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Essential Oils: A Novel Consumer and Eco-friendly Approach to Combat Postharvest Phytopathogens

Afroz Alam[1*], Abhishek Tripathi[1,2], Vinay Sharma[3] and Neeta Sharma[2]

[1]Department of Bioscience and Biotechnology, Banasthali University, Rajasthan, India.
[2]Department of Botany, University of Lucknow, India.
[3]Faculty of Science and Technology, Department of Bioscience and Biotechnology, Banasthali University, Rajasthan, India.

Authors' contributions

This work was carried out in collaboration between all authors. Authors AT and NS conceptualized the study, performed the initial groundwork and wrote the initial draft of the manuscript. Authors AA and VS handled the further study, including the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Postharvest infections are among the chief reasons for the worsening of horticultural products in the sequence of storage and delivery. The occurrence of postharvest infections and subsequent diseases can influence the value of the fresh food products and also hamper the shelf life. Nowadays stringent rules are compulsory by the fresh produce importing nations concerning the least pesticides residue level in the palatable fraction of the fresh food products. A number of phytopathogens were reported to attain resistance against man-made antifungal agents. Disposal of waste containing these synthetic chemicals has an adverse impact on environmental track. Hence, the present scenario demanded the exploration of a natural novel antifungal substance as a substitute for the chemical applications as a postharvest treatment during storage and packing line up. Contemporary increasing awareness of consumers towards herbal based and organic products is also a matter of concern in this context. Hence, this review summarizes the utilization of essential oils of plant origin in the control of postharvest diseases of horticultural produce, their eco-friendly

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**Corresponding author: E-mail: afrozalamsafvi@gmail.com;*

and consumer friendly approach of actions, etc. The present communication also reviews the work done in past on investigating the role of essential oils in fungal deterioration of stored products.

Keywords: Environment; essential oil; food production; phytopathogens; postharvest.

1. INTRODUCTION

Around 50% of global population in the do not have availability of sufficient foodstuff supplies. There are many explanations for this crisis, one of which is the huge losses of food during the post-harvest and marketing methods. Although the crisis of food losses had been on the international agenda, earlier in the 7th particular session of the UN General Assembly of World Food Conference (1974) exceptional consideration was given to this agenda. Consequently, during the FAO Conference (1977), the initiation of a Special Action Programme for the avoidance of food losses was permitted. At the outset, this plan was gained attention on common food grains in the human diet, however, since 1983, in response to an appeal of the FAO Conference, added consideration was given to perishable and related food, viz. tuber, root crops, vegetables and fruits.

Serious efforts are required to educate the growers because they are investing their precious time, and plenty of capital money to plow up food products. The final yield is of great use for their families and also for commercial aspects. Therefore, awareness of these advancements is necessary for them so that they become an effective component of the market related financial system, where, he has to trade his produce to get back his costs with considerable profit.

Internationally, postharvest losses of vegetables and fruits have been reached up to 19% in the USA, at an anticipated yearly loss of approximately $ 18 billion [1]. Elevated losses have been recorded in African nations, ranging between 15%-30% of the harvested products [2]. Approximation of the postharvest decrease of food grains in the developing countries from maltreatment, spoilage and pest invasion is placed at 25%, which indicates that 25% of the total production never reaches the consumer, hence waste of the growers' sweat and money invested to produce it, lost irreversibly. Factors affecting post-harvest food losses of perishables differ extensively from region to region and become increasingly intricate as selling practices become more composite. Both quantitative and qualitative food losses to the exceptionally unpredictable extent occur at all junctures in the post-harvest method from harvesting, during handling, storage, dispensing and selling to ultimate delivery to the end user.

The chief sources of product degradation are physiological worsening, pest infestations, superfluous microbial growth, wounds and blemishes because of inappropriate handling or shipping, and be deficient in technology in conjunction with infrastructure. Unusual physiological deterioration happens when fresh produce comes in contact with the intense temperature, atmospheric alteration or contamination. This may cause foul-tasting flavours, stoppage to ripen or other changes in the living pathways of the produce, resulting it unhealthy for subsequent use. Physical injuries due to casual handling of fresh harvest cause inner unwanted staining, this results in anomalous physiological spoil or cracking and skin ruptures, accordingly hastily escalating water loss and the rate of regular physiological collapse. Breaks in the skin also provide the open sites for contamination by pathogens which cause decay. All living materials are prone parasitic attack. Fresh produce can become infected prior to or after harvest by numerous, widespread air, soil and water borne diseases [3]. A number of disease agents are able to pierce the intact and healthy skin of produce, whereas, others have need of a wounded skin to facilitate their easy entry into the host to cause infection. Spoilage so created is possibly the major cause of the huge losses of fresh produce. But the marketing process of fresh produce they all interact amazingly, and the effects of all are also subjective to the outer climatic conditions such as relative humidity and temperature.

