REVIEW ARTICLE

Pharmacological, Agro-biological, and Aquacultural Significance of *Pimenta dioica*

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Abstract: *Pimenta dioica*, also called as Allspice or Jamaica pepper, serves as a prominent species within the Myrtaceae family, celebrated for its complex phytochemical profile and diverse utility. Native to the Caribbean and Central America, this evergreen tree has transcended its traditional culinary boundaries to become a subject of significant scientific interest. The plant possesses a rich array of bioactive constituents, particularly eugenol, which underpins its extensive pharmacological and biological activities. In traditional medicine systems, extracts from the leaves and berries are utilized to alleviate gastrointestinal distress, respiratory conditions, and musculoskeletal ailments. Current research has further described its potent agro-biological roles, demonstrating efficacy as an eco-friendly alternative to synthetic pest control agents. Essential oils derived from the plant exhibit marked anti-helminthic, larvicidal, insecticidal, and nematicidal properties, offering sustainable solutions for pest management in agriculture and public health. Moreover, recent investigations into aquaculture have positioned *P. dioica* as a functional feed additive, capable of enhancing growth performance, augmenting immune responses, and mitigating stress in fish species such as *Oreochromis mossambicus*. This article summarizes the current scientific knowledge regarding the applications of *P. dioica*, analyzing its therapeutic potential alongside its emerging roles in sustainable agriculture and aquaculture, thereby showing its value as a renewable biological resource.

Keywords: *Pimenta dioica*; Myrtaceae; Phytochemistry; Bio-pesticides; Aqua-feed supplementation.

1. Introduction

Pimenta dioica (L.) Merr., colloquially termed Allspice or Jamaica pepper, represents a botanical entity of considerable economic and ecological value. Belonging to the Myrtaceae family, this evergreen tree has long been a subject of fascination for botanists and researchers due to its unique aromatic properties and versatile utility [1]. The plant functions as a significant repository of bioactive compounds, which have facilitated its integration into various sectors, ranging from culinary arts to traditional and modern medicine. Historically rooted in the Caribbean region, particularly Jamaica, the species has influenced global cuisines, imparting a distinct flavor profile characterized by a combination of cinnamon, cloves, and nutmeg notes [2].

Figure 1. Fruits and Leaves of *Pimenta diocia*

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Beyond its sensory attributes, *P. dioica* occupies a critical position in ethnomedicine. Traditional healing systems have exploited its therapeutic efficacy for centuries, employing it to manage a spectrum of pathologies including digestive irregularities, respiratory tract infections, and inflammatory disorders [3]. The pharmacological potential of the plant is largely attributed to its secondary metabolites, which exhibit diverse biological activities. In addition to its medical relevance, the species contributes significantly to ecological stability and socioeconomic frameworks. It acts as a keystone component in tropical agroforestry systems, aiding in soil conservation and biodiversity maintenance. Furthermore, the commercial cultivation and trade of allspice support the economic sustenance of local communities in its native regions [4]. This article provides a detailed scientific analysis of the therapeutic, insecticidal, larvicidal, and nutritional applications of *P. dioica*, evaluating its potential as a multifunctional agent in health, agriculture, and aquaculture.

2. Ethnobotanical and Pharmacological Significance

The utilization of *P. dioica* spans therapeutic and non-therapeutic domains, with a history deeply embedded in ancient practices. The dried berries, extensively used as a spice, have been found to be safe for consumption, with studies indicating that long-term culinary use does not induce electrolyte imbalances in mammalian models [5]. The versatility of the tree is evident as virtually every morphological part finds specific application in industry or medicine.

2.1. Therapeutic Applications

The pharmacological scope of *P. dioica* is broad, addressing various physiological systems. The powdered fruit is traditionally indicated for gastrointestinal ailments, including flatulence, dyspepsia, and diarrhea. Its utility extends to the management of inflammatory conditions such as rheumatism and arthritis, as well as respiratory issues like bronchitis and congested coughs [3]. In specific traditional practices, the fruits are administered with honey to treat oral infections, highlighting antimicrobial potential [6].

