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Allelopathic Plants : 25. *Schinus terebinthifolius* Raddi

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ABSTRACT

The Brazilian pepper plant (*Schinus terebinthifolius* Raddi) is an invasive species that displays multiple characteristics that allow habitat invasion, including allelopathy. This review analyzes the existing literature that characterizes the Brazilian pepper's essential oil from multiple geographic regions globally. This review reveals that the terpenoid constituents of the essential oil varies based on region, season and plant part. Laboratory bioassays and greenhouse studies demonstrating the allelopathic effects of its oils on several plant species are discussed. We suggest that future bioassays or pot cultures investigating allelopathy of Brazilian pepper should include the geographic location, plant part used (leaves vs. fruit), season harvested, phenological phase of plant and the terpenoids characterization. We also suggest field studies to investigate the persistence of Brazilian pepper's allelopathic chemicals in their surrounding environment.

Keywords: Allelopathy, bioassays, Brazilian pepper, cytotoxicity, invasive specie, phenolics, phyotoxicity, pot culture, terpenoids, *Schinus terebinthifolius*

1. INTRODUCTION

The Brazilian pepper (*Schinus terebinthifolius* Raddi), (family Anacardiaceae) is an invasive species, which has spread across the globe from its native South America to Australia and beyond (4,25,54). Hence, it is increasingly receiving attention for its allelopathic properties and uses. For example, recent literature indicates the potential use of Brazilian pepper for biological control. In a bioassay experiment, its essential oil proved effective against *S. aegypti* mosquito larvae with genotoxicity levels (tested against *Salmonella typhimurium*) indicating safe environmental use (66). Additional laboratory and field mosquito vector control research indicated the effectiveness of its extract against

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Anopheles gambiae s.s., *An. Arabiensis* and *Culex quiquefasciatus* (43). Its essential oil is effective fumigant against the mite *Tyrophagus putrescentiae* (Schrank) and very effective fumigant against the mite *Suidasia pontifica* Oudemans (18). Besides, the Brazilian pepper extract's have antibacterial and antioxidant properties (3,27,38,65). However, despite the growing interest in Brazilian pepper's allelopathic properties and uses, its research remains unorganized across fields and interests and has notable gaps in focus and coverage. A comprehensive review article on the allelopathic properties of Brazilian pepper does not currently exist in literature.

This review aims to: (i). Organize and compare existing reports of Brazilian pepper essential oil characterizations to determine, if there is a need for more complete reporting due to variations in plant part used in analysis, season collected and geographic region; (ii). Assess the existing bioassay and pot culture studies results to determine, if there is enough evidence to confirm the broad allelopathic nature of Brazilian pepper and (iii). if the existing literature is sufficient to co-relate the Brazilian pepper extract composition and allelopathic effects.

2. USES, MORPHOLOGY and DISTRIBUTION

Uses: Historically the Brazilian pepper has been used as ornamental plants in residential and roadside landscaping, traditional medicines and rarely for consumption (10,16). In South America, the plant is used as medicinal tonic to treat ulcers, gout, diarrhea and arthritis (16). Western medical research use the Brazilian pepper extract to treat bacterial vaginosis and oral disease (5,44). Several studies have investigated cytotoxicity of Brazilian pepper extract on cancer cells (57,58,63). Industrially, the Brazilian pepper's bark is used to preserve fishing lines and nets (16). Brazilian pepper is used for the copious nectar and pollen to make a peppery honey (16). Though the wood has low value as lumber due to its small trunk size and resin, but its wood is used for posts, stakes and mulch (16).

Brazilian pepper has several varieties: *Schinus terebinthifolius* var. *terebinthifolius* Raddi, *Schinus terebinthifolius* var. *raddianus* Engl., *Schinus terebinthifolius* var. *acutifolius* Engl., *Schinus terebinthifolius* var. *pohlianus* Engl. and *Schinus terebinthifolius* var. *rhoifolius* Engl (46). Its genetic analysis in southern United States indicates there are several haplotypes that easily hybridize, in some cases due to a climatic niche shift (49,70).

