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Sustainable botanical products for safe post-harvest management of perishable produce: A review

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ABSTRACT

Purpose: The objective of this review is to study the effect of plant-based products on post-harvest management of the horticultural crops. Today when the horticulture crops are loaded with pesticides, the produce does not reach the consumer in a fresh and healthy form, it becomes imperative to look for alternative products which are safe, non-toxic, environment-friendly and does not disturb the eco rhythm. **Findings:** Plant-based products can be utilized at post-harvest stage washing agents, botanical sanitizers, edible coatings (protein, lipid and starch-based, anti-microbial agents, cushioning materials during transport, preservatives and as control measure for storage diseases as various bioactive constituents. To minimize dependence on synthetic pesticides, the use of plant-based antimicrobial substances which includes essential oils, glucosinolates, volatile compounds, acetaldehydes and jasmonates at various stages of plant growth may help in the management of crops, phytopathogens and pests in a very effective manner and will provide an alternative method for sustainable agriculture and opens up a new dimension of research for the scientists. **Limitations:** The author has used all the available resources but some excellent literature is still limited for including in the study due to non-availability to resources. **Directions for future research:** Plant-based products and botanical extracts opens up a new dimension of research. Scientists can easily utilize these for plant protection, cushioning, disease management during storage, extending the shelf-life. Scientists can standardize the edible coatings for various fruits, anti-bacterial, nano-emulsions based delivery of edible coating materials and aromatic extracts for disease management.

INTRODUCTION

Food and nutrition security is the primary aim of the farmers, horticulture scientists and government as it's the basic requirement for living. One of the main global challenges that the world today faces is to provide nutritionally rich and safe food for the ever growing population while ensuring soil health, human health and environment. Food and Agriculture Organisation states that food production should increase by 70% to reach 9 billion tonnes by 2050 (FAO, 2011). Horticulture crops are a rich source of essential nutrients like carbohydrates, proteins, minerals, antioxidants, flavonoids, vitamins and dietary fibers. They play a significant role in maintaining nutritional security of the world's population as crucial as cereal crops play in food security. To increase the production of horticultural despite monsoon, unseasonal rains, floods and hailstorms, the farmers with the help of horticultural scientists and government have played an essential role since the advent of human civilization. Due to improper handling practices, inadequate storage facilities and poor transportation, it has been reported that 15-40% of the produce is lost because of which the per capita demand could not be fulfilled. The farmers are not getting lucrative benefits during surplus production and fragmented supply chain.

There is the use of lots of chemicals for waxing, coating and shelf life enhancement. The produce we get is totally laden with chemicals and hazardous for human health, plant health, soil health and the environment. The recent usurp in the cancer cases can also be attributed to this though confirmed links are not available. Similarly, postharvest food loss and food waste are one of the most significant contributing factors to worlds rising food insecurity, under-nutrition and malnutrition. It occurs all over the world, but in developed countries, it is mostly at the consumer end (food waste) whereas in developing countries it is throughout the supply chain starting from farm harvest to retail shelf which directly impacts the lives of millions of poor, smallholder farming families every year. Postharvest losses can be explained as the degradation in three aspects i.e., value, volume and nutrition from farm to consumer. The most common causes of the losses are rough handling, inadequate cooling, no infrastructure facilities at the farm, breakage of the cool chain, improper temperature maintenance, inadequate packaging materials, rough handling during loading and unloading and dumping of the produce at the market yard.

These factors incite the scientific community to look for the alternate materials to be utilized for management of the crop at different stages shifts our focus to the use of plant-based botanical products and extracts. Further causes which enhance the application of botanicals in the handling of perishable produce are rise in urban middle-class population throughout South Asia which is increasing day by day also shifts the focus towards nutritive and healthy foods coupled with climate change puts substantial pressure on the planet's resources. In the changing environmental scenario, climate change, rapid adulteration of the crops, deteriorating soil conditions, the scientific communities focus is shifting towards utilization of plant-based products for pre and post-harvest management of crops to sustain the environment and develop a shift from chemical-based pre and post-harvest management to plant-based pre and post-harvest management. Botanical based plant management will have specific control on various important issues of plant health control and will not also cause pollution problem to the environment, soil, plant health, and human health. The present review deals with botanical products that have been and can be utilized for postharvest management of the horticultural crops.

