Biological Functions of Active Components of *Melaleuca alternifolia* Essential Oil and Their Applications in Agricultural Pest Control

Fengmei YANG[1,2], Ranran NIE[1], Yourong FU[1], Yuyun LIAO[1], Bingkun CHEN[1], Qiwei ZHANG[1], Qianhua JI[1,2*], Yanjun GUO[1,2*]

1. College of Life Sciences, Zhaoqing University, Zhaoqing 526061, China; 2. Institute of Pomology, Zhaoqing University, Zhaoqing 526061, China

Abstract This paper systematically introduces the extraction process of the active components from the essential oil of *Melaleuca alternifolia*, elucidates the biological functions of these active components, and summarizes their applications in agricultural pest control. Furthermore, the paper examines the future developmental directions of *M. alternifolia* essential oil in pest control, along with the current challenges associated with its application. The aim is to offer insights for future research on botanical essential oils, particularly regarding their biological functions and applications in agricultural pest control.

Key words *Melaleuca alternifolia*, Environmentally friendly, Essential oil, Biological function, Agricultural pest control

1 Introduction

The plant *Melaleuca alternifolia* Maiden et Betche, a species belonging to the genus *Melaleuca* within the family Myrtaceae, is indigenous to the southeastern coastal regions of Australia. However, it has been introduced globally, with significant cultivation occurring in China, particularly in Guangdong, Guangxi, and Hainan[1]. The extraction of the branches, leaves, and roots of *M. alternifolia* results in the production of essential oil, which is characterized by both a higher yield and superior quality compared to other tea tree essential oils. Research has demonstrated that this substance possesses a wide range of functions, including broad-spectrum antimicrobial, antibacterial, antioxidant, and antiviral properties. Additionally, it exhibits effective insecticidal activity and offers the advantages of being environmentally friendly and less likely to induce drug resistance in pest control applications[1-2].

2 Extraction process of the active components of *M. alternifolia* essential oil

The essential oil derived from *M. alternifolia* is a natural botanical extract characterized by terpinen-4-ol as its primary active component. This essential oil has diverse applications across various sectors, including personal care, cosmetics, food, pharmaceuticals, and agriculture. As the understanding and application of essential oils derived from *M. alternifolia* increase, and as demand continues to rise, the extraction technologies for these oils are being optimized towards a more natural, environmentally friendly, efficient and safe direction. Table 1 provides a comprehensive summary of the commonly employed methods for the distillation of water vapor, as well as various extraction techniques including pressing, supercritical fluid extraction, molecular distillation, and other methods utilized for the extraction of essential oils from *M. alternifolia*. This table also analyzes the advantages and disadvantages associated with the instrumentation and application scope of these methods, with the objective of offering a valuable reference for research and production in the field of plant essential oils.

3 Biological functions of the active components of *M. alternifolia* essential oil

3.1 Antioxidant effect Plant essential oils exhibit both direct and indirect antioxidant activity, which is primarily influenced by their high phenolic content[9]. *M. alternifolia* essential oil is characterized by a higher concentration of phenolic acids and terpenes, both of which are classified as natural antioxidant compounds. The chemical reaction mechanism involves the phenolic hydroxyl group present in phenolic acids, which can generate phenoxy radicals through a dehydrogenation reaction. These phenoxy radicals exhibit greater stability, thereby facilitating the termination of the reaction. Terpenoids, in contrast, possess unsaturated bonds, making them susceptible to addition reactions[6]. Consequently, they exhibit a high vulnerability to redox reactions with strongly oxidizing agents and function as potent reducing agents[10]. The antioxidant constituents of *M. alternifolia* essential oil include α-terpineol, terpinolene, and γ-terpineol, *etc.* The antioxidant efficacy of these components was evaluated by Kim *et al.*[11], who ranked them from weakest to strongest as follows: γ-terpineol, terpinolene, and α-terpineol. *M. alternifolia* essential oil has been utilized as an antioxidant within the pharmaceutical and cosmetic industries. As research progresses and advancements in science and technology continue, it is anticipated that its application will expand further into agricultural pest control and everyday life.

Received: January 5, 2025 Accepted: February 5, 2025

Supported by Undergraduate Training Programs for Innovation and Entrepreneurship of Guangdong Province (202310580005); Youth Project of Zhaoqing University (QN202443); China Agriculture Research System of MOF and MARA (CARS-26).

