Mini review
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Application of cinnamaldehyde for the postharvest storage of fresh horticultural products

Abstract

Transition from hunting and gathering to agriculture is the main cause of civilization. Humans have some basic needs including light, air, water, shelter and as well as food to survive. Horticultural products provide energy, proteins, vitamins and essential minerals for human. The postharvest losses of horticultural products are very high and the rates of losses significantly depend on the type of products and postharvest handling practices. Since the acceptability of the synthetic agrochemicals had been decreasing due to their scientifically confirmed negative impacts on human and environment health, it is required to find some safer alternatives. Essential oils are among the most tested and well known biomaterials providing beneficial effects on the storability of horticultural products. Herein, we aimed to highlight the importance and mechanism of cinnamaldehyde, the major organic compound of cinnamon essential oil (*Cinnamomun zeylanicum* L.) on the prevention for the postharvest storage of fresh horticultural produce.

Keywords: cinnamaldehyde, postharvest storage, horticultural products

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Introduction

Horticultural products are the crucial sources of energy (carbohydrates), proteins, vitamins and essential minerals for human nutrition. Freshly harvested horticultural produce are alive; and they continue to do respiration & subject to continuous changes after harvest. This cause senescence and deterioration of the fresh produce, which results with quality and quantity loss. The estimated loss of fresh horticultural produce after harvest is more than 30% on the world.[1] To reduce the postharvest losses, it is utmost important to understand the biotic and abiotic factors involved in product deterioration, which significantly vary among the products. In general, postharvest handling practices involve cold storage, enhancement of bioactive compounds, blocking of ethylene biosynthesis, controlling atmospheric gaseous composition and fumigation & sanitation against microbial decay.[2,3] However, the acceptability of the synthetic agrochemicals had been decreasing due to their scientifically confirmed negative impacts on human and environment health.[4,5] This led the studies on safer alternatives, including plant essential oils and the valuable results of those studies suggested that the essential oils of different plants have significant influence on postharvest storability of fresh produce.[6–8]

Cinnamon essential oil is one of the important plant essential oils, which alone or in combination with other plant-derived products, has significant benefits on the storability of fresh horticultural products,[9–11] including the prevention of microbial decay.[12] Cinnamaldehyde (C6H5CH=CHCHO), the major organic compound of cinnamon essential oil (*Cinnamomun zeylanicum* L.). It is naturally synthesized by the shikimate pathway and gives the flavour and odour to cinnamon.[13] The major effects of cinnamaldehyde on fungi has been reported to be inhibition of cell division and chitin synthase.[14] It was also reported to act as an ATPase inhibitor and disturb the cell membrane.[15] Therefore, this review paper examined the application of cinnamaldehyde for the postharvest storage of fresh horticultural produce.

Antifungal effects of cinnamaldehyde

Cinnamaldehyde has been reported to have a wide spectrum antifungal efficacy in inhibiting the growth and development of funguses.[16–19] In such studies, Utama et al.[20] noted that the cinnamaldehyde inhibits the growth of *Penicillium digitatum*, *Rhizopus stolonifera*, and *Colletotrichum musae* with the doses of 0.09-0.42 mmol dish^{-1}. In an elder study by Smid et al.[21] it was noted that cinnamaldehyde is a very potent fungicidal agent, where the reduction of the fungal population in the tulip bulds was reduced about 40 times when was treated with 515 mg/l cinnamaldehyde.

Similarly Sivakumar et al.[22] reported that the control of pathogenic fungi at the rambutan (*Nephelium lappaceum* L.) fruits is difficult with the fungicides due to high residue risks. Thus, they performed biological studies with cinnamaldehyde and reported that the cinnamaldehyde (30 ppm) provides 100% inhibition of the mycelial growth of *Botryodiplodia theobromae* and *Gliocephalotrichum microchlamydosporum*. Duan et al.[18] studied the effects of incorporated application of cinnamaldehyde with wax on *P. digitatum* at Ponkan fruits. They reported that the cinnamaldehyde application significantly reduced the mycelial growth of *P. digitatum*. The continued studies of Duat et al.[18] revealed that the success of the cinnamaldehyde in prenvetion of the mycelial growth of *P. digitatum* can be due to the increased activities of catalase, superoxide dismutase and peroxidase enzymes or by the increased concentrations of total phenols and flavonoids.

