Chapter

Essential Oils Based Nano Formulations against Postharvest Fungal Rots

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Abstract

Postharvest phytopathogenic rot fungi affect the quality and quantity of perishable fruits and vegetables. About 30–40% peaches deteriorate annually after harvest in world whereas 40–50% losses are reported from Pakistan. Our research envisages importance of an eco-friendly plant essential oils based nano formulations as a management strategy against postharvest deteriorating fungal rots by enhancing their shelf-life and to attenuate reliance on synthetic fungicides. Plant essential oils mode of action against fungal postharvest rots is responsible of rupturing plasma membrane of fungal cell wall. The natural ripening process of perishable commodities does not get affected by the presence of antifungal packaging in the form of plant essential oil nano formulations as no significant alteration in weight loss of produce was recorded. Challenges in applying EOs for microbial suppression in postharvest systems include optimizing their positioning in commercial fruit storage containers. Several innovative approaches are analyzed in terms of work environment and implementation regarding disease management along with future perspectives in concerning field.

Keywords: fungal plant pathology, postharvest pathology, bio management of fungal rots with plant essential oils, nanoencapsulation, molecular phylogenetics

1. Introduction

Postharvest fruit losses usually develop along the food supply chain by fungal rots during handling, storage, transportation, processing and marketing, thus resulting in the decline of quantity, quality and shelf life of perishable fruits. Fungal postharvest rots pose a serious threat limiting the market value of peaches, resulting in serious economic losses worldwide [1]. Furthermore, postharvest fungal rots are often the major concern influencing consumer requirements. Accordingly, postharvest deteriorations primarily progress from damages that arise most prominently before, during and after harvesting. Once spores of fungi are inoculated in fruit from these wounds, they result in rapid fruit deterioration. Germinating conidia of fungi may enter intact fruit cuticle and establish internally in the host [2]. These infections completely develop into active decay as fruit is fully matured and become susceptible.

The high metabolic activity of peaches results in ethylene production and is mainly subjected to rapid quality decrease. This causes several negative effects *viz*. increased fungal rots susceptibility and fruit physiological disorders consequently resulting in the growth potential of microbes on fruit surface [3]. Various postharvest fungal rots of the genera; *Fusarium, Penicillium, Alternaria, Botrytis, Cladosporium, Colletotrichum, Trichothecium, Aspergillus* and Stigmina deteriorate quality of the stone fruits [4, 5]. To reduce conservational pollution owing to fungicides their excessive use against phytopathogenic rots is reduced in the previous years. Moreover, biological control has emerged as an applicable strategy to combat major fungal postharvest deterioration of perishable fruits [6, 7].

2. Postharvest losses

Postharvest fruit losses mostly arise laterally in the entire food supply chain from handling to consumption declining quality and market value of produce [1]. Usually, immature peaches show no visible rot symptoms but as they mature symptoms are clearly visible. These latent infections usually become active when the fruit ripen, worsening the disease incidence in harvest and post-harvest. *Fusarium* spp., *Rhizopus* spp., *Penicillium* spp., *Cladosporium* spp., *Botrytis* spp., *Aspergillus* spp., *Monilinia* spp., are major destructive postharvest fungal rots infecting perishable stone fruits like peaches. These postharvest fungal rots are now frequently reported in regions with high technology stores resulting in fruit rotting, and it is estimated that about 25–50% of the produce is lost in the developing and developed countries, respectively nectarines [8].

Postharvest diseases of stone fruits are characteristically triggered by a diversity of fungal rots, yet some of their casual agents, confirmation is still progressing. Sufficient awareness regarding epidemiology of opportunistic fungal rots is available whereas knowledge of their occurrence after quiescent infections during long term storage is limited. Usually, storage rots cause significant losses after latent infections [9]. Fungal pathogens cause significant fruit losses after harvest and results consequently in an essential reduction in the global supply. Several strategies have been altered to manage postharvest fungal rots around the globe. Fungal Rots caused by phytopathogenic postharvest rots incite severe agricultural and horticultural crop losses annually [10]. Bio-management with antimicrobial agents is explored as a substitute against postharvest fungal rots of perishable fruits [11].