Fengmei YANG, master, assistant professor, research fields: orchard ecology. * Corresponding author. Yanjun GUO, master, professor, research fields: horticulture; Qianhua JI, PhD., professor, research fields: pomology.

Table 1 Comparison of extraction processes for *Melaleuca alternifolia* essential oil

Extraction technology	Advantage	Disadvantage	Extraction condition	Active component	Extraction rate	Reference
Distillation of water vapor	Safe, fast extraction, lower extraction cost, less impurities in the final product of *M. alternifolia* essential oil	Requiring heating, low oil production	Heating reflux extraction at 1 ∶ 10, taking upper layer of light yellow oil	Terpinen-4-ol, 1,8-Cineole	1.6%	[3-4]
					2.5%	[5]
			Material-liquid ratio 1 ∶ 20, soaking for 6 h, extracting for 6 h	Terpinen-4-ol, 1,8-Cineole	2.293%	[6]
Pressing method	Flexible production, good oil quality, simple process	Low oil yield, high labor intensity, low productivity	Squeezing the oil out of the plant material with an external force	Terpinen-4-ol, 1,8-Cineole	20.9%	[7]
Ethanol solvent extraction	Retaining the original flavor, high production efficiency	Higher requirements for technical equipment, residual solvents in the finished product	Rotary, stirred, countercurrent and heated reflux extractions	1,8-Cineole, Terpinen-4-ol, α-Terpineol	1.15%	[6]
Supercritical fluid extraction	Safe and green, high extraction efficiency, low impurity rate	Higher technical and equipment requirements, higher costs	Extraction of *M. alternifolia* by supercritical CO_2 technology	Terpinen-4-ol, 1,8-Cineole	Terpinen-4-ol: 47.52% 1,8-Cineole: 2.42%	[7]
Molecular distillation	Addressing adverse reactions associated with high concentrations of 1,8-Cineole, resulting in increased content and improved quality of TTO	Inadequate fluid dispensing devices, liquid flow susceptible to turbulence	Controlling the flow rate of evaporate and residue at approximately 1 ∶ 3	Terpinen-4-ol, 1,8-Cineole	2.37% (wet weight) 1.23% (dry weight)	[8]

3.2 Antimicrobial effect The essential oil derived from *M. alternifolia* is recognized as one of the most potent natural antimicrobial agents identified to date[12]. It is frequently employed in the treatment of various conditions, including wounds, burns, abrasions, and acne, and is incorporated into products such as antiseptics, shampoos, and soaps. It is recognized as one of the most potent stimulants of the immune system, effectively addressing a wide range of viral, bacterial, and fungal infections. Additionally, it has demonstrated efficacy in promoting the healing of wounds and acne. It exhibits broad-spectrum fungicidal and antimicrobial properties. The research conducted by Niu[6] demonstrated that *M. alternifolia* essential oil, in conjunction with the Main Camp brand tea tree essential oil, exhibited inhibitory effects against Gram-positive bacteria (*Staphylococcus aureus*, *S. albus*), Gram-negative bacteria (*Escherichia coli*, *Pseudomonas aeruginosa*), and fungi (*Candida albicans*). Valente *et al.*[13] demonstrated that both the free oil and the nanoemulsion exhibited antifungal activity against *Pythium insidiosum* in Brazil, with significant inhibition observed against *Cryptococcus* sp. Research indicates that *M. alternifolia* essential oil may serve as a complementary therapy in the treatment of sepsis; however, additional studies are required to validate its appropriateness for clinical use. While investigating the inhibitory effects of essential oil extracted from *M. alternifolia*, clotrimazole, and chlorhexidine on *Candida albicans*, Lakshminarayan *et al.*[14] compared the efficacy of the mouthwashes containing 1% clotrimazole, 0.2% chlorhexidine, and 1% *M. alternifolia* essential oil against *C. albicans*. The study revealed that the inhibition zones for both *M. alternifolia* essential oil and chlorhexidine increased with the volume of the agents administered, indicating that both exhibited significant antifungal activity. Vito *et al.*[15] conducted a study examining the efficacy of probiotics and *M. alternifolia* essential oil in the treatment of vaginal candidiasis. Their findings indicated that the essential oil exhibited fungicidal activity *in vitro*. Di *et al.*[16] also discovered that guided suppositories formulated with *M. alternifolia* essential oil may be effective in the treatment of vaginal bacterial infections and candidiasis. In 2019, Niu[6] demonstrated that *M. alternifolia* essential oil possesses the capability to inhibit and eliminate the formation of biofilms by *S. aureus*. This effect is attributed to significant damage to the integrity of the bacterial cell membrane, resulting in increased membrane permeability. Consequently, this leads to cell lysis and the subsequent leakage of cellular contents, ultimately resulting in the death of the bacterial cells.