Morphology: Brazilian pepper is a shade-tolerant perennial evergreen shrub-like tree that typically grows 3 – 10 m in height but can reach heights of 16 meters (4,16,46). Typically, the plant has a short smooth gray multi-stemmed trunk with bark that may become scaly over time (46). Branches are wide-spreading, horizontal and non-pendulous (46) (Figure 1). The odd pinnate compound elliptical leaves range from 8 to 20 cm in length, arranged in 4-12 paired fine-toothed lateral leaflets along the narrowly-winged rachis and ending at a terminal leaflet (9,35) (Figure 2). Leaflets have a shiny, resinous coating and are often green but can sometimes have a red coloration (16). When pierced, the stems and twigs release a resinous sap, while the crushed leaflets release a pungent peppery or turpentine odour (9,16). While Brazilian pepper plants are known to have shallow root systems, little is published regarding root morphology.

Figure 1: Brazilian pepper plant (61)

Figure 2. Brazilian pepper leaves (61)

Brazilian pepper reaches maturity within three years of germination (46). Inflorescences are axillary or terminal panicles from the leaf axils near the terminus of current-season stems (16,35). Brazilian pepper is typically dioecious (with male and female flowers on different plants), with small white flowers (2 to 11 cm) (9,16). Flower production between male and female plants is synchronous (16,29). Both male and female flowers are similar in size, shape and colouration (16). The pistillode does not function in male flowers, while stamens are sterile in female flowers (16). Pollination is primarily insect-based, with diverse pollinators from the orders Hymenoptera, Lepidoptera, Diptera and Coleoptera (16,29).

Soon after flowering, the fruit develops as a glossy green spherical drupe that becomes bright red when ripe. The fruit has a small flesh with one dark brown seed (0.3 - 6.5 mm dia) (16). Each inflorescence contains dense clusters of fruit with as many as 1,200 per panicle (16,29,46). Fruits are commonly dispersed by mammals and birds, gravity, or water (29,46). Seeds are buoyant and can be dispersed to large distances (approximately 17 kms in fresh water and 22 kms in saline water) (22,47). Seed germination peaks several weeks after disbursement and is influenced by the soil type, soil salinity, soil moisture and associated species (29,55,46). Interestingly, seed germination is significantly improved by animal ingestion (or other method of scarification) (16). Seed viability varies by geographic location (16,29,68). Once established (10-15 cm tall), seedlings have a survival rate of 66-100% (29).

Native to Brazil, Argentina and Paraguay, Brazilian pepper is now found in the United States, Australia, the Bahamas, Bonin Island (Japan), southern China, Fiji, Mauritius, Mediterranean Europe, New Caledonia, New Zealand, North Africa, Puerto Rico, Samoa, South Africa and Vanuatu (4,25,54). It has broad ecological range, growing best in low-elevation, mesic areas including pinelands, hardwood hammocks, wetlands, saltmarsh, coastal dunes, grassland, shrubland and mangrove forests (29,34,46). Brazilian pepper is sensitive to cold temperatures but mature plants can withstand a wide range of physico-chemical and hydrological conditions, including soil pH, flooding (freshwater, saline and semi-saline) and drought (4, 28). Seedlings are much more susceptible (16).

It is particularly successful in disturbed habitats (71). In United States, Florida has identified Brazilian pepper as a Category I invasive species, while California has placed it on the Invasive Plant Council List B (9,16). Within Australia, Brazilian pepper is a restricted plant in New South Wales and Queensland (4,26).

Brazilian pepper is able to displace native species, altering community structure and function (16). A wide variety of characteristics allow Brazilian pepper to proliferate. Brazilian pepper has a rapid growth rate, up to 3 m a year and forms very dense monotype thickets (30). Brazilian pepper re-sprouts from trunk or roots after damage from cutting, fire, or herbicide treatment, though seedlings have limited tolerance (16,46,55). Fire facilitates the invasion of Brazilian pepper in some ecosystems (67). The plants have wide spectrum of distribution vectors (16,29). While there is no research to indicate the role of soil microbiota in Brazilian pepper establishment, but the arbuscular mycorrhiza assist in its establishment plants (17).

Brazilian pepper may also have a competitive edge in an ecosystem through novel weapons. The novel weapons hypothesis suggests that native species may not have an effective defense strategy against exotic threats posed by invasive species, such as allelopathic chemicals (10). Negative allelopathy is the chemical inhibition of one organism (commonly discussed in reference to plants) by another, often through secondary metabolites, resulting in plant injury (phytotoxicity). Plants in the family Anacardiaceae, to which Brazilian pepper belongs, often produce leaves, sap and fruit that contain a wide variety of terpenes, organic acids and other complex organic chemicals, which may have allelopathic potential (45).

