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Review

A review on the use of essential oils for postharvest decay control and maintenance of fruit quality during storage

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ABSTRACT

Postharvest diseases are one of the major causes for the postharvest loss of horticultural fresh produce during the supply chain. The incidence of postharvest diseases can affect the quality and restrict the shelf life of the horticultural fresh produce. At present strict regulations are enforced by the fresh produce importing countries regarding the minimum pesticide residue levels in the edible portion of the fresh produce. Some fungal pathogens were reported to develop resistance to synthetic fungicides. Waste disposal of fungicides has an impact on environmental footprint. All theses above-mentioned reasons have necessitated the search for a natural novel fungicide to replace the synthetic fungicide application in the packing line as postharvest treatment.

Consumer preference to organic fresh produce is increasingly becoming popular in the developed countries. Therefore, this review summarises the use of essential oils in the control of postharvest diseases of horticultural commodities, their mode of actions, effects on the defence mechanism and quality of fresh fruit. Future research must be focused on conducting large scale trials to prove the feasibility of combination treatments. The cost benefit analysis of the treatments needs to be carried out in order to implement their application and the commercial applications of essential oils and host pathogen infection must be investigated in detail in order to control latent infections during postharvest storage.

1. Introduction

Fruit and vegetables are rich in essential vitamins, minerals, fibre, and health promoting compounds, and the consumption thereof has increased during the past years. Consumers have a right to good quality produce that is safe for consumption and therefore they are increasingly interested in the nutritional value, good taste and flavour of the fruit and vegetables they consume. According to consumers, the term “quality” can be defined as a fruit with a perfect shape, size, colour, aroma, and an absence of defects such as cuts, bruises or decay. The latter is also not safe for consumption. An increasing population has created greater demand for fruit and vegetable consumption resulting in a greater demand for crop production and necessitating marketing to the domestic as well as the overseas markets.

Postharvest decay during the supply chain has been identified as a major factor causing postharvest loss which could result in significant economic loss, especially in the fruit marketing chain (Prusky, 2011). Incidences of postharvest diseases may occur during the different stages of the postharvest chain; during harvesting, field handling, packing operations, transportation and storage. For example, postharvest decay in citrus fruit caused by green mould (*Penicillum digitatum*) and blue mould (*Penicillum italicum*) leads to significant economic losses during export.

On the other hand, certain fungal infections in fruit caused by certain strains of Penicillium spp., Alternaria spp. and Fusarium spp. could produce mycotoxins under specific conditions. Incidence of mycotoxin production increases when an infected fruit is used in processing. Mycotoxin contamination occurrence is thus regarded as a critical risk factor, to the extent that reports of the Food and Agricultural Organization (FAO, 2004) indicate that 25% of the global commodities are affected by mycotoxins every year (Schatzmayr et al., 2006). *Penicillium expansum* (blue mould disease) causes significant spoilage in pears and apples, amongst others, during their long-term storage, even at low temperatures such as −1 °C or 0 °C. *P. expansum* infections in apples and pears are also becoming a health hazard-related issue due to their production of patulin (Neri et al., 2010). The European Commission (EC) has

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introduced a separate limit of 10 mg kg^{-1} patulin for different apple products and a limit of 10–50 μg kg^{-1} has been regulated in the EU for fruit juices and fruit-based products (Commission Regulation, EC No. 1881/2006).

Incidences of postharvest decay in fruit and vegetables depend on the type of commodity and cultivar, maturity at harvest and ripening stage, storage and transportation conditions, and retailer shelf conditions. Postharvest pathogens could infect the fruit after harvesting (wound infections) or while the fruit is still attached to the mother plant in the field. Some diseases such as anthracnose caused by *Colletotrichum gloeosporioides* (mango, papaya and avocado) or *Colletotrichum musae* (banana) show symptoms after ripening and these types of infections are known as quiescent infections (Snowden, 1990). Grey mould rot (*Botrytis cinerea*) in strawberries is also a quiescent infection that causes significant postharvest damage during storage (Moorman, 2014). Stem-end rot in citrus caused by *Lasiodiplodia theobromae* and *Phomopsis citri* are quiescent infections at the stem end region of the fruit (Snowden, 1990).

Postharvest diseases such as brown rot (Monilinia spp.) in peaches and other stone fruits (Ogawa and English, 1991) infect the fruit just before harvesting; in other words, the symptom may not yet have developed at the preharvest stage but may become more prominent during postharvest storage. Traditionally, postharvest decay control is initiated in the field, thus farmers must implement good orchard sanitation procedures. At the same time, proper postharvest handling practices must be adhered to in order to prevent cuts and bruises to fruit surfaces. Fruit exhibiting signs of postharvest disease symptoms should not be packed into cartons with healthy fruit and if initial symptoms are detected on the fruit, they should be removed from the cartons. Generally, depending on the disease postharvest control is achieved with an application of preharvest fungicide treatment and after harvesting, a postharvest dip or drench treatment is applied to the fruit. The fungicide, guazatine, is commonly used as a prestorage drench treatment to control sour rot (*Geotrichum candidum*) in citrus fruit during the wet seasons, but it is not registered in the EU (European Food Safety Authority EFSA, 2013).