In conclusion, *M. alternifolia* essential oil exhibits significant bactericidal properties and may serve as a primary component in pharmacological formulations administered via subcutaneous or intramuscular injection for the treatment of infections caused by *S. aureus*. Additionally, it has potential therapeutic applications for managing nausea and ulcers associated with tumor rupture[17]. Furthermore, this essential oil is recognized as a safe natural antimicrobial agent, warranting further investigation and development for broader applications.

3.3 Antiviral effect There is a limited number of studies investigating the antiviral activity of *M. alternifolia* essential oil. The

existing literature contains only a few reports regarding the susceptibility of herpes simplex virus to this essential oil[18-19], as well as its efficacy in the treatment of recurrent herpes labialis[20]. While investigating the experimental observation of poliovirus inactivation by *M. alternifolia* essential oil, Wang *et al.*[21] employed a cellular infection assay to assess the titre of infected cells both prior to and following the exposure of the virus to various concentrations of the essential oil solution. Their findings indicated a significant cytotoxic effect of the essential oil on the poliovirus in suspension. The successful incorporation of *M. alternifolia* essential oil into a range of antiviral products holds significant importance in the fields of drug discovery and development.

3.4 Antiseptic effect The essential oil derived from *M. alternifolia* is a widely utilized medicinal essential oil in Australia, recognized for its efficacy in treating bruises, insect bites, and skin infections. In the 1920s, it was reclassified as a more effective topical antiseptic agent compared to phenol. Budhiraja *et al.*[22] investigated the bioactive components of both crude and purified essential oils through the induction of leukocyte differentiation. Their findings suggest that the antiseptic activity of *M. alternifolia* essential oil is, in part, attributable to the activation of leukocytes[23]. Furthermore, an investigation into the antimicrobial and antiseptic properties of *M. alternifolia* essential oil and *Thymus vulgaris* essential oil against seven species of fungi revealed that these essential oils are effective agents for the prevention and control of mycelium-borne diseases. The findings suggest that they may serve as viable alternatives to conventional chemical fungicidal preservatives, offering a safer and more environmentally friendly option.

3.5 Preservation In recent years, *M. alternifolia* essential oil has increasingly been utilized in the domain of post-harvest fruit preservation to inhibit the post-harvest proliferation of pathogenic fungi[24-25]. Fungi represent the most significant pathogens responsible for fruit rot. Currently, numerous studies, both domestic and international, have been conducted on the efficacy of *M. alternifolia* essential oil in inhibiting pathogenic fungi affecting fruits and vegetables. Notably, these studies have yielded significant results, particularly in the preservation of fruits and the prevention and control of diseases in bananas and other crops[26-27]. Zhu *et al.*[28] demonstrated that *M. alternifolia* essential oil significantly inhibited the growth of anthracnose mycelium in plantain. Furthermore, it altered the internal structure of the conidia of the pathogen, thereby effectively inhibiting spore germination. The inhibitory effect was found to be most pronounced at a concentration of 0.05% (*v/v*). Szczerbanik[29] demonstrated that *M. alternifolia* essential oil exhibited a more pronounced inhibitory effect on the growth of various fungi, including *Botrytis cinerea*, *Rhizopus*, *Colletotrichum gloeosporioides*, and *Fusarium oxysporum*. Yu *et al.*[30] conducted a study examining the impact of various fruit preservation treatments on fruit quality, disease control, and the associated advantages and disadvantages of their commercial applications. The findings indicated that the preservation effect of *M. alternifolia* essential oil was evident not only in its direct destructive effects on the morphology, ultrastructure, and cellular metabolism of postharvest pathogenic fungi but also in its ability to indirectly enhance the fruit's disease resistance mechanisms. Shao *et al.*[31] determined the optimal processing conditions for the preservation of strawberries through fumigation treatment utilizing *M. alternifolia* essential oil, employing a one-way test method. Similarly, Zhai *et al.*[32] applied a solution containing 82.95 g/L of aqueous acrylic acid in conjunction with 0.65 mL/L of *M. alternifolia* essential oil for continuous spraying over a duration of 10.2 min. This treatment was found to be effective in extending the ornamental lifespan of peony cut flowers, reducing the rate of water loss, and minimizing the shrinkage rate of flower diameter.

