies have revealed that *Eucalyptus* EOs can be used as herbicides, so it has great potential for weed control (15).

The inhibitory effects of *E. citriodora* on weeds are correlated with accumulated total phenols in plants, which have great herbicidal potential (44). Besides the volatile oil from *E. citriodora* is phytotoxic and could be used as bioherbicide for future weed management programmes (15). Puig *et al.* (103) demonstrated that the incorporation of *E. globulus* harvest residues into the soil as a green manure could be a feasible and environmentally friendly practice for weed control in organic maize-based cropping systems. Thus the *E. globulus* biomass is an optimal candidate for its potential use as bioherbicide (102).

Pest Management: In addition to weed management, the insecticidal effects of *Eucalyptus* compounds on certain pests can also be used as natural insecticides. Numerous studies have reported the insecticidal effects of *Eucalyptus* EOs. Different *Eucalyptus* species (*E. camaldulensis*, *E. globus*, *E. terreticonis*, *E. grandis*, *E. guineensis*, *E. globifera*, *E. rostrat*, etc.) contains some pest control compounds. For example, Tunc *et al.* (138) reported that the volatile compounds of *E. camaldulensis* caused 45 % and 65 % mortality of stored product insects such as *Tribolium castaneum* (Herbst) and *Ephestia kuehniella*, respectively.

Maciel *et al.* (80) revealed that the *Eucalyptus* EOs could act as the alternative natural products to control *Lutzomyia longipalpis*. The insecticidal activity of *Eucalyptus* oils has been associated with components such as 1,8-cineole, citronellal, citronellol, citronellyl acetate, p-cymene, eucamalol, limonene, linalool, -pinene, -terpinene, -terpineol, alloocimene, and aromadendrene (18). The *E. saligna* leaf EOs are potential contact toxicants and repellents for integration into insect pest management practices (21).

6. MEDICINAL AND COMMERCIAL USES

Numerous common pharmaceuticals, such as anti-cancer, antidiabetic drugs and antiviral, are derived from traditional plant-derived medicines (81). The aromatic medicinal plant *Eucalyptus* and its EOs have been used in folk medicine since ancient times (50,72).

Eucalypts are considered to have cytotoxic and anti-cancer properties (22). *Eucalyptus* EOs were mainly used for its antimicrobial, antifungal, antiseptic, astringent, anti-inflammatory, wound healing, disinfectant and expectorant properties (112). The presence of EOs, flavonoids or tannins in *Eucalyptus* leaves are responsible for their antibacterial, larvicidal, fumigant, antioxidant activities and anthelmintic properties (54). For example, the antiviral activity of the extracts of *E. camaldulensis* and *E. torelliana* are due to hydrolysable tannins ellagitannins (1).

EOs and phenolic acids extracted from *Eucalyptus* leaves have a crucial role against many diseases such as cancer, cardiovascular, neurodegenerative diseases (88). The EOs could be useful as compounds in drug development and design against Corona Virus Disease 2019 (COVID-19) (Fig. 2). Common signs and symptoms may include: fever, cough, pneumonia, tiredness difficulty in breathing and multiple organ failure (9). The epidemic caused by this virus has brought a serious impact on the global economy and human life. For medicinal purposes, the value of *Eucalyptus* oil is due to its main constituent 1, 8-cineole (cineole or eucalyptol) (115).

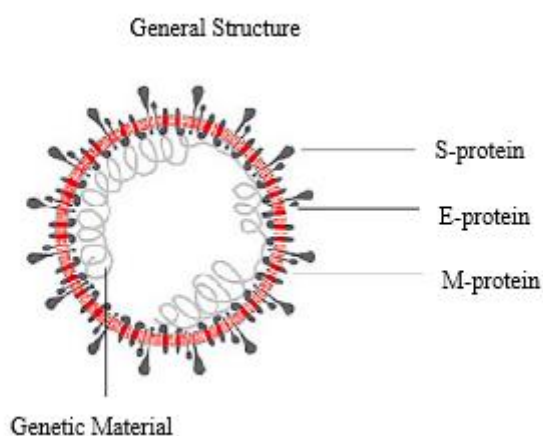


Figure 2. General structure of coronaviruses (9)

Many *Eucalyptus* species are abundant sources of promising medicinal flavanones (52). Adeniyi *et al.* (1) found that the compounds extracted from *E. camaldalensis* and *E.torelliana* have some therapeutic potential against *Helicobacter pylori*. In a recent research, two C-methyl flavanones were identified in *Eucalyptus* for the first time: 6-C-methylpinocembrin (7 mg/g DW) in *E. megacarpa* and 6,8-C-dimethylpinocembrin (6 mg/g DW) in *E. agglomerata* (52). It reported that flavanone pinocembrin (5,7-dihydroxyflavanone) has wide range of pharmacological properties : neuroprotective effects, neutralisation of reactive oxygen species and reduction of inflammation (52).

Eucalyptus EOs also could be used for medicinal and perfumery industries (141). Indeed, the use of *Eucalyptus* EOs in cosmetic and personal hygiene products is gradually increasing (112). Several studies investigated the antioxidant potential of EOs from various *Eucalyptus* species such as *E. polyanthemos*, *E. perriniana* and *E. camaldulensis* (14). Bhuyan *et al.* (22) revealed the significant potential of *E. microcorys* as a source of phenolics, antioxidants and antimicrobial agents. It is reported that EOs of *E. globules* are used in medicine, perfume and food industry (149). The EOs from *E. citriodora* could be an excellent choice as preservative of wood, leather goods and wood artifacts (18). In addition, some studies have reported that *E. globulus* EOs can be used as antioxidant food additive prevent many chronic diseases (3). Some *Eucalyptus* EOs and *Eucalyptus* leaf extracts have been approved as food additives and antioxidant in Australia, Japan and in Europe. Even the *Eucalyptus* EOs are regarded as safe and non-toxic by the United States Food and Drug Authority (FDA) (87). Besides flavonoids, important compound in *Eucalyptus*, is beneficial to human health as protective dietary agents (62). Terpenes and terpenoids are used for treating various ailments, food and beverages. Astani *et al.* (10) reported the antiviral activity of monoterpenes, which commonly occur in *Eucalyptus*, hence *Eucalyptus* monoterpenes may be suitable anti-viral agents. Volatile terpenoids provide specific flavours to food and drinks, such as the ginger flavour caused by zingiberene and grapefruit flavour caused by nootkatone (98). In addition, the high content of phenolic compounds in *Eucalyptus* pre-hydrolyzed liquor has contributed to its large use in AgNPs biosynthesis (119).

7. MAJOR EUCALYPTUS SPECIES ALLELOPATHIC RESEARCH

This part in allelopathic summarises the 7-most important species (*E. camaldulensis*, *E. citriodora*, *E. globulus*, *E. grandis*, *E. grandis x E. urophylla*, *E. tereticornis*, *E. urophylla*) allelochemicals/Phytochemicals (Table 1) and allelopathy research (Table 2).