3. ALLELOPATHIC RESEARCH

Laboratory and greenhouse studies have established the allelopathic nature of *Schinus terebinthifolius* plant parts (leaves and berries). The allelopathic effects of Brazilian pepper are species-specific (10,52). Table 1 summarises early research on allelopathic effects of *S. terebinthifolius* in bioassay, pot culture, or field study. Most of these studies focussed on phytotoxicity as an allelopathic effect. One study explored cytotoxicity in a plant species. This review focusses on allelopathic effects on plant species. However, allelopathic effects on other organisms are briefly presented.

Table 1. Literature review of allelopathic effects of *Schinus terebinthifolius*

Country	Plants species	Effects on Recipient plant	Reference
	Bioassay		
USA	*Pleurosigma, Melosira, Palmerina, Amphidinium*	Variable germination inhibition by species	39
Tunisia	*Triticum durum L.*	Germination inhibition, reduced radicle length	53
South Africa	*Allium cepa, Lactuca sativa*	Lettuce germination inhibition	56
USA	*Lactuca sativa*	Significant inhibition of radicle growth	31
	Bioassay and Pot Culture		
USA	*Bidens alba, Rivina humilis*	Reduced biomass accumulation for both species, germination inhibition in *Bidens alba*	48
USA	*Pinus palustris, Pinus elliotii, Quercus virginiana, Liatris laevigata, Aristida stricta, Myhlenburgia capillaris and Solidago fistulosa*	Pot Culture: No germination inhibition; Reduced biomass likely due to competition Bioassay: Reduced germination of all species	50
	Pot Culture		
USA	*R. mangle, A. germinans*	Reduction of growth, leaf production, and biomass of *A. germinans,* while, *R. mangle* was unaffected	21

3.1 Phytotoxicity

3.1(i) Pot Cultures

In pot cultures, the growth, leaf production and biomass of *Avicennia germinans* (black mangrove) seedlings was significantly reduced when exposed to intact *S. terebinthifolius* fruit in 30 ppt saltwater, while intact fruits did not impact the *Rhizophora mangle* (red mangrove) seedlings at any salinity levels (21). Exposure to crushed fruit significant impacted the growth, leaf production and biomass of seedlings in both mangrove species at all salinity levels tested, with greater effects seen at higher salinity. In addition to documenting allelopathic effects of Brazilian pepper, Donnelly *et al*. (21) demonstrated how abiotic factors like salinity influence the effects of allelopathic chemicals in natural systems.

Nickerson and Flory (2015) used the greenhouse pot cultures to investigate the influence of *S. terebinthifolius* seedlings on the germination and growth of tree species *Pinus palustris* (Longleaf pine), *Pinus elliotii* (Slash pine), *Quercus virginiana* (Live oak) and the herbaceous species *Liatris laevigata* (Clusterleaf blazing star), *Aristida stricta*

(Wiregrass), *Myhlenburgia capillaris* (Pink hair grass) *and Solidago fistulosa* (Pinebarren goldenrod) (50). They showed that the presence of immature Brazilian pepper did not reduce germination of investigated species but reduced the final biomass, likely due to competition rather than allelopathy. They also used growth chamber bioassays to investigate the effects of fruit extract on germination and found that the extract reduced the germination of all native test species.

3.1(ii) Lab Bioassays

Brazilian pepper fruit extract (from crushed berries) in an enriched seawater medium was applied in varying concentrations to four species of microalgae, resulting in species-specific impacts (39). The epibenthic microalgae *Pleurosigma* was not significantly impacted by any concentration of *S. terebinthifolius* extract, whereas *Melosira* and *Palmerina* were inhibited at all dilutions tested. *Amphidinium* showed a mixed response to exposure to the extract. Hargrave's research (39) suggests that Brazilian pepper may have variable impacts on primary production and community structure in shallow coastal habitats, where microalgae significantly contribute to biodiversity.

Irrigation of wheat seeds (*Triticum durum L.*) with aqueous dilutions of *S. terebinthifolius* extract inhibited the seed germination and the extract reduced the radicle length (53).

Brazilian pepper extract obtained through hydrodistillation significantly reduced the mitotic index of onion and lettuce (56). The *S. terebinthifolius* extract reduced the germination rate of the lettuce by 65.15%; The effect on the germination rate of the onion was not statistically significant. Pawlowski *et al* (56) research was repeated with *S. molle* but the effects were more pronounced with *S. terebinthifolius*. The major component of each extract was α-pinene. The results suggest synergy with the minor compounds in the essential oil to produce the stronger inhibitory effects with *S. terebinthifolius*.