Currently, there is a lack of comprehensive systematic research on the mechanisms underlying the bacteriostasis and preservation of *M. alternifolia* essential oil. This essential oil comprises a diverse array of components that interact in complex ways. The prevailing perspective suggests that it functions as a membrane-disrupting agent. By compromising the structural integrity of cellular membranes, it induces the leakage of intracellular substances within fungal cells, thereby stimulating autolysis and resulting in alterations in cellular morphology. Other scholars contend that *M. alternifolia* essential oil serves as a natural broad-spectrum antibacterial agent, exhibiting potent antioxidant properties. This oil has the potential to significantly prolong the storage and preservation periods of fruits and vegetables. *M. alternifolia* essential oil holds considerable value in the preservation of these perishable items, and as research in this area deepens, its antifungal preservation effects are expected to be further substantiated.

4 Applications of the active components of *M. alternifolia* essential oil in agricultural pest control

The plant *M. alternifolia* possesses significant potential for agricultural pest management and plays a crucial role in the advancement of sustainable agricultural practices. The volatile components of *M. alternifolia* essential oil were analyzed using gas chromatography-mass spectrometry (GC-MS), and the relative content of each component was determined through peak area normalization. A total of ten primary components were identified, specifically α-pinene, sabinene, α-terpinene, p-cymene, limonene, 1,8-cineole, γ-terpinene, terpinolene, terpinen-4-ol, and α-terpineol. The quantitative analysis indicated that the predominant components of *M. alternifolia* essential oil are primarily terpenoids, with the content of terpinen-4-ol reaching as high as 40.09%[33-36]. A substantial body of research indicates that the active components exhibit significant inhibitory, repellent, and contact toxicity effects on agricultural pests.

4.1 Inhibitory effect The essential oil derived from *M. alternifolia* exhibits considerable inhibitory effects on agricultural pests. Several studies have demonstrated that this essential oil ef-

fectively controls a diverse array of agricultural pests, including aphids, leafhoppers, and mites. The mechanisms of action are believed to involve interference with the olfactory senses of the insects, as well as impacts on their digestive and respiratory systems[2].

Liao *et al.*[37] demonstrated that *M. alternifolia* essential oil significantly inhibited the activities of three enzymes in *Sitophilus zeamais*. These enzymes include two detoxification enzymes: glutathione S-transferase (GST) and carboxylesterase (CarE), as well as acetylcholinesterase (AChE), which is a neurotransmitter enzyme. Paulo *et al.*[38] conducted a study on the insecticidal and antifeedant properties of *M. alternifolia* essential oil against *Ascia monuste orseis*. Their findings indicated that the essential oil elicited an antifeedant response and significantly inhibited fecal production until mortality occurred in *A. monuste orseis*. Furthermore, the adverse effects observed were found to increase linearly with the concentration of the essential oil.

4.2 Repellent effect As an aromatic plant, *M. alternifolia* possesses distinctive odors and biological activities capable of effectively repelling agricultural pests and safeguarding crops from infestations. The sesquiterpenes and esters present in its essential oil exhibit a potent repellent effect on pests, thereby facilitating pest control by influencing their sensory perception and behavioral responses. Liao[33] investigated the repellent effects of *M. alternifolia* essential oil on the pests *S. zeamais* and *Tribolium castaneum*. The study revealed that the essential oil exhibited a certain degree of repellent efficacy against both species; however, it was observed that the repellent effect diminished over time. Additionally, Zhang *et al.*[36] assessed the repellent activity of *M. alternifolia* against *T. castaneum* utilizing the grey correlation degree method. Their findings indicated that the repellent activity of the principal component, (-)-terpinen-4-ol, was more potent than that of γ-terpinene and 1,8-eucalyptol.