3. Hazardous affects of synthetic fungicides

Fungicide use is very common at postharvest stage but as far as fruits are concerned, use of fungicide after harvest is strongly prohibited by FAO. The applications of synthetic fungicides rapidly increased throughout the preceding era. About four hundred thousand tons of fungicides are globally applied, which represents 17.5% of universal pesticide applications. The practice of hazardous fungicides to manage phytopathogenic postharvest fungal rots is limited, due to the toxic residual effect and long degradation period.

Application of synthetic fungicides against postharvest rots is known to be vastly effective and widely practical technique in orchards [12]. On the other hand, these chemicals have toxicologic hazards, which are dangerous to human health and cause ecological pollution. It is pertinent to mention that in few developed countries the use of fungicides is strongly prohibited by law after harvesting. Presently, the trend of using synthetic fungicides is reducing and practice of their use in agricultural products is rapidly minimizing [13]. Long term extensive practices of these hazardous fungicides may create resistance in pathogens, leading to severe conservational pollution with a serious threat to human health [14].

Lately, fludioxonil and azoxystrobin stayed registered in the USA as a post-harvest management application against peach decaying rots. Still, post-harvest use of these fungicides in European Union are banned because of fungicide regulatory concerns. Moreover, community stresses towards decrease in fungicides application, encouraged by more awareness of conservational and health concerns. The lack of an effective post-harvest strategy against fungal rot of peaches focuses the need for developing novel and eco-friendly control methods [13].

4. Plant essential oils

Fungicidal action of various plant EO's have been widely examined under various environmental conditions [15, 16]. Essential oils such as fenugreek, eucalyptus, turmeric, lime, thyme, fennel, clove, sage and peppermint are reported for their suppressive effect against postharvest fungal peach fruit rots [17]. Different techniques to apply essential oils against these decaying rots have been reported including; dipping, *in situ* uses and spraying however, there are several interests above potential sensory contamination concerns [18].

Use of synthetic fungicides as a chemical control is widely applied and highly effective method after harvesting fruits and vegetables [12]. However, it is pertinent to mention that fungicides have toxicological risks effecting environment and human health. World is moving towards trend of minimizing abundant use of synthetic chemicals in agricultural products [13]. Long term extensive practices of chemical fungicides may result in pathogen resistance, leading to severe conservational pollution posing hazardous effects on health [14].

An excessive concern regarding essential oils and plant extracts application as a promising biological substitute of conservative synthetic fungicides is raised. This may be credited to environmental effluence and fungicide challenge in postharvest phytopathogenic rots [19]. Applications of plant EO boons an alternate eco-friendly strategy against postharvest fungal rots of fruits besides vegetable [20]. The biotic action of plant EO's as antifungal and antimicrobial agents is in debate. As a complex mix of various aromatic volatile compounds plant essential oils from numerous plant parts *viz.* leaves, flowers, cloves, rhizomes, buds, roots, etc. are consistently in practice against several postharvest fungal rots. Essential oils extracted from plants are widely in use due to their antimicrobial, antifungal, insecticidal, and cytotoxic properties [21]. Moreover, the eco-friendly use of plant essential oils is popular to increase the shelf life of food products, as consumers are always conscious about various health concerns raised by hazardous additives. Essential oils also symbolize a defense mechanism against postharvest rots owing to their antimicrobial characteristics [22].

Eco-friendly use of plant EO's against contagious pathogens present in many horticultural produces helps in analysis of positive outcomes towards efficient options regarding fruit protection. Plant essential oils from various natural herbs and plants possess strong antifungal characteristics, *in-vitro*, that it may be used as a natural and eco-friendly strategy against perishable fruits decaying [18]. Stone fruits are highly sensitive to fungal infections. Currently, the management of postharvest fruit rots with plant essential oils (EOs) has been considerably observed as an innovative trend in biological conservation.