In laboratory bioassays and greenhouse pot cultures, irrigation with aqueous extracts of Brazilian pepper leaves reduces both germination and biomass accumulation of *Bidens alba* (Beggarticks) and reduced the biomass of *Rivina humilis* (Common name: Rouge plant) (48).

The effectiveness of Brazilian pepper wood chip mulch for weed suppression was demonstrated in a laboratory bioassay (31). In Ferguson *et al* study (31), Brazilian pepper did not inhibit germination but significantly inhibited the radicle growth of *Lactuca sativa*. This is the only study found in the literature where two research teams investigated the allelopathy using the same species, in this case, *Lactuca sativa*. Interestingly, both papers report drastically different effects of the extract on germination rates. The difference in findings is likely due to the nature of the two experiments, one being application of essential oil dilution and the other being exposure to wood chip mulch of the species.

Several authors reference a 1974 study of the inhibitory effects of Brazilian pepper leachate on germination of *Bromus irgidus* (37,48,49). But, as stated in Morgan and Overholt (48), these results were limited and published in an abstract that was not peer reviewed.

There are no references suggesting that Brazilian pepper exhibits phytotoxic effects in its native range. This supports the hypothesis of Morgan and Overholt (48), that the Brazilian pepper exhibits allelopathic tendencies when outside of its native range, are due to the lack of co-evolved tolerance of the native species to these chemicals rather than an interfering mechanism evolved through natural selection.

3.2 Cytotoxicity

In addition to phytotoxic effects, Pawlowski *et al*. (56) also noted a mutagenic effect on plant cells exposed to the Brazilian pepper extract. The extract induced the chromosomal abnormalities in both the onion and lettuce.

3.3 Allelopathic effects on other organisms

Extract from Brazilian pepper proved cytotoxic to multiple types of cancer cells (57,58,62,63). The cytotoxicity of the extract against bacterial cells is well-documented (19,20,24,27,36,38,44,65,66). Furthermore, the plant's extract has been demonstrated to be cytotoxic to various fungi (3,15,27,41,42,64). Interestingly, the extract was shown effective against the herpes simplex virus type 1 (51). The extract, however, appears to have lower toxicity in animals (65).

The extracts of *Schinus terebinthifolius* damages the DNA and mutations in bacteria (19). In contrast, a 2010 study indicated that the genotoxicity levels against *Salmonella typhimurium* indicated safe environmental use of Brazilian pepper extract for mosquito larval control (66).

4. ALLELOCHEMICALS: CHARACTERIZATION

Extracts of *Schinus terebinthifolius* contains primarily the phenolics, terpenoids, flavonoids and alkaloids (1,5,11,12,32,41,45,63). Many of the isolated chemicals in the oils of plant parts from Brazilian pepper are terpenoids, naturally occurring organic chemicals, that are derived from 5-carbon isoprene units (Table 2).

Table 2. Classes of terpenoids in *Schinus terebinthifolius*

Hydrocarbon Monoterpenoids	**Hydrocarbon Sesquiterpenoids**
δ-3-Carene	Biocyclogermacrene
p-Cymene	α-Cadinene
α-Fenchene	β-Caryophyllene
Limonene	β-Elemene
Myrcene	Germacrene D
α-Phellandrene, β-Phellandrene	**Oxygenated Sesquiterpenoids**
α-Pinene	α-Cadinol
1-β-Pinene	Caryophyllene oxide
Sabinene	Epi-α-Muurolol
Sylvestrene	
Oxygenated Monoterpenoids	
Carvone	
p-Cymen-7-ol	
Verbenone	

4.1 Characterization of Terpenoid Fraction

Gas chromatography and mass spectroscopy analysis of essential oil extracted from *S. terebinthifolius* berries shows the relative percent composition of these chemicals in the oil, which varies across different geographic regions (Table 2). The monoterpenoids α-Phellandrene and β –Phellandrene are major part of the oils, with the exception of the Reunion Island population tested.