4.3 Contact toxicity The essential oil derived from *M. alternifolia* contains active components that exhibit permeability and diffusibility, allowing for rapid penetration into the bodies of pests. This interference with the normal physiological functions of the pests ultimately leads to their mortality. Liao[33] demonstrated that, under consistent time conditions, the contact toxicity of *M. alternifolia* essential oil against *S. zeamais* and *T. castaneum* significantly increased with higher treatment concentrations. Additionally, Zhang *et al.*[36] reported that γ-terpinene, the principal component of *M. alternifolia* essential oil, exhibited the most pronounced contact toxicity against *T. castaneum*, surpassing the effects of 1,8-eucalyptol and (-)-terpene-4-ol. This study further confirmed the contact toxicity of this essential oil on *T. castaneum*. Alimi *et al.*[39] demonstrated that *M. alternifolia* essential oil exhibited significant contact toxicity against both adults and larvae of *Hyalomma scupense*. Additionally, Chohan[2] investigated the biological activity of *M. alternifolia* essential oil and its primary components against peach aphids. The study revealed that the contact toxicity of the essential oil could reach as high as 92.58% following a 72 h exposure of the aphids to a concentration of 4 g/L of the essential oil.

5 Conclusions

Currently, *M. alternifolia* essential oil demonstrates promising potential in antibacterial, antiviral, and antioxidant applications, and it has been extensively utilized across various industries on a global scale. However, domestic research on *M. alternifolia* remains relatively superficial, and several issues persist. Firstly, *M. alternifolia* is cultivated in limited quantities in China and has not been effectively promoted or utilized. Given that over 90% of *M. alternifolia* is found in Australia, the process of introduction is complex. Additionally, the relatively outdated methods of essential oil extraction contribute to higher production costs. Secondly, *M. alternifolia* essential oil exhibits varying components based on their geographical origin. These compositional differences, influenced by the distinct environmental conditions of each region, subsequently impact their pharmacological and insecticidal properties. The components and their relative concentrations in *M. alternifolia* essential oil differ both domestically and internationally due to variations in cultivation practices. Consequently, the absence of a standardized quality benchmark poses challenges for the development and utilization of the essential oil, significantly impeding research and development efforts related to essential oils in China. In contemporary agricultural practices, the issue of excessive use of chemical pesticides has become increasingly significant. In the context of promoting green agriculture, *M. alternifolia* essential oil has garnered attention due to its efficacy in pest control and its environmental protection benefits. There is optimism regarding the future application of more advanced essential oil extraction technologies and related products from *M. alternifolia* in the management of agricultural pests. This advancement is anticipated to contribute to the sustainable development of agriculture, as well as to enhance the yield and quality of agricultural products.

References

[1] ZHONG ZS, FAN LF, HUANG JB. Chemical components and antimicrobial activity of tea tree oil from introduced *Melaleuca alternifolia*[J]. Journal of South China University of Technology (Natural Science Edition), 2011, 39(1): 53-57. (in Chinese).

[2] CHOHAN AT. Insecticidal activity of *Melaleuca alternifolia* essential oil against *Myzus persicae*[D]. Hefei: Anhui Agricultural University, 2019. (in Chinese).

[3] LI BX, ZHANG L. Extraction of tea tree essential oil and its activity against methicillin-resistant *Staphylococcus aureus* (MRSA)[J]. Shandong Journal of Animal Science and Veterinary Medicine, 2021, 42(6): 11-13. (in Chinese).

[4] NIU B, LIANG JP, QIN WW, *et al.* Establishment of detection methods for 1,8-cineole and terpinen-4-ol in tea tree essential oil preparation[J]. Progress in Veterinary Medicine, 2019, 40(4): 69-75. (in Chinese)