The living parts of all vegetables, fruits and root/tuber crops have 65 to 95% water content, and these living processes usually continue following harvest. Hence, their post-harvest existence depends on the rate at which they exhaust their stored up energy (food reserves) and their rate of the water loss. As soon as water and food reserves get exhausted, the produce starts to decay and finally dies. Fruits due to their high sugar content are very susceptible to attack by microorganisms. Effective quality management and disease control of fresh produce starts in the field. As said by Ippolito and Nigro [4], Preharvest conditions have a bigger effect on the quality of postharvest than handling systems of postharvest on the quality of postharvest. Stress factors prior to harvest, for instance, water shortage, changeable or intense environmental conditions, high levels of nitrogen can result into fruit being more vulnerable to postharvest diseases. Thus, managing total tree health and implementing proper and best possible production, management and executive practices are essential to guarantee utmost quality, long shelf life and reduction in postharvest losses at the retail end.

2. FUNGICIDES: HAZARDOUS CHEMICALS TO CONTROL POST HARVEST DISEASES

Generally, losses during postharvest have been controlled at large scale, primarily by the application of postharvest fungicides [5,6]. However, at smaller extent, it is done during the course of postharvest management practices to decrease inoculum or efficient implementation of the cold chain system [7]. Though, improved storage methods and competent procedures of collecting the ripened fruit can bring down the expansion of pathogens yet fungicides are frequently used as the easiest option to stop or in any case reduce losses. These fungicides are the chief resources for the management of postharvest diseases. Their global use is inconsistent, encompassing about 26% of the plant safety market in Asia and Europe, and only 6% in the USA [8]. Approximately 23 million kilograms of fungicidal chemicals are applied to vegetables and fruit per annum, and it is usually established that production as well as selling of these delicate products would not be feasible exclusive of their use [9].

As an easy safeguard of crops, stock up food grains and insect/pest control the growers usually depends upon the use of chemical fungicides [10]. The increase in pesticide use has been alarming for the general health. During 1980s the exponential increase was observed in the marketing of these hazardous chemicals that increase the health related risks in the surroundings. Consequently, a report of the National Academy of Sciences (1986) was focused on excessive and unorganized use of synthetic pesticides and related carcinogenic danger. This threat is more severe in case of fungicides than the impact of herbicides and insecticides jointly besides developing tolerance towards pathogens (Research Council, Board of Agriculture, 1987).

One dilemma with these man-made chemicals is their effectiveness, which has been improved, so has been their side-effects, and also their price [11-15]. In addition, man-made fungicides can put down considerable residues in the treated produce [16-19]. Improvement of resistance against frequently used fungicides inside the populations of postharvest pathogenic forms has also turned out to be a major setback [20-21]. For instance, several man-made fungicides are presently utilized to manage blue mould rot of citrus fruit. However, the use of these fungicides is not decisive, as fungi like, *Penicillium italicum* and *P. digitatum* have attained resistance against the frequently sprayed fungicides on the members of the citrus family, and this become an issue of great worry [22]. Maximum research efforts have been till date, aimed at chemically controlled diseases of horticultural crops and a huge quantity of man-made chemicals are used. Though, owing to the emergence of new physiological races of pathogens, many of these synthetic chemicals are increasingly becoming futile [23-24].

On the other hand, as harvested vegetables and fruits are frequently treated with fungicides to slow down postharvest diseases, there is an increasing probability of their direct interaction with human beings because they are connecting link between chemicals and the crops. The use of man-made chemicals to manage postharvest decay has been restricted to some extent due to their carcinogenicity, elevated and sharp residual toxicity, extended contamination and their effects on food and other side-effects on humans [25-26].

Therefore, a sensible call for exclusion of the use of synthetic fungicides and incorporation of the optional eco-friendly approaches to combat immense losses of the crops because of postharvest putrefication [27]. The use of non-chemical procedures and non-selective fungicide (active chlorine, sodium bicarbonate, sodium carbonate and sorbic acid) treatments may offer an option in this direction. Inoculum reduction attained through cleanliness and elimination is also useful [28], and physical treatments such as heat therapy, hot water treatments, low temperature storeroom and radiation can also considerably lower the disease stress on harvested produce [29-30]. Skilled and well planned harvesting and handling practices that lessen damage to the commodity, together with improved storage conditions are most favourable practices for maintaining host resistance [31] and will also support in curbing disease development after harvest.