(i). *E. camaldulensis*

E. camaldulensis is most widely planted tree worldwide, it has many adverse allelopathic effects on many native plant species. Its accumulated litter in forest/agroforestry soil (37,113) severely inhibited the adjacent annual herbs rarely survive to maturity. Terpenes and phenolic acids are its important phytotoxic compounds (37). Fifteen phenolic compounds were isolated from its leaves (53). The p-hydroxybenzoic, p-coumaric, gallic, syringic, gentisic and vanillic acids are allelopathic compounds in the bark, fresh leaves or litter of *E. camaldulensis*, these delays the germination, seedling mortality and reduces the growth and yield of other plants (60). This specie plant parts adversely effects many plants and crops. Its leaves also contained kaemperol, quercetin, ellagic, vanillic, gallic, ferulic, caffeic, chlorogenic and p-coumaric acids (48). In the wild, the *Hordeum leporinum*, *H. stebbinsii*, *Hypochoeris glabra*, *Bromus rigidus* and *Spergula arvensis* rarely grew in, its litter accumulation zone (37). The p-Cymene, Terpinen-4-ol, Cryptone, Spathulenol completely inhibits the germination and seedling growth of *Portulaca oleracea* and *Amaranthus hybridus* (142). Its leaf volatile oil decreases the cell division in the root apical meristem of onion (*Allium cepa*), inhibits the spinach (*Spinacia oleracea*) growth, reduces

the radical growth of garden cress (*Lepidium sativum*), barnyard grass (*Rumex acetosella*), tomato (*Solanum lycopersicon*) and wild oat (*Avena fatua*) (85). Its leaf extract reduces the germination and radicle growth of chickpea, pea and teff (*Eragrostis tel*) (48).

Table 1. Allelochemicals/Phytochemicals present in 7-Major Eucalyptus spp.

Eucalyptus spp	Allelochemicals/Phytochemicals	References
<i>E. camaldulensis</i>	Hydrolysable tannins, ellagitannins, p-cymene (68.43%), 1,8-cineole (13.92%), 1-(S)- α -pinene (3.45%) and R-(+)-limonene (2.84%), p-hydroxybenzoic, p-coumaric, gallic, syringic, gentisic and vanillic acids; kaempferol, quercetin, ellagic, ferulic, caffeic and chlorogenic acids, erpinene-4-ol, cryptone, spathulenol	1,48,60,111,142
<i>E. citriodora</i>	Spathulenol and α -, β -, and γ -eudesmol, cineole, α -pinene, p-cymene, citronellal, citronellol	18,20,92
<i>E. globulus</i>	Hyperoside, rutin, quercitrin, ellagic acid and kaempferol 3-O-glucoside, citric, malic, shikimic, succinic and fumaric, eucalyptol, 1,8-cineole, limonene, p-cymene, c-terpinene, α -pinene and a-terpineol, gallic, caffeic, gentisic, p-coumaric and chlorogenic acids and the terpenoids cineole, camphorol	36,69,101,102,139
<i>E. grandis</i>	α -Pinene, 1,8-cineole; γ -terpinene and p-cymene, 28-allelochemicals, terpenes	8,18,70,151
<i>E. grandis</i> x <i>E. urophylla</i>	Alloocimene, α -pinene	18
<i>E. tereticornis</i>	Cineole, α -pinene, p-cymene, 1,8-cineole, Eos	18,61,90
<i>E. urophylla</i>	γ -Terpinene; 27-terpenoids were identified, dominated by 1,8-cineole, followed by Bicyclo[4.1.0]hept-2-ene, Hexanoic acid, 4-hexen-1-yl ester, 3,7,7-trimethyl-, α -terpineol, 2,4,6-Octatriene, 2,6-dimethyl-, (E,Z)-, 1R- α -Pinene, (+)-4-Carene, β -Pinene, β -Myrcene, etc.	18,105

Ahmed et al. (4) found that the allelopathy of *E. camaldulensis* reduced biomass (25-80 %) of some legume crops, such as cowpea (*Vigna unguiculata*) and pigeon pea (*Cajanus cajan*). In addition, many plants (*Sorghum halepenses* and *Convolvulus arvensis*) growth was reduced by its leaf residues (6). Its shoot aqueous reduced the height, leaf area, shoot dry weight and leaf photosynthesis of *Amaranthus retroflexus* L. (33). The leaf extracts of *E. camaldulensis* inhibited the growth and many physiological processes of *Triticum turgidum*, *Phaseolus vulgare*, *Sinapis arvensis*, *Eruca vesicaria* and *Scorpiurus muricatus*. Dawar et al. (34) reported that undiluted leaf extract of *E. camaldulensis* impeded the radical elongation of cucumber, onions, tomatoes and sorghum. The *E. camaldulensis* infested soil significantly reduced the growth (length, width and number of leaves) of *Aloe vera* plants (125).

Microbes etc. : Limam et al. (72) found that *E. camaldulensis* was significantly inhibitory to bacteria *Serratia marcescens*. Its EOs also exhibit great antibacterial and insecticidal potential. Sabo et al., (110) found that its EOs was active against many Gram positive (0.07-1.1 %) and Gram negative bacteria (0.01-3.2 %). Furthermore, its EOs and extracts were most active against bacteria than other species of genus *Eucalyptus*. Cheng et al. (30) found that EOs from its leaves had excellent inhibitory effects against both *Aedes aegypti* and *A. albopictus* larvae, due to the α -terpinene, α -phellandrene, limonene, p-cymene,

c-terpinene, terpinolene compounds. The virucidal tests showed that crude extracts of *E. camaldulensis* were active on test viruses: poliovirus type 1, coxsackievirus B and echovirus 6 (1).

(ii). *E. citriodora*

EOs extracted from *E. citriodora* have been tested as a potential natural herbicide, with citronellal (64.7 %) and citronellol (10.9 %) as the major compounds (20). The volatile oils of *E. citriodora* leaves have strong phytotoxic effects on *Parthenium hysterophorus*. The EOs from its leaves drastically decreased the seed germination, seedling length, chlorophyll content and respiratory activity of *P. hysterophorus* (122), its oil also reduced the growth of mature weeds (67). EOs emulsions reduced the growth (root and shoot length) of weeds (*Angallis arvensis*, *Cyperus rotundus*, *Cynodon dactylon*) in a dose-response manner and the phytotoxicity was more severe in *A. arvensis* (63). Its 3 % oil significantly reduced the germination and seedling's growth of *Sinapis arvensis*, *Sonchus oleraceus*, *Xanthium strumarium* and *Avena fatua* and completely dried these plants (20). *E. citriodora* EO and its two major monoterpenes viz. citronellal and citronellol showed phytotoxicity to *Amaranthus viridis*, *Echinochloa crus-galli*, *Triticum aestivum* and *Oryza sativa* (16), while inhibited the germination and root elongation of two weeds *Cassia occidentalis* and *Echinochloa crus-galli* (17) and the oil from leaves was the most phytotoxic to test weeds (16). *E. citriodora* was phytotoxic to many plants species. It significantly suppressed the germination and seedling growth of *Bidens pilosa*, *Amaranthus viridis*, *Rumex nepalensis* and *Leucaena leucocephala* (116), *Digitaria pertenuis*, *Eragrostis cilianensis* and *Setaria geniculata* (78). Its main compound (citronellal) showed toxicity to *Ageratum conyzoides*, *Chenopodium album*, *Parthenium hysterophorus*, *Malvastrum coromandelianum* and *Phalaris minor* (123). The 25 % fresh leaf extract of *E. citriodora* is very inhibitory to seeds germination rate, root and bud length of *A. fatua* due to the accumulation of total phenolics content (44).

