Crop Protection 115 (2019) 142–151

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Topical procedures adopted in testing and application of plant-based extracts as bio-fungicides in controlling postharvest decay of fresh produce

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ARTICLE INFO

Keywords:
Natural compounds
Fruit
Vegetables
Food preservation
Fresh produce
Postharvest diseases
Biological control

ABSTRACT

Fresh horticultural produce is normally treated with antifungal substances to avoid fungal infections, maintain high quality status and prolong their postharvest storage period. However, chemical fungicides are gradually banned in the fresh produce market due to their detrimental residual effects to consumer's health. Development of resistant strains of fungi is another setback associated with chemical fungicides. This often necessitates the invention of new fungicides with modified mode of action. Accordingly, a technique of formulating organic fungicides from plant extracts has received attention from product development food scientists. The use of plant extracts on horticultural produce has received extensive acceptance from consumers. The acceptance is caused by an idea that plant extracts can be non-toxic at concentrations higher than toxic concentrations of chemicals. The introductory studies that successfully demonstrated the antifungal properties of plant extracts on fruit and vegetables were well received by the fresh produce industry, but barely on commercial scales. The significant improvements in this field need careful considerations for ensuring relevant future inventions. This review discusses advances on the techniques used to obtain, assess, and apply plant extracts for antifungal activities on horticultural produce. Hereon, gaps that need attention, recommendations for future investigations and guideline for successful applications at commercial consignments are also revised.

1. Introduction

Horticultural produce is characterised by high perishability and susceptibility to microbial infections during growth, harvesting as well as postharvest storage (Abdullah et al., 2016; Perez et al., 2018; Brasil and Siddiqui, 2018). Fresh produce is normally treated with fungicides immediately after harvesting to prevent infections, contamination and suppress germination of fungal spores (Rodríguez-Cabo et al., 2018; Peña et al., 2018).

Researchers in the fresh produce industry are working on finding the equilibrium where food quality is preserved without sacrificing the safety of the consumers (Mari et al., 2014). Application of chemical fungicides on horticultural produce has raised issues in World Health Organization (WHO; Palou et al., 2016; Dukare et al., 2018). Residual toxicity, carcinogenicity and environmental pollution effects together with the development of new resistant fungal strains reduce the success of chemical fungicides (Onaran and Yanar, 2016). Genetically, fungi are related to animals more than they are related to plants (Arif et al., 2009). This means fungicides are likely to cause health hazards to the consumer before they affect the produce. Patients receiving serious medication are likely to suffer from chemical fungicides. Fluconazole, an antifungal remedy for human pathogens, was found to cause mortality, anaemia and renal impairment in patients with human immunodeficiency virus (Bicanic et al., 2008).

Fortunately, the plant kingdom has provided humans with a variety of compounds known for therapeutic and immunization purposes since the ancient ages (Dellavalle et al., 2011). The phytochemicals, chemical compounds produced by plants for repelling or tolerating competitors, predators, or pathogens, are also beneficial as antimicrobial agents in various applications. However, the use of phytochemicals has not been fully explored for application on produce that cannot defend itself against pathogenic infections (Pretorius and Van Der Watt, 2015). The application of plant extracts with antifungal effects on horticultural produce promises a huge success. Plant extracts have extended thresholds to toxicity and this will improve consumer acceptance due to organic antifungal treatment (Tomazoni et al., 2016). Furthermore,

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https://doi.org/10.1016/j.cropro.2018.09.016
Received 7 June 2018; Received in revised form 18 September 2018; Accepted 24 September 2018
Available online 05 October 2018

combustion of chemicals during manufacture of chemical fungicides can be eliminated while safer medicinal benefits may be obtained from the application of plant extracts. Consumption of produce with medicinal plant extracts is necessary in developing countries where majority of the population cannot afford modern immune boosters.

Fungi also change their mode of action to counteract the action of fungicides (Arif et al., 2009). This reduces the efficiency of using chemicals because of their extra specification compared to crude extracts (Abad et al., 2007). The composition of secondary substances with antifungal activity in plant extracts is very wide, enabling them to present biological activities at a broader spectrum (Nerio et al., 2010; Da Cruz-Cabral et al., 2013). There have been advances in the methods of obtaining extracts. Initially, hydrous extraction was done with just cold or hot water as a solvent. Eventually, organic acids and alcohols were introduced as solvents because they could acquire active phytochemicals at elevated levels (Do et al., 2014; Choudhury et al., 2017; Kapadiya et al., 2018). Chavez-Quintal et al. (2011) associated the antifungal activity of papaya (*Carica papaya*) leaves and seed extracts against *Rhizopus stolonifer, Fusarium* sp. and *Colletotrichum gloeosporioides* with the high content of alkaloids, flavonoids and terpernes compounds. Those chemicals were higher in alcoholic extracts compared to hydrous extracts. There are many studies where solvents with polarity higher than water were used to improve extractability of phytochemicals with potential antifungal activities (Table 1).

