Role of natural volatiles and essential oils in extending shelf life of fresh fruits: A review

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Abstract
Fruits trading is a million rupees industry in the India, and are economically important in many other countries. However, they are perishable in nature and susceptible to biological damage. Food safety and fruit quality are the major concerns of the food chain from farm to consumer, especially with increasing regulations in recent years. At present, the industry depends on pesticides and fungicides to control food spoilage organisms. However, due to consumer concerns and increasing demand for safer produce, efforts are being made to identify eco-friendly compounds that can extend the shelf life of fruits. Most volatiles and essential oils produced by plants are safe for humans and the environment. In this review, we discuss the efficacy, minimum inhibitory concentrations, and mechanisms of action of volatiles and essential oils that control microorganisms (bacteria and fungi) on fruits.

Keywords: Postharvest diseases, bacteria, fungi, plant extracts and essential oils

1. Introduction
There are two major concerns for the handling and consumption of fresh fruits. First is their short shelf life, and second is food safety. Fresh fruits in particular are gaining increasing attention in the current food safety [1]. Standard fruit production practices discourage growers from washing fruits after harvest and during storage. This may contribute to the buildup of food-borne bacteria and may pose a food safety risk to consumers since small fruits are eaten fresh. Also, small fruits have a very short shelf life due to their susceptibility to spoilage pathogens, physiological disorders and mechanical injury [2]. This is partly due to their high nutrient content and water activity which make them susceptible to fungal attack. Thus, losses during harvest, handling and marketing are sometimes as high as 50% [3]. Pathogens may also produce mycotoxins that make the fruit harmful to consumers [4]. However, under optimal conditions, fungicides are not effective in controlling the diseases and growers may try to overcome this challenge by increasing fungicide applications, which in turn leads to higher residue levels in produce [5]. High levels of pesticide residues on fruits are of particular concern because they are consumed fresh shortly after harvest. Other concerns with excessive pesticide application are increased cost, handling hazards, and threats to the environment [6]. Therefore, many restrictions are imposed on pesticide application in many countries around the world [7]. Therefore, new disease control technologies that are safe for humans and the environment are needed [6]. Biological control, such as the use of plant volatiles is an exciting alternative [8]. Plants synthesize an enormous number of volatiles (phenols or their by-products). Many of them are responsible for flavor, while some have useful anti-microbial compounds [8]. At present, there are many research results on the efficacy of plant volatiles to control fungal and microbial growth on fruits.

2. Control of Food Born microorganisms by Volatiles and Essential Oils on Fruits
Most of the studies reported control of food borne pathogens such as Salmonella typhimurium, Salmonella enterica, E. coli, and Listeria monocytogenes etc., on the application of natural volatiles and essential oils (EOs) [9]. Sun et al. [10] studied chitosan coating mixed with six different essential oils in vitro to control E. coli and Penicillium digitatum in blueberries during storage. Carvacrol and cinnamaldehyde had high antimicrobial capacity and were selected for in vivo studies to control blueberry pathogens. Sánchez-González et al. [11] tested biodegradable coatings with and without bergamot essential oil on table grapes during storage. They found that incorporation of bergamot essential oil improved the antimicrobial activity of the coatings and significantly reduced mold, yeast, and mesophile counts.
4. Effect of Volatiles and Essential Oils on Fruit Quality
Wang et al. [14] found that treatment with thymol and eugenol extended strawberry shelf life and increased fruit free radical scavenging capacity, thereby enhancing resistance to spoilage and deterioration. Essential oil treated fruits were found to have higher amounts of sugars, flavonoids, anthocyanins, organic acid and phenolic compounds. The increase in phenolic content may have led to increased oxygen radical absorbance capacity (ORAC) and decreased fruit spoilage in essential oil treated strawberries [14]. Carvacrol, anethole, and perillaldehyde also enhanced antioxidant activity and increased total anthocyanins, phenolics and hydroxyl radical (•OH) scavenging capacity in blueberry fruit tissues [15]. Chitosan coating with carvacrol and cinnamaldehyde was also found to maintain blueberry firmness and effectively extended blueberry shelf life [10]. Similarly, postharvest essential oil treatments (perillaldehyde, linalool, cinnamaldehyde, cinnamic acid, anethole, and carvacrol) enhanced antioxidant capacity in raspberries with perillaldehyde being the most effective [19]. Grape berries in a modified atmosphere package with eugenol or thymol had lower weight loss, lower changes in skin color, reduced ripening, and lower decay throughout storage [17]. Sánchez-González et al. [11] tested chitosan-coated packages of grapes alone or in mixture with bergamot essential oil and found chitosan mixed with bergamot oil to be the most effective to control respiration rate, water loss and antimicrobial activity during storage. Chitosan packages infused with O. vulgare essential oil also preserved the quality, physical, physiochemical and sensory attributes of grapes in storage [18].

5. Mechanism of Fruit Resistance to Microbial Attack Treated by Volatiles and Essential Oils
Plant volatiles play a major role in self-defense. Pérez et al. [19] observed that a 25% decrease in (E)-hex-2-enal content during strawberry development and ripening coincides with activation of latent infection, and appearance of visible disease symptoms, leading to extensive fruit damage. Six and nine-carbon volatiles are produced in plant tissues in response to wounding in LOX (lipoygenase) and HPL (hydroperoxide lyase) pathways. In addition to their role in aroma biosynthesis, products of LOX and HPL pathways, have antimicrobial and antifungal activities and may have a role in plant-pathogen interactions. Some have also shown a stimulatory effect on some pathogenic fungi. In Arabidopsis thaliana, (E)-hex-2-enal activated several self-defense genes (i.e., lipoxygenase 2 and allene oxide synthase), lignified leaves and accumulated pathogenesis-related proteins (i.e., 3 transcripts, and camalexin), which reveals that volatile treatments stimulate a wound-repair mechanism, and will ultimately act as a physical barrier to the pathogen penetration [47]. Externally applied essential oils improved fruit resistance to fungal attack, mostly due to increased antiproliferative activity and free radical scavenging capacity in strawberries [14]. This has also been reported in kiwifruit (Actinidia delicosa cv. ‘Hayward’) against B. cinerea with the application of grape (cv. Isabella) volatiles which induced mechanisms of resistance in the host [8].

6. Conclusion
Several researchers have mentioned the toxicity of volatiles and essential oils after extended exposure. Research is needed to study the effect of volatiles and essential oils on vegetative and reproductive phases of fungal development, fruit quality (firmness, sensory evaluations), cell wall structure and integrity and their role in plant self-defense and postharvest storage.

7. References