The allelochemicals present in leaf leachate inhibited the seeds germination and seedling growth of *Vigna radiata*, *V. mungo* and *Arachis hypogea*. The leachates also inhibits the germination and most inhibitory to plumule than radicle elongation of *A. hypogea* and *V. mungo* crops (124). Its crude oils inhibited the germination and growth of *Phaseolus aureus*, *Lens esculentum*, *Avena sativa* and *Hordeum vulgare* (66). The volatile oil/ aqueous extracts of *E. citriodora* from leaves inhibited the seed germination and seedling growth of *Triticum aestivum*, *Zea mays*, *Raphanus sativus*, *Cassia occidentalis* (15), *Hippeastrum hybridum* (44), *Stylosanthes guianensis*, *Cucumis sativus* and *Phaseolus vulgaris* (3). Cao and Luo (25) reported that the aqueous extract of bark and leaf, and leaf volatiles of *E. citriodora* showed allelopathic effects on weeds (*Bidens pilosa*, *Digitaria pertenuis*, *Eragrostis cilianensis*, *Setaria geniculata*) and crops (corn, rice, cucumber, bean and *Stylosanthes guianensis*).

Microbes : *E. citriodora* EOs also show great antimicrobial activity against some bacteria, microbial pests, etc. For example, the Algerian *E. citriodora* leaves' EOs are antifungal against the tested microorganisms (e.g., *Microsporium canis*, *M. gypseum*, *Trichophyton*

mentagrophytes and *T. rubrum*) (137). The EOs of *E. citriodora* also inhibited the pathogen *Staphylococcus intermedius* (27).

(iii). *E. globulus*

The *E. globulus* plant is known for its richness in bioactive compounds [EOs, phenolic acids, flavonoids and hydrolysable tannins (31)]. The dominant compounds in its essential oil are 1,8-cineole, limonene, p-cymene, c-terpinene, α -pinene and α -terpineol (139). The leachates of *E. globulus* leaves also contains many water-soluble compounds (phenolic compounds ellagic, gallic, caffeic, gentisic, p-coumaric, and chlorogenic acids and the terpenoids cineole, camphorol and α -pinene) with phytotoxic potential (36). The aqueous extract of *E. globulus* leaves (101) has several water-soluble compounds (phenolic acids such as chlorogenic and p-coumaric derivatives; flavonoids as hyperoside, rutin, quercitrin, ellagic acid and kaempferol 3-O-glucoside) and other low molecular weight organic acids (citric, malic, shikimic, succinic and fumaric). The eucalyptol was found to be the main component (102). The *E. globulus* is most allelopathic among all species of *Eucalyptus* genus and its leachates contain large number of allelochemicals. Its allelopathic effects have been widely studied and showed that *E. globulus* adversely affects the weeds, crops, various microorganisms and viruses, etc.

The plant community under *E. globulus* canopies had lower species richness than plant community in open areas (19). Its applied EOs inhibited the seeds germination of *Parthenium hysterophorus* and significantly reduced the chlorophyll content and cellular respiration of mature plants (67). Its aqueous extracts significantly reduced the seed germination (%) germination speed and the initial growth of shoots and roots of cultivated species: mustard (*Brassica campestris* L.), cabbage (*B. oleracea* L. cv. capitata), broccoli (*B. oleracea* L. cv. italica), turnip (*B. rapa* L.), kale (*B. pekinensis* L.), tomato (*Lycopersicon esculentum* Miller.), rucola (*Eruca sativa* L.) and radish (*Raphanus sativus* L.) (147). Babu et al. (89) found that aqueous extracts of fresh leaves of *E. globulus* significantly suppressed the establishment of vegetative propagules and early seedling growth of purple nutsedge (*Cyperus rotundus* L.) and bermuda grass (*Cynodon dactylon* L. Pers) weeds. Another study indicated that the aqueous leachates (5, 10, 15 and 20 %) reduced the seed germination the chlorophyll synthesis in leaves and protein of *E. globulus*, carbohydrates and nucleic acids (DNA and RNA) contents in both shoot and root of the seedlings were decreased with increase in leachate concentration of finger millet (*Eleusine corocana* Gaertn cv. AKP-2) (95). Through direct and soil-based bioassays, Del Moral and Muller (36) found that natural fog drip collected from beneath *E. globulus* suppressed the growth of *Bromus rigidus* and *B. diandrus*, probably via chlorogenic, p-coumarylquinic and gentisic acids. The growth rate of *Costus speciosus* was inhibited by the leachates of juvenile, mature and senescent leaves of *E. globulus*, and the chlorophyll and total nitrogen contents were also decreased (68). In addition, the biomass of *Digitaria sanguinalis* and *Chenopodium album* (103), the germination and seedling growth of *Phaseolus aureus*, *Lens esculentum*, *Hordeum vulgare*, *Avena sativa* were adversely affected by the crude oils and the pure components, limonene and cineole purified from *E. globulus* (66). The spraying of *E. globulus* leaves aqueous extracts, suppressed the germination of *Lactuca sativa* and *Agrostis stolonifera*, reduced the

shoot and root biomass, protein contents and chlorophyll concentrations *L. sativa* adult plants (102).

In addition to the above plants, there are many crops and weeds adversely affected by the *E. globulus* allelopathy, such as *Sorghum vulgare* (12), *Hordeum vulgare* (87), *Portulaca oleracea* (84), *Castanea sativa*, *Cucumis* sp. (13), *Solanum melongena* (35), *Cicer arietinum*, *Zea mays* and *Pisum sativum* (48). *E. globulus* adversely effects the germination, seedling growth, photosynthesis, growth rate, root and shoot length of seedlings of these crops and some weeds, [*Amaranthus retroflexus* and *Echinochloa crus-galli* (100)]. Therefore, the above crops should be not be used in mixed planting with *E. globulus* in agroforestry.

Microbes : EOs extracts from *E. globulus* have antimicrobial effects against many pathogens, bacteria and viruses [*Fusarium spp.*, *Rhizoctonia solani*, *Macrophomina phaseolina* (34), *Staphylococcus aureus*, *Bacillus subtilis*, *Listeria innocua*, *Escherichia coli*, *Pseudomonas aeruginosa* (149), *Pediculus humanus capitis* (148) *Bacillus cereus*, *Enterococcus faecalis*, *Candida albicans* (91)]. Recently, one research reported that essential oil from *E. globulus* effectively in inhibits the growth of IFV-A (H1N1) (9).