This off-putting consumer awareness of chemical preservative drives consideration towards natural substitutes [32]. Exacting attention paying attention to the impending relevance of plant based essential oils and extracts from plants has been of immense importance in recent years. Their potential use as customary additive came forward from a growing inclination to substitute man-made antimicrobial means with natural ones. Phyto-compounds are expected to be far more beneficial than artificial pesticides for absolute extent of intricacy, diversity and newness of chemicals, reactions and the fact [33] as they are eco-friendly in character, non-toxic and contain no residual or phytotoxic properties [34-36].

In the past few years, it has become obvious, as a result of public view and environmental laws, that new and secure substitutes to routine synthetic pesticides are both satisfying and consented. More than a couple of troubles have hurried the investigation for more toxicological and environmentally secured and more exacting and industrious pesticides. The mounting frequency with respect to pesticide resistance is additionally boosting the call for new pesticides. Consequently, normal mixes have dynamically more get to be in the spotlight of those worried in the innovation of pesticides.

Effective phytochemicals are anticipated to be significantly further helpful than the man-made pesticides, since they are effortlessly decomposable, not considered as load in as natural toxins and contain no left over or phytotoxic properties [34-36]. Utilization of the synthetic fungicides has been viewed as one of the financially savvy and most continuous methodologies for the management of post-harvest infections. However, these chemicals as a rule, take a long period to be debased completely bringing on substantial danger to individual, residential creatures, and so forth [25,37-38]. Like identified human pathogenic microbes, phytopathogens are likewise disposed to creating "drug" resistances to diminish the productivity of these pesticides to a vast degree [9]. In like manner, there is a persistent necessity to work towards the pursuit of more secure antifungal agents, for instance, essential oils, which are believed to be renewable, non-petrochemical, normally biodegradable and effortlessly available.

3. PLANT DERIVED NATURAL ANTI-FUNGAL PRODUCTS

Actually, a few antimicrobial constituents are available in the leaves, stems, barks, roots, blossoms, and products of plant. An associate on the antimicrobial activity of these plant determined substances, overwhelmingly flavours and herbs, is practically in use for quite a long time [39]. In various occurrences, nonetheless, constituent’s concentration in herbs and flavours, vital for microorganisms inhibition surpass those subsequent from typical use in food [40]. Indeed, even thus, naturally occurring essences in plants do positively assume a part in confining the development of food borne decay and woe bringing on microorganisms in food.

Plants contain a practically unexploited pool of common pesticides that can be utilized straight or as formats for fake pesticides. Various components have expanded the interest of the pesticide industry and the pesticide commercial centre in this amazing wellspring of regular pesticides. These incorporate pulling back benefits with ordinary pesticide revelation strategies, expanded natural and toxicological worries with synthetic pesticides, and the abnormal state of reliance of present day horticulture on pesticides.

An extensive variety of secondary metabolites of plants have been known till date, and there are conjectures that an awesome pool of these compounds exists that stay unexplored. There is developing backing that the greater part of these compounds are involved in the dealings of plants with different species, essentially the protection of the plant against abiotic and biotic stresses especially from plant invading infesting pests. In outcome, these secondary metabolites symbolize an immense pool of bio-active chemical structures. The asset is essentially unexploited for use as pesticides. The secondary metabolites of plants are really an unending storage facility of bioactive compounds with an extensive variety of fascinating exercises. Therefore, unlike synthetic antimicrobial compounds, the secondary metabolites acquired from plants are practically guaranteed to have an exceptional biological

Table 1. Antimicrobial activities of essential oils and extracts obtained from important plant species [41]