Table 3. Influence of Geographic Location on oil composition (6,8,60,69)

Brazil (Barbosa, 2007)		Tunisia (Bendaoud, 2010)	
Compound	Oil (%)	Compound	Oil (%)
β -Phellandrene	18.1	α-Phellandrene	34.4
α-Phellandrene	13.0	γ-Cadinene	18.0
α-Pinene	12.9	β -Phellandrene	10.6
Sabinene	3.3	p-Cymene	7.3
Germacrene D	3.1	α-Pinene	6.5
		1-β-pinene	3.1
Reunion Island (Vernin, 2003)		Germany (Richter, 2010)	
Compound	Oil (%)	Compound	Oil (%)
Limonene	17.7	Limonene	23.7
p-Cymene	15.7	α-Phellandrene	21.1
		α-Pinene	16.9
		β -Phellandrene	10.8

However, the oil composition cannot be used as a fingerprint, even in Brazil there is great variation in the essential oil composition (extracted from leaves). Barbosa (6) found 33.8% of the oil content of leaves to be germacrene, while Silva (65), Chowdhury (13) and dos Santos (23) did not detect this chemical, and Pawlowski (56) found germacrene in small quantities. Another study (not included in this Table-2) due to the lack of specificity on plant part used, found 23.7% germacrene (63). Three of the leaf extract samples, showed similar β-caryophyllene content (7.1-12.3%), while Pawlowski (56) reported only 2.71% and dos Santos (23) did not detect this sesquiterpenoid. Interestingly, the ripe fruit did not show any β-caryophyllene. Three of these studies found α-pinene (6-13%) in the ripe fruit, while Affonso (2) failed to detect this monoterpenoid. The Santana *et. al*. (2012) study (not included in Tables 3 and 4) showed the α-pinene content of 9.1%.

Table 4. Variations in chemical composition of oils in leaves of *S. terebinthifolius* Raddi in Brazil (6, 13, 23, 56, 66)

Barbosa (6)		Silva (66)	
Compound	%	Compound	%
Germacrene D	33.8	p-Cymen-7-ol	22.5
β-Caryophyllene	12.3	β-Caryophyllene	10.1
1-β-Pinene	5.2	Carvone	7.5
Biocyclogermacrene	4.6	Verbenone	5.2
		Caryophyllene oxide	5.2
Chowdhury (13)		dos Santos (23)	
Compound	%	Compound	%
α-Pinene	51.8	Limonene	14.2
β-Caryophyllene	7.1	α-Pinene	7.9
Sabinene	3.7	α-Phellandrene	3.9
Pawlowski (56)			
Compound	%		
α-Pinene	31.6		
trans-Ocimene	12.3		
β-Phellandrene	6.6		
Sabinene	6.2		
β-Pinene	6.0		

A comparison of studies in Egypt using ripe fruit also showed great variations in the essential oil composition (Table 5). Two studies using leaves cultivated in Egypt also show much different chemical compositions (27,40). El Massry *et al*. (27) reported the following major constituents extracted from leaves: caryophyllene alcohol (13.1%), geranyl-n-butyrate (12.2%), β-sesquiphellandrene (8.6%), sabinene (7.63%) and α-gurjunene (7.2%). Ibrahim (40) reported that 24.2% of the terpenoids are α-phellandrene, but did not report the plant part containing these compounds.

Table 5. Variations in chemical composition of oils in ripe fruits of *S. terebinthifolius* Raddi in Brazil

Barbosa (6)		dos Santos (23)	
Compound	%	Compound	%
β-Phellandrene	18.1	Myrcene	20.4
α-Pinene	13.0	Limonene	17.0
1-β-pinene	5.0	α-Pinene	6.0
Sabinene	3.3	α-Phellandrene	3.9
Germacrene D	3.1	Sabinene	2.9
Affonso (2)		Cole (14)	
Compound	%	Compound	%
α-Fenchene	20.8	δ-3-carene	30.4
Limonene	20.8	Limonene	17.4
α-Phellandrene	14.9	α-Phellandrene	12.6
Sylvestrene (iso)	13.9	α-Pinene	12.6
1-β-Pinene	10.1	Myrcene	5.8
Myrcene	9.3		

Additionally, the concentrations of these oils vary by season (flowering or non-flowering plant) and plant part (leaf or fruit) (Table 6). As the tree transitions from a non-flowering to a flowering state, the oil composition of the leaves change as well due to the shift in metabolism (6). Germacrene D content in the oil drops by half, while the Biocyclogermacrene content more than quadruples.