(iv). *E. grandis*

E. grandis is most important timber plant, hence, it is common specie in *Eucalyptus* plantations. Compared with the above *Eucalyptus* species, there are few reports on the allelopathic effects of *E. grandis*. The major compounds found in *E. grandis* are monoterpene hydrocarbons (α -pinene, γ -terpinene and p-cymene). Its EO decreases the germination (%), seedling growth, mitotic index and meristematic cells of *Lactuca sativa* (8). Zhang *et al.* (151) identified 28-allelochemicals from the roots of *E. grandis*. It was found that the concentrations of allelochemicals in the soil of old plantations/forests of *E. grandis* were higher than in the roots (58). By GC-MS analyses, a total of 33 potential allelopathic compounds were detected in naturally decomposing *E. grandis* leaf litter. Of these compounds, terpenes were the major allelochemicals, which significantly decreased the growth and photosynthetic pigments of *Setaria viridis* (70).

The *E. grandis* inhibits the growth of plants. Its leaf litter decomposition, exert strong allelopathic effects on *Elymus sibiricus* and *Cichorium intybus* (145) and *Setaria viridis* (70). The leaf powder of *E. grandis* significantly inhibited the emergence and growth of *Phaseolus vulgaris* and *Zea mays*, moreover, it was more inhibitory to both crops than *E. camaldulensis* (108). In agricultural forestry (agri-silvicultural crops) viz., *Abelmoschus esculentus*, *Amaranthus caudatus* (58), *Vigna unguiculata* (beans) (59) were not compatible with *E. grandis*. However, maize (*Zea mays*) and sorghum (*Sorghum bicolor*) (59), could be used as intercrop with *E. grandis* (40). *E. grandis* adversely affected the squash (*Citrullus vulgaris*) (45). Zhang *et al.* (153) found that the aqueous extracts of its roots suppressed the germination and early seedling growth of *Raphanus sativus*, *Phaseolus aureus* and *Lolium perenne*. The high concentrations of root extracts from 4-years old *E. grandis* were very inhibitory to germination of target species, with the inhibitory rates of 48.51 % for *R. sativus*, *P. aureus* and 56.56 % in *L. perenne*, respectively. The allelopathic compounds in roots and rhizosphere soil of younger *E. grandis* plantation may play important roles (151).

Pests : Nowrouziasl *et al.* (93) estimated the fumigant toxicity effects of EOs from *E. grandis* against adults of pest (*Sitophilus oryzae* L.). They found the mortality of 1-7 day old adults of insect pest increased with increasing concentration and exposure time from 24 to 72 h. The bioactivity of *E. grandis* volatile organic compounds (VOCs) in the rhizosphere soils of *E. grandis* exerts toxic impacts on *Eisenia fetida* earth worms (134).

(v). *E. grandis* x *E. urophylla*

E. grandis x *E. urophylla* is fast-growing hybrid clone. It is an important pulp tree, widely grown in many provinces of southern China. There are fewer reports about its allelopathic potential than above *Eucalyptus* species. Tang *et al.* (133) found that it significantly inhibited the seeds germination and growth of chili, tomato and *Brassica chinensis* (77), their biomass was negatively correlated with the total phenolic content in soils of *E. grandis* x *E. urophylla* (77). Since both *E. grandis* and *E. urophylla* are allelopathic plants, thus, the allelopathic effects of their hybrid (*E. grandis* x *E. urophylla*) may be stronger than either of the parent plants. *E. grandis* x *urophylla* was most inhibitory against *Zea mays*, *Phaseolus vulgaris* and *Cucurbita pepo* growth than *E. grandis* and *E. urophylla* (45).

Microbes : Zhou *et al.* (153) reported its leaf essential oil fungicidal activity against fungi (*Setosphaeria turcica*, *Magna porthe grisea*, *Botrytis cinerea*, *Fusarium graminearum*) at 2.5 mg/mL concentration significantly inhibited the mycelium growth. The terpenes played an important role in the inhibitory effects of *E. grandis* x *E. urophylla* essential oil on pathogenic fungi (*Fusarium oxysporum*, *Pyricularie grisea*, *Glorosprium musarum* and *Phytophthora capsic*) and pest insects (*Spodo pteralitura* Fabricius and *Helicoverpa armigera* Hubner) (75).

(vi). *E. tereticornis*

It is most controversial tree specie in the agroforestry systems. Because of its fast growth, it efficiently absorbed water and nutrients from soil and ranks first in dry matter production. However, it exerts adverse effects on adjacent agricultural crops (97), e.g. it reduced the wheat (*Triticum aestivum*) germination, growth and grain yield up to a distance of 9 m from tree row under field conditions (97). In India, *E. tereticornis* reduced the seedling growth and photosynthesis of *Amaranthus viridis* (61). The soil extracts from the *E. tereticornis* shelter belt had negative effects on yield of crops [chickpea (*Cicer arietinum*), lentil (*Lens esculentum*), wheat (*Triticum aestivum*), cauliflower (*Brassica oleracea*), toria (*B. campestris*), beerseem clover (*Trifolium alexandrinum*)] which increased with distance from *E. tereticornis*. The plant toxins in these soils, reduced the seeds germination of *Lens esculentum* (121). Sunil and Khara (130) reported that water extract of leaves (green, brown and decayed) from 6-years old *E. tereticornis* trees and bark had inhibitory effects on seed germination, primary root and shoot development of *Phaseolus vulgaris* seedlings. Furthermore, the soil collected beneath *E. tereticornis* plantations was found rich in phytotoxic allelochemicals and inhibited the germination and growth of *Phaseolus aureus* and *Vigna radiata* (65). It also inhabited the seeds germination and growth of other crops [maize (*Zea mays*), red gram (*Cajanus cajan*) and sesame (*Sesamum indicum*)] (131), so

attention should be paid in planting of this specie in Agroforestry.

Microbes : Besides, the leaf extracts of *E. tereticornis* suppressed the pupal and adult activity of *Anopheles stephensi* at higher doses, with the highest dose of 160 ppm plant extract causes 100 % mortality (90).

(vii). *E. urophylla*

E. urophylla is the dominant specie in forest plantations in south China. There is less vegetation underneath its canopy than under local trees. 27-terpenoids are identified in its headspace volatiles. The 1,8-cineole, the main compound of terpenoids in *E. urophylla*, plays an important role in allelopathy of its leaves (105).