Plant Essential oils (PEOs) as volatile liquids obtained by several extraction techniques from plants and herbs, hold plentiful natural bioactive compounds with anti-fungal characteristics. Several studies regarding fungicidal characteristics of plant essential oils against postharvest fungal rots were reported *viz. Penicillium* spp., *Fusarium* spp., *Cladosporium* spp., *Alternaria* spp., *Aspergillus* spp. and *Botrytis cinerea* [23–25].

5. Plant essential oils based nano formulations against deteriorating fungal postharvest rots

Postharvest fruit decay is controlled with essential oils and is observed as an innovative drift in natural conservation [24]. Clove essential oil (CEO), as a natural antimicrobial agent, is generally recognized as a safe substance, shows strong in vitro activity against fungal rots [26]. Various studies revealed importance of essential oils *viz.* Eucalyptus [27], Thyme, Savory, Cinnamomum, Peppermint [28] and their anti-fungal efficacy against postharvest fungal rots of fruits *viz.* peaches, pears, apples, banana [29], citrus [30], strawberry, grapes, avocado, mango, and papaya. Another study revealed that organic extracts of various parts of *Lawsonia inermis* L. against *Aspergillus niger*, *Penicillium notatum*, *Fusarium oxysporum*, *Colletotrichum gloeosporioides* and *Rhizopus stolonifera* were highly effective in different environments [31, 32].

Furthermore, it was also reported that plant EO treatments have the prospective to control black, green and blue mold disease on fruits. It was narrated that the mycelial growth and conidial sprouting were distinctly affected by essential oils in a dose dependent manner [33]. Ultimately plant pathologists and scientists found excellent substitutes against postharvest fungal rots of perishable fruits and vegetables in the form of biocides [34].

Plant essential oils were applied against peaches with soft watery lesions and fluffy mycelium of fungus on outer surface, collected during fruit market survey at Cairo Egypt with soft watery lesions and fluffy mycelium of fungus on outer surface during fruit market and essential oils resulted insignificant reduction in growth of fungal mycelia [35].

However, the efficacy of plant essential oils holds significant importance in restraining pathogens mode of dispersal, by minimizing the spore load on fruit surfaces in the storage atmosphere [36]. Usually, plant essential oils are harmless together for the ecosystem and anthropological wellbeing, hence attention in their use as antifungal agents of postharvest fungal rots is increasing rapidly. Plant essential oils are non-hazardous to the treated fruits, vegetables and environment followed by human consumption. Plant EO's are elementary active natural pesticides and beneficial agents against various fungal phytopathogenic rots [37].

Plant EO's extracted from anise (*Pimpinella anisum* L.), thyme (*Thymus capitatus* L.), lemon (*Backhousia citriodora* F. Muell.) spearmint (*Menta spicata* L.) hold excellent antimicrobial nature and revealed inhibitory results against postharvest fungal peach rots. The fundamental component, citral, in citrus essential oil showed fungitoxic effect against various threatening postharvest phytopathogenic rots. Clove (*Syzgium aromaticum*) essential oil has been used since ages for its excellent properties including antifungal applications. In the previous dual eras, growing concern has been determined on clove EO to reduce postharvest fungal rots and progress storage quality of agricultural products [24, 26].

Moreover, eucalyptus (*Eucalyptus globulus*) essential oil possesses broad biotic activity, including anti-fungal, anti-microbial, acaricidal and nematicide features. The central components present in Eucalyptus EO, including eucalyptol, γ-terpinene, limonene, *p*-cymene, 1,8-cineole, α-pinene, ocimene α-terpineol, camphene and linalool play major fundamental role in disrupting cell wall of phytopathogenic rot fungi. Plant EO's are of utmost importance in holding fungistatic properties. Destruction of fungal spore germination by plant essential oils show fundamental role in limiting the spread of phytopathogenic rot pathogens [36]. Many essential oils can enhance shelf life and preserve quality harvested fruit while having no detrimental impact on the fruit itself [37].