Plant species used	Major activities
Oil from roots and flowers of *Raphanus sativus* L.	Effective against *Fusarium avenaceum, Phoma* spp., and *Alternaria brassicae*
Oil from *Juniperus communis* L.	Effective against *Aspergillus niger*
Oil from *Mentha piperata* L. and *M. officinalis* L.	Both oils exhibited antimicrobial activity
Oil from *Mentha canadensis* L.	Oil of the plant from Formosa showed the highest antibacterial and antifungal activity
Oil from *Cymbopogon citratus* (DC.) Stapf, *Mentha arvensis* L.	*Mentha arvensis* was effective against *Penicillium italicum* causing fruit rot of *Citrus reticulata*
Oil from rhizome of *Curcuma angustifolia* Roxb.	Effective against some saprophytes, plant pathogens and dermatophytes
Oil from seeds of *Bunium bulbocastanum* L.	active against fungi and bacteria
Oil from seeds of *Lantana camara* L.	Effective against *Curvularia lunata, Fusarium oxysporum* and some other fungi
Oil from roots of *Cedrus deodara* (Roxb. ex D.Don) G.Don	Showed antifungal responses against the fungi tested
Oil of *Mentha arvensis var. piperascens* Malinv. ex Holmes	Strong antifungal activity against 17 out of 23 fungi tested; and was more active than some fungicides tested
Oils from leaves of *Caesalpinia sappan* L.	Strong efficacy against *Aspergillus nidulans*
Oil from seeds of *Nigella sativa* L.	Showed antifungal activity against *Aspergillus* spp. and *Curvularia lunata*
Oil from leaves of *Mansoa alliacea* Gentry.	Effective against *Helminthosporium oryzae* at 500 ppm, killed 12 fungi out of 21 tested and proved to be nonphytotoxic to host; and much more active than some commercial fungicides tested
Oil from *Blumea membranacea* DC.	Fungitoxic against *Cladosporium cladosporoides, Aspergillus sydowi* and *A. luchuensis* while in effective against *Fusarium oxysporum*
Oil from leaves of *Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson	Effective against *A. niger* and *Clathridium corticola* at 1:1000 dilutions
Oil from the leaves of *Cestrum diurnum* L.	Fungicidal activity against *Rhizoctonia solani* at MIC of 0.7%. At this concentration it exhibited the mycelia growth of all the 39 fungi tested indicating thereby wide range of activity
Oil from leaves of *Ocimum americanum* L.	The oil at 3000 ppm exhibited broad range of activity inhibiting all the 31 fungi tested
Oil from leaves of *Ocimum canum* Sims	Showed fungitoxicity against *Aspergillus flavus, A.vesicolor* and the number of other fungi
Oil from fruits of *Cinnamomum glaucescens* (Nees) Hand.-Mazz.	Showed fungitoxicity against all the storage fungi tested.
Essential oils from epicarp of *Citrus medica* L.	Showed fungitoxicity against *A. flavus, A. vesicolor* and several other storage fungi. The oil was thermostable and broad spectrum
Oil from leaves of *Schinus molle* L.	Showed toxicity against *A. flavus, Alternaria alternata,Penicillium italicum.* Oil was thermostable and toxicity lasts for at least 12 months, the maximum time taken into consideration
Oil from Pericarp of *Prunus persica* (L.) Batsch.	Showed toxicity against all the storage fungal pests tested
Oil from epicarp of *Citrus sinensis* (L.) Osbeck	Showed fungitoxicity against some important storage fungi tested
Oil from leaves of *Cymbopogon citratus* (DC.) Stapf	Showed toxicity against *A. flavus, A. niger* and many other storage fungi
Essential oils from leaves of *Melaleuca alternifolia* (Maiden & Betche) Cheel and *Monarda citriodora* Cerv. ex Lag.	Showed fungitoxicity against several storage fungi tested