Table 1. Major Phytochemical Constituents of *Pimenta dioica* Essential Oil

Plant Part	Extraction Method	Major Compounds identified (%)	Reference
Leaves	Hydrodistillation	Eugenol (65.8-74.7%), Methyl eugenol (15.2%), β -Caryophyllene, Myrcene, 1,8-Cineole	[4]
Berries	Hydrodistillation	Eugenol (60-90%), Methyl eugenol, β-Caryophyllene, Humulene	[1, 2]
Leaves	Steam Distillation	Eugenol, Chavicol, Myrcene, Limonene	[6]
Berries	Solvent Extraction	Polyphenols, Glycosides, Tannins (Ericifolin, Gallic acid)	[1, 6]

Aqueous extracts of the berries are frequently employed to mitigate flatulence and diarrhea, while hot infusions (tea) prepared from Allspice are utilized for alleviating dysmenorrhea (menstrual cramps), dyspepsia, and symptoms of the common cold [2, 4]. Topical applications are also prevalent; preparations involving the berries are applied to relieve myalgia, bruising, and joint soreness [4]. Furthermore, the essential oil, often blended with ginger and lavender, serves as a potent agent in aromatherapy, purported to induce relaxation and alleviate stress [4].

Table 2. Pharmacological Spectrum of *Pimenta dioica* Extracts

Activity	Extract/Form	Model Organism/Target	Observations	Reference
Antimicrobial	Leaf Essential Oil	*H. pylori*, *E. coli*, *S. aureus*	Significant inhibition zones; potential as natural preservative.	[6]
Anthelmintic	Essential Oil	*Pheretima posthuma* (Earthworm model)	Caused paralysis and death comparable to Albendazole standard.	[9]
Diuretic	Aqueous Extract	Rat model	Moderate diuretic activity observed in preliminary screenings.	[3]
Antinociceptive	Essential Oil	Mice	Reduced pain response in chemical nociception models.	[3]
Antioxidant	Berry Extract	*In vitro* assays (DPPH)	High radical scavenging activity attributed to phenolic content.	[1, 7]

2.2. Non-Therapeutic and Industrial Utilization

Beyond healthcare, *P. dioica* holds substantial industrial value. The dried unripe fruits are a staple culinary spice, integral to the flavoring of meats and baked goods. Essential oils extracted from the leaves and berries are pivotal in the fragrance industry, utilized in the formulation of high-grade perfumes, candles, and cosmetic products [4]. In the food industry, leaf extracts serve as natural fumigants, while the essential oil acts as a preservative and flavoring agent in liqueurs, non-alcoholic beverages, and processed meats [2, 7].

The plant also offers structural utility; young woody shoots are harvested for crafting walking sticks and umbrella handles, demonstrating the durability of its timber [2]. In regions like Nigeria, the berries are employed in indigenous culinary preparations, including fish smoking, imparting both flavor and preservative qualities [5]. Moreover, the essential oil is increasingly recognized as a viable botanical alternative to synthetic commercial pesticides and fungicides, aligning with the global shift towards green chemistry [4].