[5] SONG JM, WU JM, ZHU ZH, *et al.* Advances in studies on essential oils of *Melaleuca alternifolia*[J]. Journal of Anhui University (Natural Sci-

ence Edition), 2019, 43(6): 85 – 91. (in Chinese).
[6] NIU B. Development of tea tree essential oil disinfectant and study on its sterilization mechanism[D]. Beijing: Chinese Academy of Agricultural Sciences, 2019. (in Chinese).
[7] ZHONG YS, CHENG WJ, LI QY, *et al.* Extraction of plant essential oils and their application in poultry production[J]. China Feed, 2024, (9): 9 – 14. (in Chinese).
[8] HUYNH Q, PHAN TD, THIEU VQQ, *et al.* Extraction and refining of essential oil from Australian tea tree, *Melaleuca alternifolia*, and the antimicrobial activity in cosmetic products[J]. Journal of Physics: Conference Series, 2012, 352(1): 374 – 379.
[9] WEN PF, PENG Y. Research advances on antioxidant mechanism of plant essential oil[J]. Feed Industry, 2017, 38(2): 40 – 45. (in Chinese).
[10] SINGH HP, MITTAL S, KAUR S, *et al.* Chemical composition and antioxidant activity of essential oil from residues of *Artemisia scoparia*[J]. Food Chemistry, 2009, 114(2): 642 – 645.
[11] HYUN-JIN K, FENG C, CHANGQING W, *et al.* Evaluation of antioxidant activity of Australian tea tree (*Melaleuca alternifolia*) oil and its components[J]. Journal of Agricultural and Food Chemistry, 2004, 52 (10): 2849 – 2854.
[12] CARSON CF, HAMMER KA, RILEY TV. *Melaleuca alternifolia* (tea tree) oil: A review of antimicrobial and other medicinal properties[J]. Clinical Microbiology Reviews, 2006, 19(1): 50 – 62.
[13] VALENTE JDS, FONSECA ADD, BRASIL CL, *et al.* *In vitro* activity of *Melaleuca alternifolia* (tea tree) in its free oil and nanoemulsion formulations against *Pythium insidiosum*[J]. Mycopathologia, 2016, 181(11 – 12): 865 – 869.
[14] LAKSHMINARAYAN N, WADGAVE U. Efficacy of clotrimazole, chlorhexidine, and tea tree oil against *Candida albicans*: An *in vitro* study [J]. Journal of Dental Sciences and Oral Rehabilitation, 2016, 7(2): 53 – 56.
[15] VITO MD, FRACCHIOLLA G, MATTARELLI P, *et al.* Probiotic and tea tree oil treatments improve therapy of vaginal candidiasis: A preliminary clinical study[J]. Medical Journal of Obstetrics and Gynecology, 2016, 4(4): 1090 – 1096.
[16] DI VM, MATTARELLI P, MODESTO M, *et al.* *In vitro* activity of tea tree oil vaginal suppositories against *Candida* spp. and probiotic vaginal microbiota[J]. Phytotherapy Research, 2015, 29(10): 1628 – 1633.
[17] SATCHELL AC, SAURAJEN A, BELL C, *et al.* Treatment of dandruff with 5% tea tree oil shampoo[J]. Journal of the American Academy of Dermatology, 2002, 47(6): 852.
[18] SCHNITZLER P, SCHÖN K, REICHLING J. Antiviral activity of Australian tea tree oil and eucalyptus oil against herpes simplex virus in cell culture[J]. Pharmazie, 2001, 56(4): 343 – 347.
[19] MINAMI M, KITA M, NAKAYA T, *et al.* The inhibitory effect of essential oils on herpes simplex virus type-1 replication *in vitro*[J]. Microbiology & Immunology, 2003, 47(9): 681 – 684.
[20] CARSON CF, ASHTON L, DRY L, *et al.* *Melaleuca alternifolia* (tea tree) oil gel (6%) for the treatment of recurrent herpes labialis[J]. Journal of Antimicrobial Chemotherapy, 2001, 48(3): 450 – 451.
[21] WANG Y, WANG ZW. Experimental observation on the inactivation of poliovirus by tea tree oil[J]. Journal of Third Military Medical University, 2004, (13): 1169 – 1170. (in Chinese).
[22] BUDHIRAJA SS, CULLUM ME, SIOUTIS SS, *et al.* Biological activity of *Melaleuca alternifolia* (tea tree) oil component, terpinen-4-ol, in human myelocytic cell line HL-60[J]. Journal of Manipulative & Physiological Therapeutics, 1999, 22(7): 447 – 453.