Plant species used	**Major activities**
Essential oil from leaves of *Melaleuca citrina* (Curtis) Dum.Cours.	Showed fungitoxicity against *A. flavus, A. niger* and many other storage fungi
The oil from leaves of *Cymbopogon flexuosus* (Nees ex Steud.) W.Watson	Effective against *Aspergillus flavus, Penicillium italicum* and *Alternaria alternata.* The oil showed broad spectrum, inhibited heavy doses of inocula, thermostable and toxicity persisted for at least 12 months
Oil from leaves of *Ocimum tenuiflorum* L. and *O. gratissimum* L.	*Ocimum sanctum* showed absolute toxicity against *A. flavus* but was moderately active against *A. niger.* However, *O. gratissimum* was found to exhibit absolute toxicity against both the tested fungi
Oil from the flower buds of *Syzygium cumini* (L.) Skeels	Clove oleoresin at 0.2 to 0.8% (v/v) was tested against *Candida albicans, Pencillium citrinum, Aspergillus niger* and *Trichophyton mentagrophytes* and was highly effective against *T. Mentagrophytes* and *Candida albicans, however, P. citrinum* and *A. niger* were relatively more resistant. Clove oleoresin was first dispersing in sugar solution and then used for antifungal testing
Essential oil extracted from leaves of *Eucalyptus pauciflora* Sieber ex Spreng.	MIC was 0.3, 0.4, 0.5 and 0.6% against *Alternaria, Aspergillus, Penicillium,* and *Rhizopus* respectively
Oil extracted from dried, crushed flowering plants of *Thymus serpyllum* L.	Oil showed antifungal properties against *A. flavus, A. awamori, A. niger, A. foetidus* and *A. oryzae.* It also inhibited all the three stages of asexual reproduction,that is, spore germination, mycelial growth and spore formation
Essential oil and phenolic extracts of *Dennettia tripetala* G. Baker (pepperfruit)	Oil and phenolic extracts inhibited growth of several food borne microorganisms including *Penicillium* spp. and *Aspergillus* spp. etc.
Oil of *Foeniculum vulgare* Mill.	The GC-MS of the oils showed estragole (53.08, 56.11 and 61.08%), fenchone (13.53, 19.18 and 23.46), and α-phellandrene (5.77%, 3.30%, and 0.72%), respectively. Strong antifungal property against *Alternaria alternata*, *Fusarium oxysporum*, and *Rhizoctonia solani* at 40 ppm.
Essential oil from the leaves of *Chenopodium ambrosioides* L.	The oil completely inhibited the mycelial growth of *Aspergillus flavus* Link., at 100 µ/ml. Further, the oil exhibited broad fungitoxic spectrum against *Aspergillus niger, A. fumigatus, Botryodiplodia theobromae, Fusarium oxysporum, Sclerotium rolfsii, Macrophomina phaseolina, Cladosporium cladosporioides, Helminthosporium oryzae and Pythium debaryanum* at 100 µg/ml
The oil of *Putranjiva roxburghii* Wall.	exhibited the greatest toxicity The oil was found to be fungicidal and thermostable against *A. flavus* and *A.niger*, at its minimum inhibitory concentration (MIC) of 400 ppm
The essential oil of *Citrus medica* L.	The oil exhibited a wide spectrum of fungitoxicity, inhibiting all 14 fungus species of *Arachis hypogea*
The essential oil of *Cymbopogon flexuosus* (Nees ex Steud.) W.Watson, *Trachyspermum ammi* (L.) Sprague and their active constituents	Oil of *C. flexuosus* and its major constituents Citral 38% and Geraniol 24.56% as well as oil of *T. ammi* and its constituents Thymol 80.7%, ρ-cymene 11.4% and α-pinene 7.9% were found effective against *A. flavus* and *Penecillium italicum*

activity which liable to work in shielding the plants from the pathogen. These acquisitions, consolidated with expanding needs and ecological weight, are significantly mounting the enthusiasm for plant products with pesticide action [41].

The persuade of the present world scenario is moving towards the lessened or no pesticide use in rural/agricultural practices. In response, various new physical and organic strategies have been assessed as more secure substitutes of man-made fungicides. The utilization of natural products (plant separates/key oils), biocontrol specialists (yeast and bacterial foes), and non-selective biofungicides (sodium bicarbonate, sodium carbonate, sorbic acid and active chlorine) are amongst the advances, that are presently being assessed for the eco-friendly control and management of postharvest diseases.

Active principles of many plants have also been isolated phytochemical that have shown strong inhibitory activity in opposition to the postharvest fungi (Table 1). Unlike traditional pesticides which are usually based on a single active ingredient, the bioactive compounds derived naturally from plants are made up of a composite array of novel phytochemicals that affect not only one physiological function, but rather affects several processes [37], hence, can be considered as broad spectrum. Moreover, many investigations have recently focused on alternatives to synthetic pesticides in order to conform with the set standards of food safety. Such products that are resultant from higher plants (mostly angiosperms) are reasonably better bio-efficacious, environmentally safe and economical and can be the ultimate candidates to be used as agrochemical [42].

The stabilizing nature of of different plant extracts has been identified for a considerable time and now there has been transformed wakefulness in the antimicrobial properties of extracts acquired from plants with aromatic properties. A few plants extracted with various organic solvents have demonstrated inhibitory action against various storage parasitic strains [43-48]. The active constituents of numerous plants have additionally been isolated phytochemical that have demonstrated firm inhibitory relationship, contrary to the postharvest fungi. Not at all like customary pesticides which are typically in view of a single active component, the bio-active mixes derived naturally from plants comprise of a composite cluster of novel phytochemicals that influence one physiological capacity, but rather affects several processes [37], henceforth, can be considered as wide range. Besides, numerous examinations have as of late centred around contrasting options to manufacture pesticides to adjust with the set principles of food security. Such produces that are gotten from higher plants are moderately better bio-efficacious, economical and environmentally more secure and can be a tremendous possibility to be utilized as agrochemical [49].

4. ESSENTIAL OILS: A NEW CONSUMER FRIENDLY APPROACH FOR POST-HARVEST DISEASE CONTROL

Aromatic plants, herbs and spices are astounding assets of phytochemicals with amazing antioxidative agents and antimicrobial properties. These days, there is a continually expanding obvious concern over the measure of pesticide deposit in their day by day food, and this anxiety has focused the specialists to discover reasonable arrangements and choices of engineered pesticides. Lately, there has been broad concern in "GRAS" (mostly considered as protected) compounds. Naturally occurring bioactive compounds of plant source are cases of "GRAS" compounds. Spices have extraordinary antimicrobial activity viz., cinnamon, clove, mustard, vanillin and so forth. While among the herbs; basil, oregano, rosemary, sage and thyme are viewed as best antimicrobial agents. All these are considered as the brilliant source of essential oils. Frequently, phenols and their derivatives present in the essential oils show unbelievable antimicrobial movement [50-52].