Applications in post-harvest management

A range of bio-agents, chemicals, and plant-based products have been used to delay or slow down the ripening process, for reduction of post-harvest losses, maintenance of color and produce quality by lengthening the metabolic activities of the harvested fruit crop. These bio-agents serve as an important barrier for respiration, transpiration, restrict the growth and range of microorganism, reduce shriveling and ultimately lead to enhanced shelf life of thereby increasing their marketability period. In these, the botanicals provide the safest alternative for post-harvest management of horticultural commodities. Postharvest management includes practices from harvesting, washing the produce, sanitization of the fresh produce, bio-based edible coating and packaging and cushioning for quality and management of diseases found during storage and transport.

Botanical washes

Agriculture Chemicals and pesticides are specifically made in such a way that they are “waterproof" and not washed by rain or irrigation water. Many horticultural commodities like grapes, apples, cucumbers, citrus fruits are also wax coated to preserve their quality and maintain the appearance of the produce from the farm to the consumer home. In addition to agricultural chemicals and other obnoxious residues, more than 20 persons may have handled the fruit or vegetable before it reaches the consumer. Botanical washes perform their action by effectively and safely removing coated wax, soil particles and agricultural chemical residues. It breaks through wax and applied chemicals leaving fruits and vegetables completely safe and clean. It uses ingredients from citrus, corn, and coconut and various other crops. A detailed description of botanical washes is presented below:

Coconut based washes

Coconut is an important crop whose each and every part can be utilized. Coconut-based soap is good for scrubbing off the wax, microbes, and soil from delicate fruits and vegetables. It is free of fragrance and adulterants. Virgin coconut oil has antimicrobial activity and is rich in medium- chain fatty acid (MCFA) which have effective ability to inhibit some species of the virus by breaking their membranes (DebMandal & Mandal, 2011). Kim and Rhee (2016) presented that MCFAs were antibacterial agents against *Escherichia coli*. The antimicrobial effect of MCFAs and VCO was studied by Shilling et al. (2013) and found it effective against *Clostridium difficile* and concluded that the growth of microbe was limited to exposure of bacterial cells to 0.15-1.2% coconut oil. The MIC of Free fatty acid (FFA) showed their anti-bacterial activity against both types of bacteria (gram-negative and gram-positive) (Nugyen et al., 2017).

Citrus peel extracts

Citrus is the most versatile group of horticultural crops which has uses in many applications. Citrus peel extracts can be used as food wash. Citrus washes reduce the harmful effect of food poisoning as it eliminates harmful micro-organisms and enhances the post-harvest life and maintains the quality of raw and cooked foods before packaging and distribution to retailers. Citrus peel extracts keep the produce fresh two-three times longer than conventional washes which result in very low spoilage of the produce. The lemon peel contains an antibiotic called coumarin in the form of a flavoprotein which acts as a defense mechanism against pathogenic bacteria and inhibits DNA gyrase i.e., topoisomerase II – the enzyme which is responsible for negative super coiling of DNA before its translation (Kupwade et al., 2017). Citrus peel extract shows the presence of various phytochemicals including alkaloids, sterols, saponin, steroids, and terpenoids. Ali et al. (2017) has done plating of Gram positive, *Staphylococcus* *aureus* and Gram -ve *E. coli* and fungus like *Candida albican* and *Trychophyton rubrum* and treated them with methanol extract of citrus peel in respect of control and reported that the minimum inhibitory concentration required for good antimicrobial activity was only 100 µg/ml.

The benefits of the citrus-based peel extracts are that is organic, non-toxic, completely safe, effective against fungi, viruses and bacteria, including *Clostridium botulinum, Escherichia coli, Staphylococcus aureus, Listeria monocytogenes, and Salmonella choleraesuis*.