The form of the extract has also been demonstrated to play a role in its activity against pathogens. As a result, essential oils, alkaloids and proteins are among other secondary products of plant extracts that demonstrated higher activity compared to crude extracts (Abad et al., 2007; Pizzolitto et al., 2015; Lee et al., 2018). However, this improvement highly depends on the type, part and maturity stage of the extracted plant, and the mechanism of a targeted pathogen (Pizzolitto et al., 2015). The combination of these factors affects the success of the applied extracts which may complicate the assessment of fungicidal activity from an extract.

Research on fungicidal activity of plants extracts has mainly focussed on the selection of plants with high efficacy (Mahlo et al., 2010; Parveen et al., 2014; Elshafie et al., 2015; Pane et al., 2016; Esserti et al., 2017). As a result, information on the overview of recent techniques used to assess organic fungicides, and the link of research with the legislature for commercial applications is limited. The advances in the techniques used to obtain, assess, and apply plant extracts formed a background of this literature review. In this review, the common procedures of selecting a plant and a plant part to be extracted, extraction of plant samples, application of plant extracts on horticultural produce and the legislative requirements for food additives at commercial consignments are reviewed.

2. Selection of plant material for extraction of phytochemical compounds

Research has demonstrated that not all plants possess antifungal properties (De Rodriguez et al., 2017; Sarkhosh et al., 2018). Plants to be extracted are selected based on their phytochemical compositions, which differ from one plant type to another, and within plants of the same species (Stevic et al., 2017; Ullah et al., 2017). More importantly, plant parts differ in physical and physiological characteristics. These characteristics have an enormous effect on contents of antioxidant, allelopathic and antimicrobial chemicals. The antimicrobial activity of a plant can be linked with the sink and source relationship of assimilates within a selected plant. Fruit, flowers, seeds, bulbs and fresh parts are sinks of assimilates, meaning they receive extensive nourishment than the other plant parts (Mohd-Esa et al., 2010). The sink parts may contain high concentration of protection chemical compounds because they are most likely to be attacked by pathogens who want to feed on assimilates (Jorgensen et al., 2015).

Onaran and Yanar (2016) found that the seed extracts of *Cornus mas*

Table 1
Examples of studies on plant extracts that possess high contents of phytochemicals.

Plant/s	Extracted plant part	Extraction procedure	Phytochemicals obtained	Reference
Chicory (*Cichorium intybus L.*)	Leaves	Hydro-alcoholic extracts	Tannins, saponins and flavonoids	Abbas et al., 2015
Garlic pear (*Crateva adansonii*)	Leaves	Successive n-hexane, methanol, and chloroform extracts	Alkaloids, saponins, terpenoids, flavonoids and cardiac glycosides	Ajanaku et al., 2017
Indian tulip tree (*Thespesia populnea*)	Bark	Solvent extraction: ethanolic and chloroform extracts	Steroids, antioxidants, alkaloids, tannins, flavonoids and triterpenes	Anu and Usha, 2017
Barberry (*Berberis asiatica Roxb. ex DC.*)	Leaves	Microwave assisted Methanol extraction	Phenolic, flavonid, tannins, and antioxidant activities	Belwal et al., 2017
Winter cherry (*Withnaia somnifera L.*)	Roots	Green extraction, ultrasound and microwave assisted methanol extraction	antioxidant activity, total phenol and withanolide content	Dhanabi et al., 2017
Pink hippo grass (*Limnophila aromatic*)	Arial parts	Solvent extraction: water, methanol, ethanol, acetone	Antioxidant activity, phenolic compounds, flavonoids	Do et al., 2014
Horehound (*Marrubim alysson*), wild rue (*Peganum harmala*) *and* White broom (*Retama raetam*)	Arial parts	Petroleum ether, ethyl acetate and methanol	Flavonoid, phonic compounds and pigments	Edziri et al.