Allelopathy is more important than resource competition in mediating the reduction in plant biodiversity in *E. urophylla* plantations (104). Song *et al.* (128) found that leachates from *E. urophylla* foliage, litter and foliage + litter significantly inhibited the seed germination of *Leucaena leucocephala*, *Pterospermum lanceaefolium* and *Schefflera octophylla*. The *E. urophylla* roots are less harmful to seedling emergence of *Schima superba*, *Michelia macclurei*, *Cinnamomum camphora* but inhibited their seedlings growth (151). Qin *et al.* (104) studied the effects of aqueous extract of *E. urophylla* on 20 plants species for their tolerance to *E. urophylla*. They found 10-other species (*Photinia benthamiana*, *Castanopsis chinensis*, *Schefflera octophylla*, *Acmena acuminatissima*, *Castanopsis fissa*, *Ilex triflora*, *Pterospermum lanceaefolium*, *Cryptocarya concinna*, *Leucaena leucocephala*, *Albizia lebbek*) were inhibited by its aqueous extract. However, 10- species were not inhibited rather slightly stimulated (*Cinnamomum camphora*, *Schima superba*, *Cyclobalanopsis hui*, *Cinnamomum burmanni*, *Helicia cochinchinensis*, *Cyclobalanopsis myrsinaefolia*, *Machilus chinensis*, *Hovenia dulcis*, *Ormosia glaberrima*, *Michelia maclurei*) (104). It was revealed that aqueous leaf leachate and leaf volatile suppressed the seed germination and/or seedling growth of *Photinia benthamiana*, *Pygeum topengii*, *Diospyros morrisiana*, *Cinnamomum burmanni* and *Cryptocarya concinna* (46). Volatile compounds from *E. urophylla* reduces the seedling growth of radish, lettuce, *Leucaena leucocephala* and *Acacia mangium* (78). While the litter of *E. urophylla* enhanced the emergence and growth of *Castanopsis chinensis*, *Elaeocarpus sylvestris*, *Schimasuperba*, *Liquidambar formosana*, *Cinnamomum burmannii* and *C. camphora* (151).

Table 2. Allelopathic effects of the important *Eucalyptus* species on recipient plants

Donor specie	Research Method	Recipient plants	Allelopathic effects	Ref
Allelopathic effects on Crops				
<i>E. camaldulensis</i>	Bioassay	<i>Spinacia oleracea</i> , <i>Allium cepa</i> , <i>Lepidium sativum</i> , <i>Rumex acetosella</i> , <i>Zea mays</i> , <i>Solanum lycopersicon</i> , <i>Avena fatua</i>	Decreased cell division in the root apical meristem (<i>A. cepa</i>), inhibition of the <i>S. oleracea</i> , reduction in radical growth of <i>L. sativum</i> , <i>R. acetosella</i> , <i>S. lycopersicon</i> , <i>A. fatua</i>	85
<i>E. camaldulensis</i>	Pot experiment	<i>Vigna unguiculata</i> , <i>Cicer arietinum</i> , <i>Cajanus cajan</i>	Leaf litter reduced (25–80 %) the germination, shoot and root growth, leaf number, collar diameter and	4

Donor specie	Research Method	Recipient plants	Allelopathic effects	Ref
			nodulation of all test agricultural crops	
<i>E. camaldulensis</i>	Field, Bioassay	<i>Triticum turgidum</i> , <i>Vicia faba</i> , <i>Phaseolus vulgare</i> , <i>Sinapis arvensis</i> , <i>Eruca vesicaria</i> , <i>Scorpiurus muricatus</i>	Leaf extracts inhibited the growth and many physiological processes of test species	53
<i>E. citriodora</i>	Bioassay	<i>Vigna radiata</i> , <i>V. mungo</i> , <i>Arachis hypogea</i>	Inhibited the germination and seedling growth of all test crops. The leachates proved most inhibitory to germination of <i>A. hypogea</i> and <i>V. mungo</i> . The leaf leachate were inhibitory to shoot than root elongation.	124
<i>E. globulus</i>	Bioassay	<i>Phaseolus aureus</i> , <i>Lens esculentum</i> , <i>Arena sativa</i> , <i>Hordeum vulgare</i>	The crude volatile oils from the leaves inhibited the germination, seedling growth and water and chlorophyll content	66
<i>E. globulus</i>	Bioassay	<i>Sorghum vulgare</i>	Higher leaf extracts concentration decreased the seed germination, shoot and root length of seedlings but increased the number of lateral roots	12
<i>E. globulus</i>	Bioassay	<i>Solanum melongena</i>	Reduced germination and growth	35
<i>E. globulus</i>	Bioassay	<i>Cicer arietinum</i> , <i>Zea mays</i> , <i>Pisum sativum</i> , <i>Eragrostis tef</i>	Reduced the germination and radicle growth of all test plants	48
<i>E. grandis</i>	Bioassay	<i>Raphanus sativus</i> , <i>Phaseolus aureus</i>	Root aqueous extract suppressed the germination and early seedling growth of the target plants.	151
<i>E. grandis</i> , <i>E. grandis</i> x <i>E. urophylla</i>	Bioassay	Chilli, tomato and corn, <i>Brassica chinensis</i>	Significantly inhibited the germination and growth of chilli, tomato, corn and <i>Brassica chinensis</i>	77, 133
<i>E. grandis</i> , <i>E. grandis</i> x <i>E. urophylla</i>	Bioassay	<i>Zea mays</i> , <i>Phaseolus vulgaris</i> , <i>Cucurbita pepo</i> , <i>Citrullus vulgaris</i>	Both <i>E. grandis</i> and <i>E. grandis</i> x <i>E. urophylla</i> inhibited the growth of <i>Z. mays</i> , <i>P. vulgaris</i> and <i>C. pepo</i> . <i>E. grandis</i> also showed adverse effects on <i>C. vulgaris</i>	45
<i>E. grandis</i>	Field experiment	Wheat (DWR-162')	Reduced the germination, crop stand, growth and yield	97
<i>E. grandis</i>	Field experiment	<i>Vigna radiata</i>	Showed inhibitory effects on <i>V. radiata</i>	65
<i>E. grandis</i> , <i>E. tereticornis</i>	Field experiment	<i>Cicerarietinum</i> , <i>Lens esculentum</i> , <i>Triticum aestivum</i> , <i>Brassica oleracea</i> , <i>Brassica campestris</i> ,	The yield of chickpea, lentil, wheat, cauliflower, berseem, and toria was reduced by more than half. Chickpea was the most	121