[23] RICCIONI L, ORZALI L. Activity of tea tree (*Melaleuca alternifolia*, Cheel) and thyme (*Thymus vulgaris*, Linnaeus.) essential oils against some pathogenic seed borne fungi[J]. Journal of Essential Oil Research, 2012, 23(6): 43 – 47.
[24] SZCZERBANIK M, JOBLING J, MORRIS S, *et al.* Essential oil vapours control some common postharvest fungal pathogens[J]. Australian Journal of Experimental Agriculture, 2007, 47(1): 103 – 109.
[25] CHENG S, SHAO XF. *In vivo* antifungal activities of the tea tree oil vapor against *Botrytis cinerea*[C]//2011 International Conference on New Technology of Agricultural Engineering, America: Scientific Research Publishing, 2011: 949 – 951.
[26] ZHONG YJ, LIU W, LIU CM, *et al.* Application of emulsified tea tree oil in banana preservation under natural conditions[J]. Transactions of the Chinese Society of Agricultural Engineering, 2009, 25(6): 280 – 284. (in Chinese).
[27] JING W, SU ZP, ZHU DM, *et al.* Effects of tea tree oil fumigation on postharvest anthracnose disease of bananas[J]. Transactions of the Chinese Society of Agricultural Engineering, 2011, 27(5): 378 – 384. (in Chinese).
[28] ZHU DM, DING L, KUANG Y, *et al.* Inhibitory activity of tea tree oil on mycelial growth and spore germination of *Colletotrichum musae*[J]. Food Research and Development, 2008, 29(6): 134 – 137. (in Chinese).
[29] SZCZERBANIK M, JOBLING J, MORRIS S, *et al.* Essential oil vapours control some common postharvest fungal pathogens[J]. Animal Production Science, 2007, 47(1): 103 – 109.
[30] YU DD, SHAO XF, XU F, *et al.* Research progress on the role and mechanism of tea tree essential oil in postharvest fruit preservation[J]. Journal of Fruit Science, 2014, 31(2): 313 – 319. (in Chinese).
[31] SHAO XF, CHENG S, WANG HF, *et al.* Optimization of tea tree essential oil fumigation for strawberry preservation[J]. Transactions of the Chinese Society of Agricultural Engineering, 2012, 28(19): 279 – 286. (in Chinese).
[32] ZHAI FF, ZHU WX, YU B, *et al.* Effects of water-based acrylic resin and tea tree essential oil spray treatment on the ornamental quality of peony cut flowers[J]. Acta Horticulturae Sinica, 2016, 43(4): 796 – 806. (in Chinese).
[33] LIAO M. Insecticidal activity and mechanism of *Melaleuca alternifolia* essential oil against stored grain pests[D]. Hefei: Anhui Agricultural University, 2017. (in Chinese).
[34] ZHANG CE. Inhibitory effect and preservation effect of *Melaleuca alternifolia* essential oil on three pathogenic bacteria of Kyoho grape[D]. Changsha: Central South University of Forestry and Technology, 2023. (in Chinese).
[35] CHEN YX, ZHENG MJ, ZHAN HD, *et al.* Research progress on extraction and application of *Melaleuca alternifolia* essential oil[J]. Yunnan Chemical Technology, 2021, 48(12): 8 – 11. (in Chinese).
[36] ZHANG K, CUI YF. Chemical composition and antitumor and insecticidal bioactivities of essential oil from *Melaleuca alternifolia*[J]. Journal of Shenyang Medical College, 2022, 24(6): 571 – 577. (in Chinese).
[37] LIAO M, XIAO JJ, ZHOU LJ, *et al.* Insecticidal activity of *Melaleuca alternifolia* essential oil and RNA-Seq analysis of *Sitophilus zeamais* transcriptome in response to oil fumigation[J]. PLoS ONE, 2017, 11(12): e0167748.
[38] SILVA DHP, PRADO PE, FERREIRA-FILHO JP, *et al.* Insecticidal and antifeedant bioactivities of *Melaleuca alternifolia* essential oil on *Ascia monuste orseis*[J]. Revista Colombiana de Entomología, 2023, 49 (2): 1 – 6.
[39] ALIMI D, TRABELSI N, HAJRI A, *et al.* Laboratory assessment of the acaricidal, repellent and anti-cholinesterase effects of *Melaleuca alternifolia* and *Chamaemelum nobile* essential oils against *Hyalomma scupense* ticks[J]. Veterinary Research Communications, 2024, 48(3): 1379 – 1391.