Vinegar

Vinegar is one of the best natural sanitizer known to human kind from times immemorial. Vinegar can be used to sanitize, clean or surface sterilize variety of horticultural crops. The effectiveness and extent of sanitation depend upon the nature of the disease-causing agent. The effectiveness of vinegar relies on the type of bacterium or fungus present on fruits or vegetables, its concentration, water temperature and the amount of time produce is exposed to the vinegar. Zander and Bunning (2010) reported that adding vinegar to the water in a ratio of 1:2, followed by a clear water rinse reduces bacterial contamination but can affect texture and taste.

Apple cider vinegar shows its activity to the presence of acetic acid, which causes a loss in cell integrity. Its antimicrobial activity against *E. faecalis* is as efficient as 5% sodium hypochlorite (Mohanty et al., 2017). Apple cider vinegar can also be used as a food wash to remove bugs, parasites, bacteria, and other toxic residues.

Anti-bacterial sanitizers

Anti-bacterial sanitizers are derivative of natural and organic ingredients made from specially identified organic acids and bioflavonoids, which are derived from various fruits and vegetables. This sanitizer does not kill the organism but destroys the cellular membrane of microorganisms. These sanitizers can destroy 99.86% of a test culture of *Pseudomonas* with only 10 minutes of exposure and show a reduction of 99.99 % in *S.aureus* within same time; also it is not toxic to plants, human or animals.

These are effective against a broad spectrum of microorganisms and have high anti-bacterial activity, is non-carcinogenic, non-mutagenic, non-corrosive, non-toxic, non-tainting and non-volatile and is not washed away from the surface. They act by destroying the cell walls and can break down the biofilm. It is known to be adaptable to a wide pH level ranging from 2 to 12 and can tolerate temperatures up to 60°C.

In horticultural commodities packaging and processing, they are used for protection from human pathogens during fruit harvesting, sorting, grading and transportation. It is an excellent alternative to per-oxyacids and chlorine for washing the raw commodity before processing as it provides effective and safe residual sanitizing, without damaging delicate foods.

Edible packaging materials (coatings and films)

Edible films and coatings have resulted in the growing areas of interest in recent years; many scientists have reported their effectiveness when added directly to the food systems for declining microbial contaminations. Edible coatings undertake action as a semipermeable barrier, thereby giving enhanced protection for foods against the gas exchange, moisture loss, solute migration, and oxidative resperative reactions (Quirós-Sauceda et al., 2014).

The rapid diffusion of these micro-organisms in the food and their interfaces with different food components may decline their activity during storage and transport, thus limiting their usage in the horticulture industry. This limitation can be overcome by the usage of these coatings as polymeric mediums for enclosing the antimicrobial agents, which can serve as a promising source to reduce these problems by slowing their migration rate onto the surface of food and thereby maintaining the concentrations at a critical level over long duration of storage for microbial growth inhibition (Gyawali & Ibrahim, 2014). In comparison to direct application, this method imparts an entirely restricted functionality without affecting its organoleptic characteristics. Thin layered edible polymer coatings are developed from natural polymers and are applied on the surface of the foods by different mechanical processes, such as brushing, electrostatic deposition, spraying and immersion (Amon et al., 2014). The characteristics of edible coatings depend on various chemical and physical factors like chemical structure, composition, viscosity, thickness, crosslinking degree, processing conditions i.e., pH, temperature, concentration and form of additives whether it is emulsifiers, plasticizers, or cross-linking agents. Recent advancement shows that incorporating different bioactive compounds improves the performance of edible coatings. The bioactive compound such as antimicrobial agents increases their antimicrobial properties and reduces biochemical deteriorations such as texture breakdown, enzymatic browning, and development of off-flavors (Valdés et al., 2015). These edible coatings containing essential oil reduced microbial contamination by having antimicrobial activity against a number of foodborne bacterias, however, this activity can be increased by increasing the concentration of essential oil in edible coating composition, but the increase in concentration should be optimized in such a way that it should not affect the sensory properties of fresh commodity as essential oil has a characteristic aroma due to the presence of phenols.