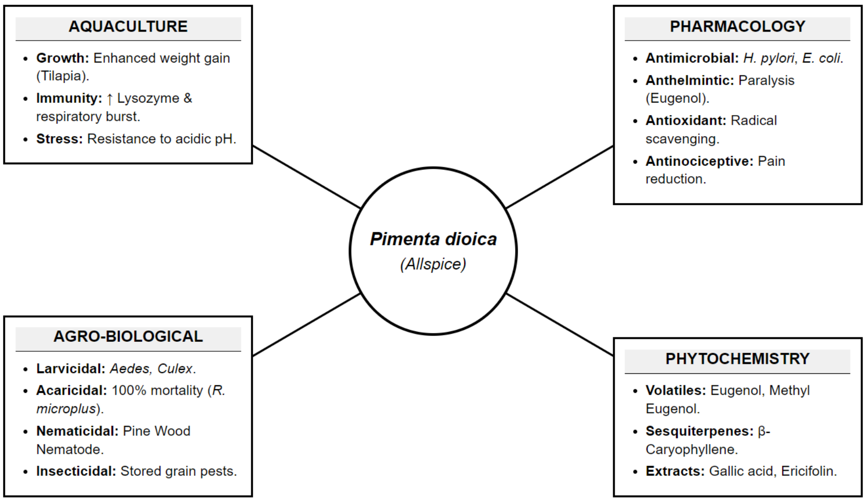

Figure 2. Biological potential and phytochemical profile of *Pimenta dioica*

3. Agro-biological Properties

The search for environmentally benign pest control strategies has directed research towards plant-derived bio-pesticides. *P. dioica* has emerged as a significant source of phytochemicals such as eugenol, alkaloids, terpenes, and flavonoids, which exhibit potent biological activity against a range of agricultural and medical pests.

3.1. Anti-helminthic Activity

Helminthic infections remain a persistent challenge in both human and veterinary medicine. Research indicates that plant-derived polyphenols can serve as effective anthelmintics, offering a safer profile compared to synthetic counterparts [8]. Investigations into the essential oil of *P. dioica* leaves have revealed significant activity against *Pheretima posthuma* (Indian adult earthworm). At a concentration of 0.15 ml/ml, the oil showed superior efficacy compared to the standard drug albendazole. This potent anti-helminthic effect is largely attributed to the synergistic action of eugenol and other bioactive constituents present in the oil [9].

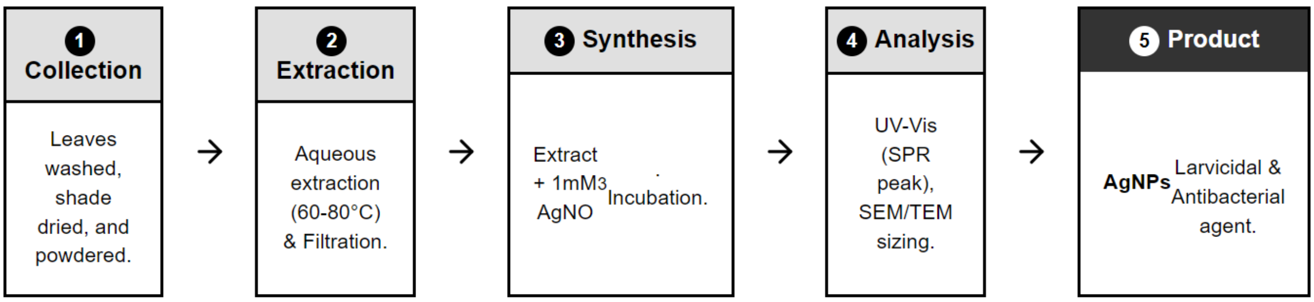

Figure 3. Protocol for the green synthesis of Silver Nanoparticles (AgNPs) utilizing *P. dioica* leaf extract as a reducing agent.

3.2. Larvicidal Potential

Vector-borne diseases such as dengue, malaria, and Zika pose severe public health risks. The control of mosquito vectors through phytochemicals is a promising avenue of research. Secondary metabolites including alkaloids, isoflavonoids, and terpenes found in *P. dioica* have shown remarkable larvicidal capabilities [10]. Essential oils obtained via hydro-distillation of the fruits have demonstrated toxicological effects against the third instar larvae and adult females of *Aedes aegypti*, indicating both larvicidal and adulticidal properties against Zika virus vectors [11].