Donor specie	Research Method	Recipient plants	Allelopathic effects	Ref
		<i>Trifolium alexandrinum</i>	affected	
Allelopathic effects on weeds				
<i>E. camaldulensis</i>	Bioassay	<i>Amaranthus hybridus</i> , <i>Portulaca oleracea</i>	The essential oil completely inhibited the germination and seedling growth on both weeds	142
<i>E. camaldulensis</i>	Pot experiment	<i>Sorghum halepenses</i> , <i>Cyperus rotundus</i> <i>Convolvulus arvensis</i>	The leaf residues reduced these weeds growth	6
<i>E. camaldulensis</i>	Pot experiment	<i>Amaranthus retroflexus</i>	Shoot aqueous extract reduced the height, leaf area, shoot dry weight and leaf photosynthesis	33
<i>E. camaldulensis</i>	Field surveys	<i>Hordeum leporinum</i> , <i>H. stebbinsii</i> , <i>Hypochoeris glabra</i> , <i>Bromus rigidus</i>	Suppressed the growth of all the tested plants	37
<i>E. citriodora</i>	Bioassay	<i>Avena fatua</i> , <i>Hippeastrum hybridum</i>	Inhibition of <i>Avena fatua</i> . Stimulation of <i>Hybridum</i>	44
<i>E. citriodora</i>	Bioassay	<i>Parthenium hysterophorus</i>	Decreased seed germination, seedling length, chlorophyll content and respiration	122
<i>E. citriodora</i>	Bioassay	<i>Ageratum conyzoides</i> , <i>Chenopodium album</i> , <i>Parthenium hysterophorus</i> , <i>Phalaris minor</i>	The main compound (Citronellal) showed toxicity to target weed species	123
<i>E. citriodora</i>	Bioassay	<i>Amaranthus viridis</i> , <i>Echinochloa crus-galli</i>	The leaves oil was most phytotoxic to test weeds	16
<i>E. citriodora</i>	Bioassay	<i>Amaranthus viridis</i> , <i>Echinochloa crus-galli</i>	Maximum germination inhibition in <i>A. viridis</i> , but least effect on <i>R. sativus</i> . Significantly reduced the seedling growth	15
<i>E. citriodora</i>	Greenhouse pot experiment	<i>Angallis arvensis</i> , <i>Cyperus rotundus</i> , and <i>Cynodon dactylon</i>	EOs emulsions reduced the weeds growth, root and shoot length in a dose–response manner. Phytotoxicity was more in <i>A. arvensis</i>	63
<i>E. citriodora</i>	Greenhouse experiment	<i>Sinapis arvensis</i> , <i>Sonchus oleraceus</i> , <i>Xanthium strumarium</i> , <i>Avena fatua</i>	Germination and seedling's growth were drastically reduced. Completely killed <i>S. arvensis</i> , <i>S. oleraceus</i> and <i>A. fatua</i> and severe injuries in <i>X. strumarium</i> at 3 % oil concentration.	20
<i>E. globulus</i>	Pot experiment	<i>Cyperus rotundus</i> , <i>Cynodon dactylon</i>	Aqueous leachate of fresh leaves significantly suppressed the establishment of vegetative propagules and early seedling growth	11
<i>E. globulus</i>	Pot experiment	<i>Amaranthus retroflexus</i> , <i>Solanum nigrum</i> ,	Reduced the emergence of the <i>A. retroflexus</i> and	100

Donor specie	Research Method	Recipient plants	Allelopathic effects	Ref
		<i>Digitaria sanguinalis</i>	<i>S. nigrum</i> , reduced the shoot biomass of <i>D. sanguinalis</i>	
<i>E. grandis</i>	Bioassay	<i>Brassica campestris</i> , <i>B. oleracea</i> , <i>B. pekinensis</i> , <i>B. rapa</i> , <i>Lactuca sativa</i> , <i>Lycopersicon esculentum</i> , <i>Eruca sativa</i> , <i>Raphanus sativus</i>	The aqueous extracts of <i>E. globulus</i> significantly reduced the seed germination, index of germination speed and the initial growth of shoots and roots of all test species	147
<i>E. grandis</i> ,	Pots experiment	<i>Amaranthus viridis</i>	Reduced seedling growth and photosynthesis	61
<i>E. grandis</i>	Field experiment	<i>Abelmoschus esculentus</i> , <i>Amaranthus caudatus</i>	Inhibited the growth of <i>A. esculentus</i> and <i>A. caudatus</i>	58
<i>E. grandis</i> x <i>E. urophylla</i>	Bioassays	<i>Urochloa decumbens</i> , <i>Panicum maximum</i>	Leaf extracts (50 %, 100 %) strong suppressed seed germination and seedling growth of <i>U. decumbens</i> and <i>P. maximum</i>	26
Allelopathic effects on trees				
<i>E. citriodora</i>	Bioassay	<i>Rumex nepalensis</i> , <i>Leucaena leucocephala</i>	Significantly suppressed the germination and seedling growth of the tested plants	116
<i>E. urophylla</i>	Bioassay	<i>Cinnamomum burmanni</i> , <i>Cryptocarya concinna</i> , <i>Machilus chinensis</i> , <i>Photinia benthamiana</i> , <i>Pygeum topengii</i> , <i>Diospyros morrisiana</i> , <i>Pterospermum lanceaeifolium</i> , <i>Acacia confusa</i> , <i>Albizia lebbek</i> , <i>A. falcataria</i>	Aqueous leaf leachate suppressed the seed germination and seedling growth of <i>P. benthamiana</i> , <i>P. topengii</i> , <i>D. morrisiana</i> and <i>P. lanceaeifolium</i> . Leaf volatile concentration > 250 g suppressed germination of <i>C. burmanni</i> , <i>C. concinna</i> , <i>M. chinensis</i> , <i>D. morrisiana</i> and <i>P. lanceaeifolium</i> .	46
<i>E. urophylla</i>	Greenhouse pot experiment	<i>Leucaena leucocephala</i> , <i>Pterospermum lanceaeifolium</i> Schefflera octophylla, <i>Albizialebbek</i>	All treatment inhibited seed germination of <i>L. leucocephala</i> , <i>P. lanceaeifolium</i> , and <i>S. octophylla</i> . Seedling survival was lower under the leachate treatments for all target species except <i>A. lebbek</i> . Foliage+litter and foliage leachates increased dry weight of <i>L. leucocephala</i> and <i>S. octophylla</i> , respectively.	128
<i>E. urophylla</i>	Greenhouse pot experiment	<i>Liquidambar formosana</i> , <i>Celtis sinensis</i> , <i>Acacia confusa</i> , <i>Bauhinia purpurea</i> , <i>Acacia podalyriifolia</i>	Significantly inhibited the growth of <i>B. purpurea</i> and <i>A. podalyriifolia</i> . Unaffected or stimulated the <i>L. formosana</i> , <i>C. sinensis</i> and <i>A. confusa</i>	28

Donor specie	Research Method	Recipient plants	Allelopathic effects	Ref
<i>E. urophylla</i>	Field experiment	20 woody species	10-species were inhibited by aqueous extract of <i>E. urophylla</i> . 10-other spp. uninhibited and stimulated	104
<i>E. urophylla</i>	Field experiment	<i>Schima superba</i> <i>Michelia macclurei</i> , <i>Cinnamomum burmannii</i> , <i>Cinnamomum camphora</i>	Seedlings growth of 4-tested trees was inhibited by <i>Eucalyptus</i> roots, but had less effects on seedling emergence	151
<i>E. urophylla</i>	Review	<i>Leucaena leucocephala</i> , <i>Acacia mangium</i>	Reduced the seedling growth of tested plants	78

Although less investigated, the allelopathy of *E. urophylla* rhizosphere soil has recently attracted attention of researchers. The allelopathic compounds of soil under *E. urophylla* significantly inhibited the seed germination and seedlings growth of *Lolium multiflorum* Lam. and *Bidens pilosa* L. (55). Chang *et al.* (28) found that *E. urophylla* rhizosphere soil significantly reduced the biomass and base diameter of *Bauhinia purpurea* L. and *Acacia podalyriifolia* L.