Furthermore, on the one hand consumers prefer purchasing fruit that is not treated with pesticides, that is free from defects and disease and safe for consumption. On the other hand, importing countries have enforced strict import regulations regarding the maximum residue limits (MRL) in the edible portion of the fruit. Green mould decay in citrus fruit is controlled during the postharvest chain by using a systemic fungicide known as imazalil (Njombolwana et al., 2013). Postharvest diseases in avocados are controlled commercially by the application of prochloraz fungicide treatments in South Africa, New Zealand and Australia (Everett et al., 2005, Scheepers et al., 2007, Smith et al., 2011). The MRL of this active ingredient for South African avocado and citrus are set at 2 mg $kg^{-1}$and 5 μg g^{-1} respectively for the EU countries and Japan (National Department of Agriculture and Fisheries (2012), Njombolwana et al., 2013).

Moreover, the development of fungicidal resistant strains (Ippolito and Nigro, 2000) and the disposal of large volumes of fungicidal dipping solutions could also affect the environment, especially soil and water resources. Resistance to thiabendazole has been reported in *P. digitatum* and *P. italicum* due to the continuous use of fungicides (Bus et al., 1991). However, *Pseudocercosporella herpotrichoides* isolates were reported to demonstrate a resistance to prochloraz (Cavelier et al., 1994). *C. gloeosporioides* isolates from mango fruit exhibited considerable variability in their sensitivity towards prochloraz (Arauz, 2000), while recently, *B. cinerea* indicated resistance to anilinopyrimidines (pyrimethanil) (Latorre et al., 2002, Moyano et al., 2004). Although Jacobs and Korsten (Personal com.) reported that *P. digitatum* demonstrated a resistance to imazalil in South Africa, there are no reports available on the extent and level of the said resistance.

Therefore, the fresh produce industry needs to find an alternative solution to postharvest fungicide applications. Among these alternative methods are: controlled and modified atmosphere storage (Kader, 1994), biocontrol agents (Droby et al., 1998, Korsten et al., 1989, 1991, Janisiewicz et al., 2001); use of food preservatives such as carbonates, bicarbonates (Smilanick et al., 1999, Palou et al., 2002a) and potassium sorbate (Palou et al, 2002b); ozone exposure (Palou et al., 2003); heat treatments (Barkai-Golan and Phillips, 1991, Fallik et al., 1999, Lurie, 1998); methyl jasmonate (Tzortzakis, 2007a, 2007b); salicylic acid (Yao and Tian, 2005); UV–C irradiation (Wilson et al., 1997a,b) ; microwaves (Karabulut and Baykal, 2002); and chitosan (Bautista-Baños et al., 2006).

Natural plant protectants, such as essential oils (EOs) and their major components, that show antimicrobial property activities, low mammalian toxicity and less environmental effects (Isman, 2000, Kalemba and Kunicka, 2003, Burt, 2004) could be used as alternatives for chemical fungicides. The EOs are natural antioxidants which are well known for their antimicrobial and biodegradable properties and do not leave any residual effect on fresh produce (Kalemba and Kunicka, 2003). EOs and their components are gaining popularity due to their volatile nature, which facilitates the use of small concentrations that are safe for consumption. Furthermore, consumers accept EOs more readily because they are widely used in general culinary practices. They are also environmentally friendly and are known as "reduced risk" pesticides (Tzortzakis, 2007a, 2007b). EOs and their components are used as flavouring agents in food. The GRAS compounds status (FDA, 2014) of EOs favours their application as biopesticides to control pests and disease to provide safe food. The antifungal activity of EOs during the vapour phase recognises the application of EOs as a biofumigant to control the postharvest diseases in fruit that cannot be subjected to aqueous sanitation in the packing line.

Therefore, this review summarises the use of EOs in combination with other postharvest treatments in the control of postharvest diseases and their effects on the defence mechanism and retention of quality properties in fresh fruit.

2. Effect of essential oil on the control of postharvest diseases

Although alternative methods are being researched to control postharvest decay during storage, natural plant products such as EOs are gaining popularity and drawing the attention of researchers globally due to their biodegradable, eco-friendly, economical and safety characteristics. The EOs reported in various studies exhibit antimicrobial, allelopathic, antioxidant and bio regulatory properties (Vaughn and Spencer, 1991, Caccioni and Guizzardi, 1994) and therefore EOs can be ideal candidates for use as pesticides (Macias et al., 1997). The EOs are obtained from different plants and have indicated fungicidal properties reported to suppress fungal growth and development *in vitro* and *in vivo* in different fresh produce (Wilson et al., 1997a,b, Meepagala et al., 2002, Imelouane et al., 2009) while also being safer for the environment than synthetic fungicides. Many EOs currently in use, are approved by the FDA as flavouring agents, and also widely used in the food industry. Their FDA approved status and their wide availability have facilitated the rapid commercialisation of EO-based pesticides (pests and insects).

Koul et al. (2008) argue that the continuous application of synthetic fungicides could cause a resistance to develop in fungal strains while it is likely that the resistance will develop more slowly during the application of bio-based EOs because of the composition of the different chemical components that characterise these oils. The EOs contain compositions of terpenes, sesquiterpenes,