The efficacy of these edible coatings to preserve quality and freshness of fresh fruits and vegetable can be attributed to finding the appropriate material for the coating that can maintain desired internal gas concentrations depending on the gas exchange and rates of transpiration of the particular produce. The wetting ability control of coatings compositions is crucial as it affects the thickness of the coating and its permeability characteristics (Casariego et al., 2008). Along with this, maintaining the surrounding atmosphere of the storage area specifically relative humidity and temperature have an impact on the internal temperature and atmosphere of fresh fruits, as it may strongly impact the respiration rates and permeability of coating membrane. The relevant characteristics of edible coating which increases their applicability are that they have very good barrier properties to moisture, important gases i.e., O_2, CO_2, and ethylene, enhances the appearance of the produce and facilitates handling, add colour and they also contain many active components such as vitamins, antioxidants, enhance nutritional composition without affecting its quality and provide a protective covering to increase their shelf life.

Methods of application

Antimicrobials in the food system can be applied in different ways to the food systems. The two major modes of applications are described below:

Direct application and indirect application

The direct application acts by altering the dispersal of active compounds on the food margin and maintain their absorbtions at the acceptable level for inhibition of microbial activity and growth during storage durations (Gyawali & Ibrahim, 2014). Indirect application has a more localized effect without affecting the organoleptic properties of the products as reported by several scientists. Quirós-Sauceda (2014) stated that indirect application will also act as a semi-permeable barrier providing enhanced protection against solute migration, moisture loss, gas exchange, respiratory and oxidative reactions.

Nanoencapsulation based application

Nanoencapsulation based application allows us to incorporate the lipophilic and hydrophilic substances with anti (microbial and oxidant properties) that would be released during the storage period of horticulture commodities to increase their shelf life. Donsi et al. (2012) reported that the nanoencapsulating systems are abundantly used as antimicrobial delivery systems for food currently, among these nanoemulsions have received particular mention as they can be made according to the specific requirement with natural food-grade ingredients, their production process (high-pressure homogenization) can be easily scaled up in the industry process.

Nanoemulsions

Nanoemulsions are colloidal systems in which the oil phase is dispersed in an aqueous phase, such that thin interfacial layers of emulsifying molecules surround each drop of oil (Ranjan et al., 2014). The nanoemulsions particle size varies from 50-500 nm. McClements and Rao (2011), reported that nanoemulsions are heterogeneous systems within nanometric size (<100 mm) and comprises of 2 liquids which are immiscible like oil and water with an emulsifies to make a homogeneous and stable phase. Oil-in-water Nano emulsions are most common and have attracted the attention of a wide range of scientists as delivery systems for food. They comprise of nanometric oil droplet dispersed in a continuous aqueous phase, each droplet surrounded by a thin interfacial layer made of biopolymer or food-grade emulsifier.

Multilayer coatings

Multilayer coating is a promising approach with a controlled release mechanism to provide better antimicrobial agent retention. This innovative and new approach lies in including into the multilayered system the antimicrobial compounds formed by the layer/barrier layer electrostatic deposition technology, which consists immersing of the solid substrates into oppositely charged polyelectrolytes film-forming solutions and then drying to remove the excess solution at the surface (Fig. 1).

These multilayered coating structures act as very useful delivery systems for antimicrobials, as the two layers inner and barrier layer manage the diffusion rate of antimicrobial components inserted embedded in the matrix layer and thereby preventing their migration on the outer side of the storage and transport package (Mustafa et al., 2015). The rate of diffusion of these antimicrobial agents through multilayers is depended on a few factors like, the tortuosity of the migration pathway, assembly thickness, the interactions between the antimicrobial agent and the polymer.