To reduce its allelopathic effects, it has been suggested to do intercropping of tolerant species. Chang *et al.* (28) found that *Liquidambar formosana*, *Celtis sinensis* and *Acacia confusa* could be suitable intercrops with *E. urophylla* in small island stressed habitats, but *Bauhinia purpurea* and *Acacia podalyriifolia* were not suitable. Therefore, more attention is needed to study the allelopathy of *E. urophylla*, especially in stressed habitats (i.e., high soil and air salinity, thin soil layers, strong wind and lack of water and nutrients).

8. MINOR EUCALYPTUS SPECIES ALLELOPATHY RESEARCH

In addition to the 7-major Eucalyptus species explained above, allelopathy researches have also been done on 68-minor *Eucalyptus* spp. Details of plant compounds/allelochemicals, allelopathic effects of minor investigated 68-*Eucalyptus* species on Plants/Plant insects pests/Plant pathogens/human pathogens are summarized in Table 3.

Table 3. Allelopathic effects of less studied 68-*Eucalyptus* spp. on Plants/plant insects/pathogens/ Human pathogens

Eucalyptus Spp.	Allelochemicals	Allelopathic effects	Ref
Allelopathic effects on Plants			
<i>Eucalyptus</i> 12ABL	Essential Oils	The leaf volatiles showed inhibited the seed germination and seedling growth of <i>Phaseolus radiata</i> , <i>Stylosanthes guianensis</i> , <i>Glycine max</i> , <i>Macroptilium atropurpureum</i>	29
<i>E. alba</i> , <i>E. deglupta</i> , <i>E. saligna</i>	Phenolic acids and volatile oils	Extracts of fresh leaves, leaf litter and roots of <i>E. deglupta</i> and <i>E. alba</i> proved phytotoxic to <i>Shorea palembanica</i> seedlings. Leaf leachates of <i>E. saligna</i> , significantly reduced the germination and radicle growth of <i>Cicer arietinum</i> (chickpea), <i>Zea mays</i> (maize), <i>Pisum sativum</i> (pea) and <i>Eragrostis tef</i> (teff)	48
<i>E. baxteri</i> , <i>E. nitida</i> , <i>E. obliqua</i>	Polyphenols	Litter extracts of <i>E. baxteri</i> and <i>E. obliqua</i> inhibited seed germination and seedling growth of wheat (<i>Triticum aestivum</i>), but <i>E. nitida</i> was not inhibitory	86

<i>E. brockwayii</i> , <i>E. salubris</i>	E. Oils fraction and the aqueous volatile fractions	Inhibited the seed germination and growth of <i>Physalis hederifolia</i> . Inhibition by <i>E. salubris</i> was stronger than <i>E. brockwayii</i>	144
<i>E. erythrocorys</i>	1,8-cineole, α -Pinene	Inhibition of seed germination and seedling growth of <i>Sinapis arvensis</i> and <i>Phalaris canariensis</i>	49
<i>E. exserta</i>	Volatile compounds	Reduced the seedling growth of <i>Leucaena leucocephala</i> and <i>Acacia mangium</i>	78
<i>E.gomphocephala</i>	-	Leaf extracts reduced the growth of leguminous crops: <i>Medicago sativa</i> , <i>Vicia sativa</i> and <i>Pisum sativum</i>	64
<i>E. intertexta</i>	-	Inhibition of seed germination and seedlings growth in <i>Acacia</i> spp (<i>A. ehrenbergiana</i> , <i>A. gerrardii</i> , <i>A. tortilis</i>)	118
<i>E. microtheca</i>	Leaf volatile oil	Fresh roots exudates inhibited the radicle growth of <i>Pennisetum glaucum</i> , while whole plant exudates was the opposite. Whole plant exudates suppressed the plumule growth, but the stem extracts enhanced.	50
<i>E. nicholii</i>	Essential oils	Strong inhibition of germination of <i>Amaranthus retroflexus</i> , <i>Portulaca oleracea</i> and <i>Acroptilon repens</i>	107
<i>E. rostrata</i>	Phenolic compounds	Leaf-litter water extract (1 %, 5 %) reduced the root lengths of <i>Vicia faba</i> and <i>Zea mays</i>	43
<i>E. salinga</i>	-	Significant reduction in germination of chickpea and seedlings growth in tef	73
<i>E. victrix</i>	-	The foliage leachate inhibited the seed germination of <i>Lactuca sativa</i> and the growth of weeds	48
Allelopathic effects on Plants insects pests			
<i>E. andrewsii</i> , <i>E. crebra</i> , <i>E. punctata</i> , <i>E. pyrocarpa</i> , <i>E. siderophloia</i> , <i>E. sphaerocarpa</i>	Essential Oils	Insecticidal to <i>Plutella xylostella</i>	47
<i>E. approximans</i> , <i>E. bicostata</i> , <i>E. maidenii</i> , <i>E. sideroxyln</i> ,	1,8-cineole, limonene,	Significantly increased the mortality of female adult mites (<i>Tetranychus urticae</i> Koch (Acari:Tetranychidae)) and decreased the total number of eggs	57
Allelopathic effects on Plant pathogens			
<i>E. anceps</i> , <i>E. melliodora</i> ,	1,8-cineole, α -pinene, aromandrene, allo-aromandrene	Antifungal effects of essential oils against <i>Rhizopus nigricans</i> , <i>Aspergillus flavus</i> , <i>Aspergillus niger</i> , <i>Fusarium oxysporum</i> and <i>Penicillium digitatum</i>	140
<i>E. astrengens</i> , <i>E. bicostata</i> , <i>E. cinerea</i> , <i>E. maideni</i>	1,8-cineol, α -pinene	High antibacterial activity to <i>Listeria ivanovii</i> and <i>Bacillus cereus</i>	115
Allelopathic effects on Human pathogens			
<i>E. alubris</i> , <i>E. stricklandii</i> , <i>E. sargentii</i> , <i>E. torquata</i> , <i>E. wandoo</i> <i>E. woodwardi</i> ,		Showed weak to-moderate cytotoxicity against non-lymphoma tumour cell lines and potent cytotoxicity against BJAB and Raji lymphoma tumour cell lines	112
<i>E.benthamii</i>	α -pinene, globulol aromadendrene, γ -terpinene	The EOs from young and adult leaves had Cytotoxic and antitumor activity to Jurkat, J774A.1 and HeLa cells lines	112
<i>E. botryoides</i> , <i>E. nitens</i> , <i>E. maculata</i> , <i>E. viminalis</i>	2',6'-dihydroxy-3'-methyl-4'-methoxy-dihydrochalcone, eucalyptin,	The leaf extracts significantly inhibited the growth of 5-Gram-positive bacteria (<i>Staphylococcus aureus</i> , <i>Bacillus cereus</i> , <i>Enterococcus faecalis</i> , <i>Alicyclobacillus acidoterrestris</i> , <i>Propionibacterium acnes</i>) and fungus (<i>Trichophyton mentagrophytes</i>)	132