The broad antifungal action of these essential oils is very much perceived [53-60] and there have been numerous reports on the antimicrobial impacts of essential oils on postharvest pathogens [36,60]. Essential oils are comprised of numerous assorted volatile substances and the elements of the oil, frequently varies among diverse species. It creates the impression that the antimicrobial impacts are the outcome of numerous synergistically acting compounds in the defence framework.

Essential (volatile) oils acquired from the plants often exist in consumable, restorative and home grown plants, which reduce inquiries with respect to their safe and sound use. Essential oils and their ingredients have been broadly used as seasoning agents in foods for the most antiquated history of this planet, and it is very much perceived that many have a broad range of antimicrobial action [51,61-62].

The structure, association and as well as presence of diverse functional groups of the essential oils play a conclusive role of their antimicrobial action. Normally compounds with phenolic groups are most capable [50,63]. Among these, oils extracted from clove, oregano, rosemary, thyme, sage and vanillin have been observed to be most continually competent against an extensive variety of microbes.

The majority of the essential oils has been studied *In vitro* to affirm their inhibitory role against postharvest organisms [64-67]. Essential oils of plant origin are by and large the blends of various components. The oils that have elevated levels of cinnamamic aldehyde (cassia oil, cinnamon bark), eugenol (allspice, cinnamon leaf, clove bud and leaf, and cove), and citral are usually considered as firm antimicrobial specialists [68-69]. It was demonstrated on the premise of few studies that the borneol and different phenolics in the terpene division of sage and rosemary oil are responsible for antifungal activity. The volatile p-cymene, carvacrol, terpenes and thymol are no doubt responsible for the antifungal action of thyme, oregano and appetizing. The terpene "thejone" in sage, and a congregation of terpenes (borneol, camphore, 1,8 cineole, a-pinene, camphone, verbenonone and bornyl acetic acid derivation) in rosemary oil are responsible for antimicrobial activity [69].

Apropos 45 diverse plant oils against three fungal strains, viz. *Candida albicans, Aspergillus niger* and *Rhizopus oligosporus* were assessed by Chao et al. [70] for their antifungal action. They found that the oils obtained from coriander, cinnamon bark, lemongrass, rosewood and savoury were discovered potent against the three parasitic strains. Diverse types of oil displayed observing action against the chosen infectious strains. Case in point, few of them were proficient just against *Candida albicans*. Pine (*Pinus sylvestris* L.), and (*Angelica archangelica* L.) oils that were utilized as a part of their study were not revealed as successful against *R. oligosporus* and *A. niger*, which have an advantageous relationship with the mycorhizae found in the plants from which the oils were isolated. Despite the hindrance of vegetative development in fungal strain, varied oils additionally repressed the mycotoxins formation by these parasites.

Essential oils of numerous plants have likewise been appeared to hamper the mycelial development of parasite and their conidial germination. The oils of dictamus, marjoram, thyme, and oregano totally hindered the mycelial development at fixation 250–400 µg mL^{-1}, while at the centralization of 250 µg mL^{-1} these oils restrained the conidial germination of parasite, *Penicillium digitatum*. The oils of rosemary, sage and lavender demonstrated 29.5%, 9.0% and 24.0% (% of untreated control) mycelial hindrance, individually. At 1000 µg mL^{-1}, dictamus, thyme, and oregano oils were found as powerful fungitoxic operators because of the formation of hydrogen bonds amid the hydroxyl group of oil phenolics and active sites of aimed enzymes [71].

Then again, the viability under *In vivo* condition and realistic activity of just a couple of the essential oils have been studied heretofore. Many of the essential oils have been perceived as defenders of stored produce from biological dwindling. A few reports are likewise accessible on essential oils with respect to their activity in upgrading the storage life of produce (leafy foods) by halting common parasitic spoiling. Dubey and Kishore [72] found that the fundamental oils from the leaves of *Citrus medica*, *Melaleuca leucadendron* and *Ocimum canum* were competent to defend several stored food commodities from bio-deterioration caused by *Aspergillus versicolor* and *A. flavus* reported active at concentrations between 500 and 2000 µg mL^{-1}.