Further studies on leaf essential oils have reported significant mortality in larvae of *Aedes aegypti*, *Culex quinquefasciatus*, and *Armigeres subalbatus*, with LC50 values of 18.5 ± 1.2 µg/mL, 28.9 ± 1.6 µg/mL, and 55.1 ± 3.1 µg/mL, respectively [12]. Nanotechnology has also been integrated with botanical extracts; silver nanoparticles synthesized using *P. dioica* leaf extract exhibited remarkable anti-larval activity against *A. aegypti*, *Anopheles stephensi*, and *C. quinquefasciatus*, while remaining non-toxic to non-target aquatic species [13]. Additionally, comparative studies have reinforced the efficacy of the essential oil as a substitute for chemical larvicides, with reported LC50 values of 104.4 µg/mL for larvae and 16.6 µg/mg for adult female mosquitoes [14].

Table 3. Agro-biological Efficacy: Larvicidal, Acaricidal, and Nematicidal Activities

Target Pest	Classification	Lethal Concentration / Efficacy	Reference
Aedes aegypti	Dengue Vector	LC50: 38.8 - 58.6 ppm (varies by origin)	[11, 14]
Culex quinquefasciatus	Filariasis Vector	LC50: ~60-70 ppm	[12]
Rhipicephalus microplus	Cattle Tick	100% mortality at concentrations >2.5%	[17, 18]
Reticulitermes speratus	Japanese Termite	High fumigant toxicity; 100% mortality in closed containers.	[19]
Bursaphelenchus xylophilus	Pine Wood Nematode	LC50: 0.609 mg/mL	[22]
Sitophilus spp.	Stored Grain Pest	High contact and fumigant toxicity.	[12]

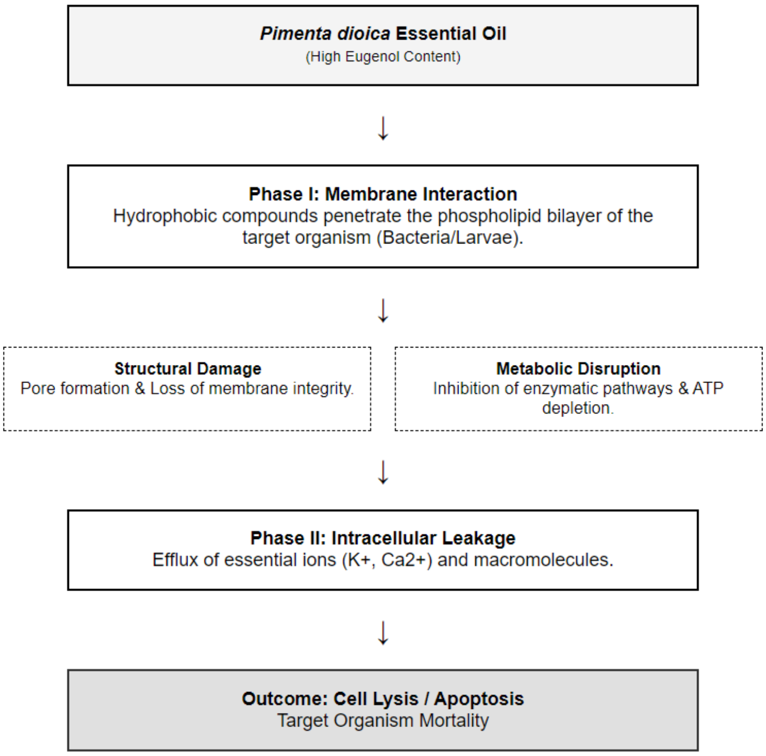

Figure 4. Mechanism of action for the antimicrobial and larvicidal activity of *P. dioica* essential oil.

3.3. Insecticidal Efficacy

The history of botanical insecticides is extensive, yet the need for novel agents is constant due to resistance development. *P. dioica* leaf essential oil has shown dose-dependent insecticidal activity against the cowpea beetle (*Callosobruchus maculatus*), a major storage pest [16]. Veterinary applications are also notable; essential oil from the berries resulted in a 100% mortality rate in *Rhipicephalus microplus* (cattle tick) larvae during in vitro bioassays [17]. Similar efficacy was observed against the Southern cattle tick (*Boophilus* *microplus*), suggesting its potential as an acaricide [18]. In structural pest management, the berry essential oil has demonstrated fumigant toxicity against the Japanese termite (*Reticulitermes speratus*), highlighting its versatility across different insect orders [19].