	8-desmethyl-eucalyptin, isolated from <i>E. maculata</i> extracts		
<i>E. caesia</i>	EOs	Antiviral effects against human herpes viruses(HSV-1), selectivity index 38.8	9
<i>E. cinerea</i> , <i>E. gunnii</i> , <i>E. odorata</i>	1,8-cineole, p-cymene, α -pinene, cryptone	<i>E. odorata</i> oil significantly inhibited the Gram + <i>Staphylococcus aureus</i> , oil from <i>E. cinera</i> and <i>E. gunni</i> showed significant antibacterial inhibition to <i>Pseudomonas aeruginosa</i>	42
<i>E. divers</i> , <i>E. olida</i> , <i>E. staigeriana</i>	24 compounds in <i>E. divers</i> , 29 in <i>E. staigeriana</i> , 20 in <i>E. oilda</i>	Essential oils of each <i>Eucalyptus</i> speciesdis were antimicrobial to Gram-positive (<i>Staphylococcus aureus</i> , <i>Enterococcus faecalis</i>), Gram-negative (<i>Escherichia coli</i> , <i>Pseudomonas aeruginosa</i>) and the yeast <i>Candida albicans</i> . <i>E. staigeriana</i> oil showed the highest activity	51
<i>E. dundasii</i> , <i>E. floribunda</i> , <i>E. kruseana</i>	1,8-cineole , p-cymene , α -thujene, and E-caryophyllene	Fumigant toxicity and repellent property against with <i>Rhyzopertha dominica</i> and <i>Oryzaephilus surinamensis</i> . EOs of <i>E. kruseana</i> have the highest insect repellency	7
<i>E. dunnii</i> , <i>E.gunnii</i>	1,8-Cineole, γ -Terpinene p-Cymene, α -Pinene p-Cymene Epiglobulol and α -Pinene	Essential oil showed strong fumigant activity to <i>Pediculus humanus capitis</i>	136
<i>E. ficifolia</i>	-	Strong antibacterial activity to Gram positive bacteria	82
<i>E. gracilis</i> , <i>E. oleosa</i> , <i>E.salmonophloia</i> , <i>E. salubris</i>	18-27 compounds	Exhibited significant antibacterial activity against all microorganisms tested except <i>Staphylococcus aureus</i> and <i>Escherichia coli</i>	83
<i>E. largiflorens</i> , <i>E. melliodora</i> , <i>E. polycarpa</i> ,	Eucalyptol	Antibacterial activity to growth of <i>Staphylococcus aureus</i>	96
<i>E.macrocarpa</i> , <i>E. perriniana</i>	Phloroglucinol, dicarbaldehyde and diterpene, macrocarpals, grandinol	Antibacterial activity Gram-positive bacteria (<i>Staphylococcus aureus</i> , <i>Bacillus subtilis</i>)	89, 146
<i>E. microcorys</i>	Total phenolics, total flavonoids, proanthocyanidins and saponins	The crude aqueous extract of leaves showed antibacterial and antifungal properties to test bacteria (<i>Escherichia coli</i> , <i>Enterobacter erogenes</i> , <i>Staphylococcus lugdunensis</i>) and fungi (<i>Geotrichum candidum</i> , <i>Aspergillus brasiliensis</i> and <i>Candida albicans</i>)	22
<i>E. occidentalis</i>	τ -cadinol ,1,8-cineol, α -cadinol and α -pinene	Toxic and repellent effects to <i>Rhyzopertha dominica</i> and <i>Tribolium castaneum</i>	120
<i>E. robusta</i>	12-Formyl phloroglucinol meroterpenoids	Anti-fungal ability against <i>Candida albicans</i>	117
<i>E. torelliana</i>	Tannins, aponins, Monoterpenes , Hydrogenated sesquiterpenes	Exhibited antiviral activity, antimicrobial activity to human enteroviruses: 6-strains of <i>Helicobacter pylori</i> (ATCC 4504, ATCC 47619, A2, TI8984, 019A, and A6); Poliovirus type I, Coxsackievirus B and Echovirus 6	1

E.O. : Essential oils.

9. FUTURE PROSPECTS OF ALLELOPATHY RESEARCH

Presently > 100- *Eucalyptus* trees species with allelopathic effects have been identified and 75- spp. have been included in this Review. The allelopathic effects of many *Eucalyptus* sp. have not been studied. Future studies should be done on following aspects.

1. Mode of release of allelochemicals: The mode of release of allelochemicals such as volatilization, leaching, root exudation and litter, etc., duration of the effects, the distance (m) of adverse effects from *Eucalyptus* tree row for agroforestry systems management. It is recommended to report the allelopathy of the whole plants, so that different management strategies can be adopted according to the allelochemicals released from different tissues.

2. Rhizosphere soil: Impact of *Eucalyptus* rhizosphere soil on selected test plant species, as only few researches have been done on the *Eucalyptus* rhizosphere soil allelopathy, allelochemicals composition and quantities.

3. Root secretions: Allelopathic effects of root secretions on soil allelochemicals and the abiotic and biotic factors of *Eucalyptus*

4. Abiotic and biotic factors: Studies the effects of these factors on the allelopathy of *Eucalyptus*.

5. What factors affects the *Eucalyptus* allelopathy. These may help us to use or control the allelopathy of *Eucalyptus*, according to specific needs.

10. CONCLUSIONS

This review, summarizes the distribution, use of allelopathic compounds produced by different *Eucalyptus* species for various purposes, particularly in medicine and agriculture. 75-allelopathic *Eucalyptus* spp. have been described and discussed. Their adverse effects on other plants, crops, and microorganisms by inhibition of germination and seedling growth, reduction of biomass and/or stimulation of fresh weight or basal diameter, etc. have been explained. Based on recent research, eco-friendly herbicides could be developed from *Eucalyptus* allelochemicals though their herbicidal function, which plays an active role in agricultural practice. Therefore, it is necessary to study their allelopathic effects on recipient plant spp., so that their negative effects can be avoided. Such approach will provide better support for agricultural and forestry management, species selection for vegetation restoration. In future study, more species with allelopathic effects of *Eucalyptus*, the factors impacting their allelopathic effects, modes of release of allelochemicals, allelopathy of *Eucalyptus* rhizosphere soil and how to reduce the negative allelopathic effects of *Eucalyptus* species, etc.

Furthermore, the allelopathic effects of these plants makes them a good choice for natural prophylactics and medicines such as insecticides, antibacterials and antivirals. Use of chemical compounds from *Eucalyptus* species in natural medicine.

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DECLARATION

We declare that all authors of this Ms. have made substantial contributions. We did not exclude any author who substantially contributed to this Ms. We have followed our ethical norms established by our respective institutions.

CONFLICT OF INTEREST

The authors announce that they have no conflict of interest.

ETHICAL APPROVAL

The authors declare that the study was carried out following scientific ethics and conduct. However, this study did not involve any use of animals, hence no ethical approval has been obtained from the concerned committee.

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