These essential oils were reported active at concentrations between 500 and 2000 µg mL^{-1}. The capability of utilizing essential oils by splashing or plunging to control postharvest rot has additionally been seen in fruit and vegetables [73-75]. Thymol is an essential oil constituent of thyme (*Thymus capitatus*) and has been used as powerful restorative drug, food stabilizer, and beverage constituent [76-77].

Fumigation of sweet cherries with thymol was discovered successful in the control of postharvest grey mold rot caused by *Botrytis cinerea* [78], and chestnut decay created by *Monilinia fructicola* [79]. Fumigation with thymol at 30 µg L^{-1} lessened the event of grey mold decay from 35% in untreated organic product to 0.5% [80]. It was similarly found that thymol was more powerful to control chestnut decay side effects on apricots, and fumigation of plums with nearly low focuses, for instance, at 2 or 4 mg L^{-1}

can essentially diminish postharvest break down without the frequency of a phytotoxicity. There are similar reports in regards to carvone, a monoterpene, isolated from the essential oil of *Carum carvi* which has been appeared to restrain sprouting of potatoes amid capacity procedure and it additionally displayed fungicidal action in shielding the potato tubers from decaying devoid of changing the flavor and worth of the treated product, and without showing mammalian poisonous quality [81-82]. It has been presented under the exchange name 'TALENT' in The Netherlands. The essential oil extracted from *Salvia officinalis* has likewise indicated supportive quality in upgrading the capacity life of a few vegetables by shielding them from parasitic decaying [83]. Tripathi et al. [84] reported the treatment of citrus with the vital oils of *Mentha arvensis*, *Zingiber officinale* and *Ocimum canum* has been found to control blue mold, along these lines upgrading time span of usability.

They reported the possible action strategy of essential oils of *Citrus sinensis* in opposition to *Aspergillus niger*, a main pathogen for several post harvest decays of fruits. The effect of essential oil of *Citrus sinensis* on morphological changes in *Aspergillus niger* was viewed under light microscopy also. The actions of *C. sinensis* oil on the morphology of *Aspergillus niger* hyphae was observed by SEM discovered detrimental changes in the morphology of the hyphae, which appeared rigorously collapsed and compressed due to lack of cytoplasm. The citrus oil as fungitoxic agent was reported by Sharma and Tripathi [60] which present two main characters, the first, its natural origin that provides more safety to people and the environment and, the second, it has a low risk for resistance development by post-harvest pathogens. It is usually thought that it is difficult for the pathogens to develop resistance against such an intricate mixture of oil components that have a diverse range of antifungal mechanisms.

The remarkable benefit of essential oils is their astounding bio-activity in the vapor stage, an element that makes them striking as impending fumigants for the assurance of stored product. These essential oils are thought to take an interest with a distinct role in the plant defence systems against the assault of phytopathogenic microbes [85].

The fungitoxic adequacy of the key oils might be because of astounding synergism in the midst of their parts. Subsequently, there would be a slight probability of the development of safe races of growths after the use of essential oils to to fruit and vegetables. Despite the fact that, the fungitoxic properties of the unpredictable constituents of numerous higher plants have been accounted for, anyhow, humble consideration has been paid to the fungitoxicity of these substances in combination. This acquaintance is needed subsequent to the fungitoxic adequacy of a large portion of the fungicides has been accounted for to be upgraded when they are composite [86-89].

The augmentation of fungitoxic impending of mixtures of the oils may be due to the cooperative act of two or more substances present in the oils [90]. This synergism would be profitable in postharvest wellbeing on the grounds because the pathogen would not fluently achieve resistance against these components. Nonetheless, more work on synergistic activity of plant products *In vitro* and *In vivo* conditions still required. The accessible content was additionally quieted on the activity sketch of the essential oils when utilized as postharvest fungitoxicants. But few recent reports have studied the mode of action of these essential oils against post harvest pathogens [60].

They reported the conceivable method of activity of essential oils of *Citrus sinensis* contrary to *Aspergillus niger*, a primary pathogen for a few post harvest rots of natural products. The impact of essential oil of *Citrus sinensis*, on morphological changes in *Aspergillus niger* was seen under light microscopy in addition. The impacts of *C. sinensis* oil on the morphology of *Aspergillus niger* hyphae analysed by SEM uncovered inconvenient changes in the morphology of the hyphae, which showed up thoroughly caved in and compacted because of absence of cytoplasm. The estimation of Sharma and Triapthi [60] discovered impressive backing from the discoveries of the surface adjustments in SEM study as saw by Billerbeck et al. [91] utilizing *Cymbopogon nardus* essential oil against *A. niger*. Zambonelli et al. [92] equally reported comparable discoveries in instances of *Pythium ultimum* and *Colletotrichum lindemuthianum* which were treated with thyme and lavender oil. Such adjustments incited by essential oils might be identified with the intercession of essential oil components with enzymatic responses identified related to wall synthesis, which consequently affects fungal morphogenesis and growth.