Emulsifiers have a very important part in expanding the role of nanoscale oil droplets by declining the pressure between the different faces and preventing the aggregation of nanodroplets by creating repulsive interacting forces. The choice of the type of emulsifier is one of the key factors to control the interfacial properties, more importantly, the charge, thickness, rheology, and size of the droplet, as well as the rejoinder of nanodroplets to various environmental stimuli i.e., pH, temperature, enzyme activity and ionic strength. McClements and Rao (2011) reported that the aptitude of nanoemulsions for the enclosing and releases of functional compounds while acting as matrices is dependent on the molecular characteristics, composition, microstructure and the nanoemulsions properties also.

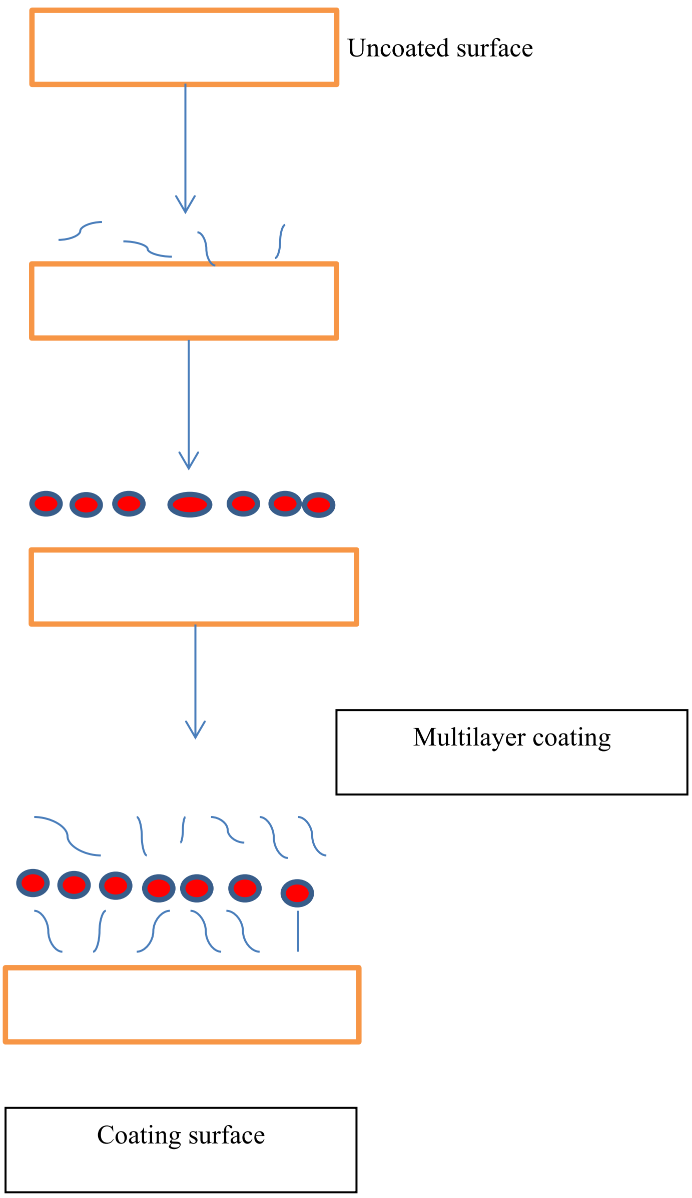

Fig. 1. Multilayered coating formation on fruit surface (Dubey et al., 2018)

Biochemical constituents of edible coating

Many polysaccharides such as sodium alginate, chitosan and hydroxyl propyl methyl cellulose are extensively used as edible coating material for minimally processed and also fresh fruits and vegetables because of the vital property like selective permeability to major gases i.e., O_2 and CO_2 and outstanding film-forming properties. These coatings act by slowing the respiration rates which in turn delays ripening and senescence that commonly causes reduced shelf life. These edible coatings by lowering the respiration rate work in a way similar to the storage of perishable crops under modified/controlled atmosphere (Janjarasskul & Krochta, 2010).

Incorporation of bioactive compounds both in the inner (bioactive enriched oil phase) and outer (bioactive enriched emulsifier layer) as shown in the Figure 2.