Essential oils provide an alternative and more ecologically friendly strategy against fungal postharvest rots [20]. The fungicidal nature of plant essential oils might be owed to synergism amongst their mechanisms, subsequently, maximum activity has been reported to be improved mutually. The fungicidal action of plant EO's might be boosted by the technique of application. The possible potentially applicable strategies of with plant essential oils by immersion or spurting against postharvest phytopathogenic rot fungi has already been observed in fruit and vegetables. The pattern of several postharvest handlings may advance the efficacy of controlling postharvest fungal rots [38].

6. Antimicrobial packaging using plant essential oils

Challenges in applying EOs for microbial suppression in postharvest systems include optimizing their positioning in commercial fruit storage containers. One approach has been to dispense them from sachets (absorptive pads saturated with the plant EO) in the central of the packaging or enclosed towards it. Antimicrobic packaging in the form of antifungal sachet comprising of volatile constituents enclosed in them are the primary example of profitable packaging and are broadly used. Bioactivity of plant EO's vapor phase was known as a distinctive practice making them eye-catching against postharvest fungal rots in storage commodities [39].

To enhance the shelf life and promote market value of perishable fruits antimicrobial active packaging is of utmost importance. As it allows packaging material to interact directly with fruits for improving its quality [40]. Usually by adding a chemical compound in a deliberate way with specific antifungal ability into the packaging. Two major mechanisms may be applied in this regard, *viz.* internally in the packaging material during manufacturing, secondly in the headspace of the packaging as antimicrobial sachet during packaging [41, 42].

Other than antimicrobial packaging against postharvest fungal rots of perishable fruits it is pertinent to mention that fumigation with high concentration compounds was also applied as a postharvest treatment, where results showed water spots on external surface with browning and softening resulting in physiological damage. Many researchers argued that the same molecules at high concentrations may have adverse effects on climacteric fruit like peaches, leading to cell necrosis, and resulting in severe losses respectively [43]. Postharvest fungal rots *viz. F. semitectum, A. flavus*, *A. alternata, F. semitectum, L. theobromae,* and *R. stolonifer* were controlled completely by using antifungal essential oil sachet.

The efficacy of EO's directly depend on the level of concentrations with significant alterations in dose dependent manner. Whereas the pathway of EO's mode of action against fungal postharvest rots might be related to their general capability of softening and dislocating the consistency of cell wall at various incubation temperatures [44].

7. Mechanism of antifungal constituents of plant essential oils

The mechanism of antifungal constituents in plant EO's *viz.* eugenol, eucalyptol & thymol include inhibition of enzymes by oxidization. Their possible concern is to damage membrane integrity and fungal cell wall degradation, which could result possible reduction in infections by post-harvest fungal rots [45]. Plant EO's as an excellent non-hazardous, antifungal agents may be adopted as an alternate management strategy to keep perishable fruits fresh during storage. Antifungal components eugenol in clove essential oil holds excellent inhibitory effect against postharvest storage fungal rots of perishable fruits [46]. One of the important factors concerning postharvest rots management is temperature in maintaining fruit quality prolonged shelf life [47].

Essential oils of various herbs and plants hold no significant impact in reducing weight of fruits during cold storage environment as compared to room incubation. It was reported that after application of EOs encapsulated with inclusion complexes average weight of stone fruits (nectarines) was not significantly reduced in cold storage [48]. Similarly, vapor treatment of *Thymus vulgaris* EO against fungal rots of peach fruit results minimum reduction of weight in cold room [49]. Cinnamon EO was also reported with a minimum reduction in average weight of peaches in cold storage incubation whereas in control (with no treatment) significant weight loss was recorded [50]. Other horticultural produce in cold storage treatments were also observed with minimum weight reduction after applying treatments of (carvacrol, eugenol, thymol, menthol, eucalyptol, oregano, and cinnamon) EO's whereas control fruit was observed with significant alterations in weight loss assessment [48, 51].

Plant essential oils mode of action against fungal postharvest rots is responsible of rupturing plasma membrane of fungal cell wall [52]. Volatile compounds in EO's acts by blocking ergosterol synthesis, internal leakage of fungal cell wall, disintegrating mycelium, disruption of cytoplasmic formation and ultimately triggering towards completed distortion [53–55].

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