A recently published study by Gan et al.[23] studid the antifulgan activity of different derivaties of cinnamaldehyde *P. digitatum* and among the multiple derivatives, the 4-methoxy cinnamaldehyde was reported to show very good antifungal activity. It was noted to damage fungal cell membrane which then reduced the spore germination and growth. In another study Guo et al.[24] tested the 21 different volatile organic compounds of Hanseniaspora uvarum to find out the main compound responsible from the control of Botrytis cinerea which is an important pathogen of cherry tomatoes. They noted that the trans-cinnamaldehyde (at the concentration of 62.5 μL L−1) has the highest ability to inhibit mycelium growth among the tested volatile compounds. Studies of Huang et al.[25] are valuable where the researchers tried to define the antifungal mechanism of the cinnamaldehyde. They noted that the trans-cinnamaldehyde changed the cell wal and cell membrane permeability and integrity of Penicillium italicum, which led to the leakage of some materials. It was also noted that the increase in the dosage of trans-cinnamaldehyde cause an increase in the ROS production. Cinnamaldehyde was also found to damage the cell membrane of Alternaria alternata.[26]

Effects of cinnamaldehyde on products' quality

Application of cinnamaldehyde was reported to reduce respiration rate of fresh-cut melon, which helps to maintain storage quality of fruits.[27] This reduces the oxidization which helps preserving the concentration of different bioactive compounds. The cinnamaldehyde also has high antioxidant potential, which contributes to oxidative stress resistance.[28] The studies of Carvalho et al.[27] also recommended that the cinnamaldehyde prevents cell membrane rupture which results with an increase in the sensory quality of the fresh-cut products. In another study with fresh-cut lettuce by Fujita et al.[29] suggested that the application of trans-cinnamaldehyde inhibits the phenylalanine ammonia-lyase (PAL) activity and reduces the browning of the fresh cut lettuce. This was then confirmed by Tanaka et al.[30] Results of these valuable studies suggested that the cinnamaldehyde is effective in reducing the weight loss, protecting sensory quality and fruit firmness, preventing the changes in flavour (soluble solids concentration and titratable acidity) and maintaining fruit colour.

Incorporation of cinnamaldehyde into other biomaterials

It is known that the combination of the substances with antifungal activity might enhance the overall fungitoxic potency.[31,32] Besides to the single application of cinnamaldehyde, its incorporation into other biomaterials was also noted to have significant influence on the storability of different products. In one of these newest studies, Istúriz-Zapata et al.[12] reported that the combination of cinnamaldehyde with chitosan provided better performance in preventing weight loss, reducing respiration, reducing ethylene production and reducing microbial decay as compared with the single chitosan application. In another study, it was noted that the combination of cinnamaldehyde with citronellal (5:16 v/v) provided higher antifungal activity against *Penicillium digitatum* than the single application of cinnamaldehyde.[33] A deeper microbiological study was conducted by Wang et al.[34] to understand the mechanism behind the combined efficacy of cinnamaldehyde and citral on the growth of *Penicillium expansum*, one of the main postharvest pathogens of fruits. They analyzed the whole gene expression profile of *P. expansum* and explored the molecular mechanism. They noted the combination of cinnamaldehyde and citral induced the dysfunction of the mitochondrial membrane and increased in the production of reactive oxidative species (ROS). This then reported to cause an oxidative stress on *P. expansum* (which resulted with an increased in SOD and CAT activities). Similar results were also reported for kiwifruits (*Actinida deliciosa* var. Qinmei) treated with the combination of cinnamaldehyde with citral again. It was noted that the treatments reduce the yeast and mold and increased the antioxidant activity of fruits. The treatment was found to slow the reduction speed of ascorbic acid, while decreasing the production of malondialdehyde (MDA) and hydrogen peroxide (H_2O_2).

At molecular basis, researchers determined which genes are down-/up-regulated by the combined application of the cinnamaldehyde and citral. Studies of Guo et al.[35] also noted that the incorporation of cinnamaldehyde with the carboxymethylcellulose-based film packaging helps to maintain the storage quality of cherry tomatoes by suppressing some metabolic activities including respiration and transpiration. Another incorporation study by Li et al.[32] suggested that the combination of cinnamaldehyce with soybean protein isolate and zinc oxide provides better quality and shelf life retention for bananas. Researchers noted that the combination prevents the weight loss, carbohydrate hydrolysis and pectin conversion.

Conclusion

This review clearly showed that the cinnamaldehyde has high antifungal activity. The discussion of the published literature showed that the main mechanisms behind this antifungal activity are: i) inhibition of cell division of funguses, ii) disturbing the cell membrane of funguses, iii) increasing the production of ROS in funguses, iv) increasing the activities of catalase, superoxide dismutase and peroxidase enzymes in horticultural produce, and v) increasing the concentrations of total phenols and flavonoids at the horticultural produce. Besides to that, application of cinnamaldehyde also significantly reduce the respiration rate at the horticultural produce which helps to maintain postharvest quality of fresh produce. Examine of existing information also showed that the synergism effect of cinnamaldehyde with other biomaterials is valuable and provides better performance. Review of existing information made it possible to do some recommendations for further studies. In line with that, it is crucial to say that the incorporation of cinnamaldehyde into edible films and coatings would improve the materials' efficacy.

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Conflicts of interest

The authors declare no conflict of interest.

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