Table 4. **Characteristics and Applications of Silver Nanoparticles (AgNPs) Synthesized using *Pimenta dioica***

Reducing Agent	Synthesis Conditions	Nanoparticle Characteristics	Application Tested	Reference
Leaf Extract	Ambient temp, Sunlight irradiation	Spherical, 20-50 nm size	High antimicrobial activity.	[13]
Leaf Extract	Heating/Boiling	Polydispersed, 15-60 nm	Larvicidal activity against mosquito vectors.	[13]

3.4. Nematicidal Activity

Plant-parasitic nematodes cause extensive economic losses in global agriculture. Natural compounds such as eugenol and cinnamic acid are potent nematicides [20]. Essential oils from *P. dioica* have shown ovicidal and larvicidal effects against gastrointestinal nematodes (GIN) in ruminants, addressing veterinary parasitic burdens [21]. In the context of plant pathology, the essential oil exhibited an IC50 value of 0.609 mg/ml against the Pine Wood Nematode (*Bursaphelenchus xylophilus*) [22]. Further research by Leela and Ramana [23] isolated eugenol as the primary active principle, confirming that both the crude oil and pure eugenol (at 660 µg/ml) possess significant nematicidal activity against the root-knot nematode *Meloidogyne incognita*.

4. Applications in Aquaculture

The aquaculture industry constantly seeks natural feed additives to improve productivity and disease resistance. Phytogenic additives can enhance nutrient absorption, modulate gut microbiota, and boost innate immunity [24, 25]. *P. dioica* seed meal has been evaluated as a functional feed ingredient for the Mozambique Tilapia (*Oreochromis mossambicus*). Supplementation with the seed powder was found to improve feed utilization efficiency, body weight gain, and disease resistance [26].

Table 5. **Impact of *Pimenta dioica* Supplementation on *Oreochromis mossambicus* (Tilapia)**

Dietary Inclusion Level	Parameter Measured	Outcome	Reference
10 g/kg	Growth Performance	Improved weight gain and specific growth rate.	[27]
10 - 15 g/kg	Immunology	Increased lysozyme activity, respiratory burst, and myeloperoxidase activity.	[26]
5 - 20 g/kg	Stress Response	Mitigated physiological stress markers (Glucose, Cortisol) under acidic pH conditions.	[28]
10 g/kg	Hematology	Prevented decline in RBC counts and Hemoglobin during stress.	[26, 28]

Biochemical analyses have demonstrated that dietary inclusion of *P. dioica* seeds positively modulates serum biochemical parameters and immunological profiles in *O. mossambicus* [27]. Furthermore, under environmental stress conditions, such as acidic pH, fish supplemented with 10 g/kg of *P. dioica* seed meal for 60 days exhibited superior haemato-immunological status compared to controls [28]. These findings suggest that *P. dioica* acts as an effective anti-stress agent and growth promoter in aquaculture systems.

5. Conclusion

Pimenta dioica is an important botanical resource, bridging the gap between traditional ethnomedicine and modern scientific application. Its therapeutic spectrum covers a wide array of human ailments, while its non-therapeutic uses reinforce its economic importance in the culinary and fragrance industries. In the agro-biological domain, the plant serves as a powerhouse of bioactive compounds with proven efficacy against helminthes, mosquito vectors, agricultural pests, and nematodes, offering a sustainable alternative to synthetic pesticides. Additionally, its emergence as a beneficial feed additive in aquaculture underscores its potential to enhance food security through improved fish health and production. Research should prioritize the isolation of novel bioactive molecules, the elucidation of their molecular mechanisms, and the development of standardized formulations to fully exploit the capabilities of this species.

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