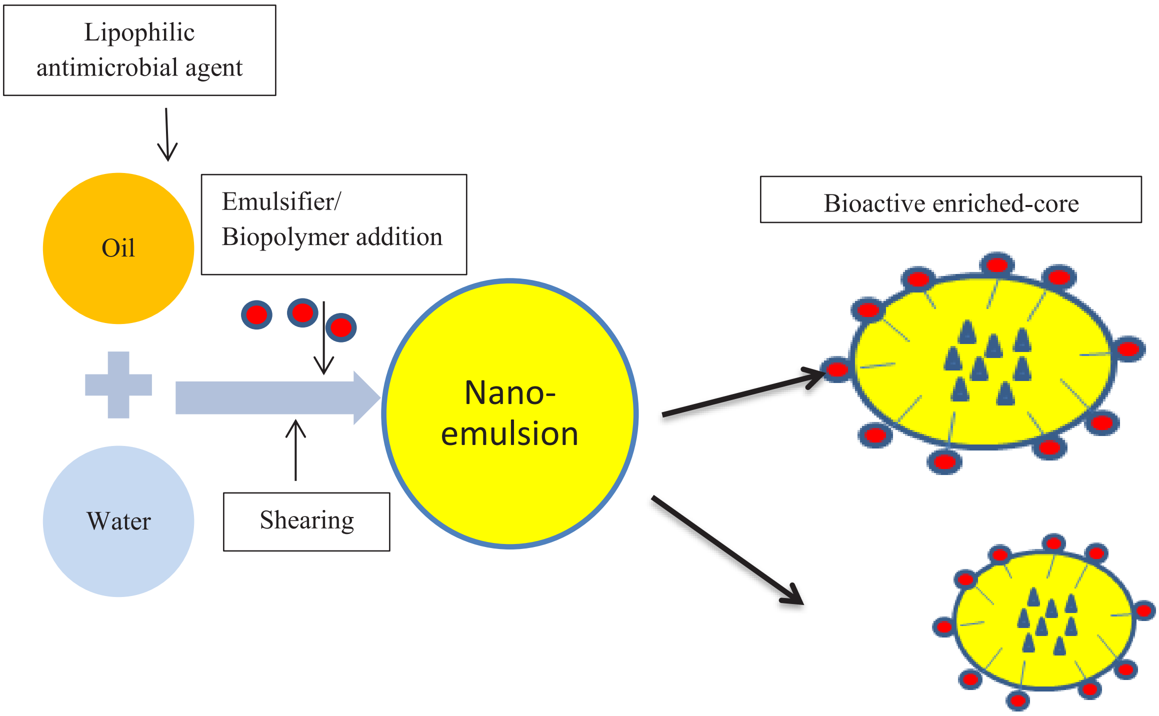

Fig. 2. Encapsulation of bioactive compounds (Dubey et al., 2018)

Protein-based coatings

Protein-based edible films can serve as an essential substitute for edible packaging materials, over the synthetic ones as they are natural and safe. They can be used to package individual portions of the foods, specifically products, which are not today packed separately for affordability and other reasons, such as size for example cashew nuts and beans. These films can also be used inside heterogenous foods for creating a partition and will act as an interface between different layers of components (Wittaya, 2012)

Starch-based coatings

Although starch has a low resistance to water and forms a weak barrier to water due to its hydrophilic property, it can be used as an edible coating when formulated with biopolymers or material hydrophobic in nature. Kamble and Chavan (2005) reported that perfectly well-matured custard apple fruits were treated with Corn starch (7%) and guar gum extended the post-harvest shelf-life by 6-8 days and retain its optimum quality parameters.

Wijewardane and Guleria (2009) suggested that Apple coated with starches in combination with bio-oil when stored under low cool temperature conditions at 2±1°C, 80-90% RH and at 18-25°C and 65-75% RH for 150 and 45 days respectively result in most effective in retaining the overall quality, overall acceptance as it causes minimum changes in most of the physical and bio-chemical characteristics. All treatments caused a significant decrease in the physiological loss in weight, firmness of the fruit, maintained pectin content and titrable acidity during storage.