In a GC/MS analysis, a total of 32 individual volatiles have been identified in the lavender ISO Standard 3515, including all 11 volatiles. The analysis of three parallel hexane extracts from the same inflorescence samples showed remarkable reproducibility of the determined relative abundances of the analysed volatiles. The relation of the GC/MS data on inflorescence volatiles with the composition of the distilled lavender essential oils was evaluated through analysis of the volatile recovery rates for the analysed cultivars and excellent results were obtained [93].

In vitro and *In vivo* studies were also conducted by some researchers. They used poisoned food technique for *In vitro* studies, and for *In vivo* studies, in their study the Kinnow fruit were pre-inoculated with pathogens (*Penicillium digitatum* and *P. italicum*), that were treated with different essential oils and then stored at 5℃ ±1℃ temperature and 85–90% RH). Their results indicated that all essential oils inhibited the growth of both pathogens over untreated PDA plates, but the inhibition was reported strongest by lemon grass oil. Likewise, under *In vivo* conditions, all essential oils influenced the incidence of decay, decay thrashing, wound diameter, respiration rate, ethylene formation, overall suitability and physiological loss in weight but lemon grass was the most effective. Further, the incidence of *Penicillium italicum* was more prominent in fruits than *P. digitatum,* though, it was reverse under *In vitro* conditions. The decay rot at all stages of storage was reported less in EOs treated fruits than untreated fruits, thereby increasing their storage life significantly. Thus, it was evident proved that essential oils have the potential to control green and blue mold without causing any injury or harmful effects on Kinnow mandarin, and EOs can be suggested as a safe and a sound system for extending its shelf life while maintaining fruit quality [94].

Zambonelli et al. [92] reported hindrance in parasitic development connected with degeneration of fungal hyphae after treatment with *Thymus vulgaris* essential oil. The citrus oil as fungitoxic agent was reported for by Sharma and Tripathi [60] which present two fundamental characters, the main, its regular source that gives more wellbeing to individuals and the environment and, the second, it has a generally safe for resistance improvement by post-harvest pathogens. It is typically felt that it is troublesome for the pathogens to create resistance against such an intricate blend of oil components that have a various scope of antifungal systems.

5. CONCLUSION

Remarkable outcomes on the utilization of natural eco-friendly products to manage postharvest decaying agents have been obtained that exhibits the level of concern toward the development of competent natural and eco-friendly fungicides that must be as proficient or better than man-made fungicides. Regardless of the fact that, more than 10,000 secondary metabolites of plant origin have been characterized artificially for their capacity as antagonistic to pathogenic chemicals, however, the aggregate magnitude of plants with powerful phytochemicals is around 400,000 or more [95]. A large number of these substances can play a key undertaking in the host–pathogen merger. Plant derived metabolites are relatively more eco-friendly and invariably non-residual in character because of their natural origin [96]. Various plants have a long history for their non-harmfulness, at any rate, when taken orally and it is a demonstrated truth. This wellbeing perspective is exceptionally imperative in formulations of such types of product for worthwhile purposes since it affects the expense of advancing and enlistment of new pesticide products.

The operating expense on the innovative work of plant based fungicides is much less compared to that on fungicides of a chemical nature [97]. Most of the chemical based fungicides have a considerably development period and registration time frame (7–10 years), with elevated cost of registration. This cost is generally because of the worry over conceivable elevated creature toxicities of such supplies that interest long-standing toxicological assessment based on trial creatures. Naturally, because of their object specificity, in general require only instant toxicological tests [98-99].

Even though the development of natural products to safeguard the postharvest decompose of perishable products is in its infantry, these products have the impending to be harmless fungicides and will substitute the artificial ones [100-110]. A well designed and incessant search of natural products may acquiesce safer optional control method comparable to pyrethryoids and azadirachtin which are being utilized in diverse regions of the globe as ultimate natural fungicides. Suitable organoleptic tests are also required prior to any approval. The produce should be efficient even for small length treatments due to the restricted postharvest life of fruit. The treatment should not have any consequence on quality factors such as flavour, acidity and aroma. The least proper dosage of the chemicals for practical application should also be worked out. Trusting in view, the virtues of the botanicals as postharvest fungi-toxicants, the products that are found effective all through the *In vitro* evaluations, should be acceptably experienced for their practical effectiveness based on *In vivo* trials, safety limit profile and organoleptic tests.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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