Table 6. Variations in chemical composition of oils in ripe fruits of *S. terebinthifolius* Raddi in Tunisia

Bendaoud (8)		Ouerghemmi (53)		Ouerghemmi (2014)	
Compound	%	Compound	%	Compound	%
α-Phellandrene	34.4	Carvacrol	35.5	para-Cymene	76.7
γ-Cadinene	18.0	α-Pinene	17.7	α-Pinene	6.9
β -Phellandrene	10.6	Nerol	14.4	Tridecane	2.6
p-Cymene	7.3	Thymyl	5.3	Bornyl acetate	2.2
α-Pinene	6.5	Camphene	3.6	Germacrene D	2.0
1-β-pinene	3.1	2-phenylethanol	3.4	Nerol	1.8

4.2 Characterization of Phenolic Fraction

While many studies focused on terpenoids, Feuereisen *et. al*. (2014) identified four anthocyanins, three bioflavonoids, gallic acid and two types of hydrolysable tannins in the fruit exocarp, showing the potential importance of these phenolic compounds for antimicrobial effects (32). Interestingly, this study concluded that 7-methoxylated flavonoids are a chemotaxonomic trait found in the Anacardiaceae plant family. El-Massry *et al*. (27) reported that 7.0% of the essential oil was phenolic compounds, identified as caffeic acid, syringic acid, coumaric acid, ellagic acid, gallic acid and catechin. Ceruk *et. al.* (2007) reported the presence of ethyl and methyl gallates.

Table 7. Variations in chemical composition of oils in plant parts *S. terebinthifolius* (6)

	Plant Part			
Chemical Name	Fruit		Leaves	
	Unripe	Ripe	Non-Flowering	Flowering
α-Pinene	3.1	13.0	1.1	-
1-β-Pinene	10.0	5.0	5.2	0.1
α-Phellandrene	0.1	13.0	1.1	-
β -Phellandrene	2.5	18.0	0.1	0.1
Z-β-Ocimene	-	-	5.2	-
β-Caryophyllene	4.8	1.6	12.0	2.9
Germacrene D	5.2	3.1	34.0	16.0
Biocyclogermacrene	-	0.6	4.6	21.0
δ-Cadinene	16.0	1.2	3.0	3.1
Epi-α-Muurolol	9.9	0.4	2.5	-
α-Cadinol	21.0	1.2	2.7	5.3
Minor Constituents	27.4	42.9	28.5	51.5

4.3 Correlating the extracts Characterization to Allelopathic Effects

These compounds are released into the environment through volatilization, leaching, root exudation and decomposition of plant materials (59). Several studies have shown the allelopathic potential of terpenoids in plant parts (7,33). This is further supported by the bioassay and pot culture studies (Table 1) that demonstrate various allelopathic effects including germination and radicle growth inhibition. It is still unclear whether these chemicals exert an allelopathic effect in isolation or if there are synergistic effects.

5. FUTURE AREAS OF RESEARCH

The various studies characterizing *S. terebinthifolius* oil extracted from berries and leaves clearly show wide variability in the oil content. The limited bioassay and pot culture studies on the allelopathic nature of Brazilian pepper seem to support the hypothesis that Brazilian pepper employs novel weapons against some plant species. However, only two of these studies characterized the terpenoids in the plant extract used. None of the allelopathy studies or chemical composition studies did not consider the (i). geographic location, (ii). plant part used in study, (iii). season harvested/ flowering state of plant and (iv). terpenoid composition. More complete information would allow researchers to begin to determine which chemicals or combination of chemicals may be responsible for allelopathic effects, especially since there are likely synergistic effects (56).

Additionally, all allelopathic studies were conducted in controlled laboratory or greenhouse settings. The effect of these allelopathic chemicals on plants in the natural environment is still uncertain. It is possible that there may be other competition strategies that are relevant to the success of Brazilian pepper in specific non-native habitats.

Although detecting allelopathic compounds in soil in the field at levels of significance can be challenging, it is worth investigating as many research questions can be answered, including the persistence of these compounds in soil. This is of particular interest since the primary method of control of this plant is chemical control with herbicide application, where the plant is left in place to decompose. This could cause a continued release of allelopathic chemicals into soil, potentially slowing regrowth of other plant species.

This review indicates many opportunities for further research into the allelopathic properties and effects of the Brazilian pepper due to the wide-spread invasive reach of the plant. It's allelopathic effects and potential uses represent a vital concern for both managing the spread of the invasive plant as well as to find its potential productive uses. With only 13 Lab. studies identified that conducted the primary research into the allelopathic effects of Brazilian pepper on other plant species, none was field study. The opportunities for further research are as under:

(i). Study the allelopathic effects of *S. terebinthifolius* under field conditons.

(ii). In field studies, detect the presence and persistence of allelopathic compounds in the surrounding soil.

(iii). In-depth allelopathic studies on *S. terebinthifolius* including the allelopathic effects of its essential oil.

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