Lipid-based coatings

Vishwasrao and Ananthnarayana (2017) suggested Palm oil contains methylcellulose which makes an edible coating material and has the potential to maintain the quality of sapota fruit.

Various tests revealed that when this coating was applied on sapota fruits the shelf life extended to 7 days at temperature 24 ± 1 °C and relative humidity 65 ± 5%. Mishra and Khatkar (2009) observed that coating of ber fruits with peanut oil emulsion (5%) was the most effective post-harvest treatment which enhanced consumer acceptability and maintained quality of ber fruits. The extended shelf-life of peanut oil-coated ber fruits was 8 and 16 days at ambient and refrigerated storage.

A combination of protein, carbohydrate and fat in the identified ratio can be developed as an appropriate coating material for specific fruits and vegetables.

Food preservative

Perishable food items require preservation from spoilage during their entire supply chain i.e., handling, preparation, storage, and distribution to extend their shelf life for desired time. Food safety and quality face many challenges such as demand for ready to serve, ready to eat and minimally processed food products, food trade globalization and distribution from the centralized processing facility. Bacteria and fungi can contaminate food products causing undesirable reactions that deteriorate organoleptic properties i.e. flavour, odor, sensory, colour and textural properties of foods.

Major concern for food preservation is rapid microbial growth, which is the primary cause of much food-borne illness. Survival and growth of these common spoilage, pathogenic and damaging microorganisms such as *Escherichia coli*, *Listeria monocytogenes, Staphylococcus aureus, Clostridium perfringens, Salmonella, Bacillus cereus, Campylobacter, Saccharomyces cerevisiae and Aspergillus niger* in packed foods are impacted by a various internal and external factors like pH, oxygen, temperature, time and relative humidity etc. (Singh et al., 2003).

Many antimicrobial compounds have been tested against the artificial synthetic preservative available to study their efficacy to control food spoilage and controlling food-borne pathogens for maintaining food quality. These can be classified into different groups on the basis of source of production. It includes mainly plant-derived compounds i.e., essential oil and plant extracts, animal-sourced antimicrobial agents, bacterial cell metabolism derived antimicrobial substances (Lucera et al., 2012), and antagonistic microorganisms.

Various techniques for preservation techniques such as drying, salting, acidification and heat treatment are in use in the food industry have been used in the food industry to prevent the growth of pathogenic microorganisms and spoilage in foods (Davidson & Taylor, 2007). To find natural alternatives against artificial preservatives to prevent bacterial and fungal growth, numerous efforts are conducted in recent years in the food industry. Owing to increased consumer awareness for healthy food, the persons are accepting foods preserved with natural additives as compared to synthetic pesticides.

To inhibit the growth of uninvited microorganisms in food, the antimicrobials can be directly added to the component by coating it on the surface or by incorporating into the packaging itself. Directly incorporating active agents into the food gives an instant but a concise period reduction of bacterial populations, whereas the antimicrobial films continue to act for a prolonged period and are more effective. (Appendini & Hotchkiss, 2002; Hanušová et al., 2009).

The essential oils are primarily used as a flavoring agent in the food industry, but they can also be a very exciting potential source of natural antimicrobials for the preservation of food. However, for their appropriate application as preservatives in the food industry, a complete know-how about their characteristics is required which includes their minimum inhibitory concentration (MIC), targeted organisms range, their mode of action and impact of food matrix components for their properties.

Cushioning materials

The packaging is an important aspect of the protection of perishable commodities and serves as an essential step during storage and transport. Rough edges of containers also enhance the usage of cushioning materials. Cushioning materials used for packaging fresh commodities are mostly derived from plants. Natural cushioning materials are mostly used for fresh horticultural produce. Paper shreds and agricultural waste commodities like straw, hulls and leaves are examples of natural cushioning materials. A detailed description of these plant-derived cushioning materials are described below:

Paper shreds

Sheets of shredded newspaper or newspaper are most commonly used as a lining material in bamboo baskets, plastic crates and CFB boxes to protect the commodities from damage (FAO, 2011). Packaging perishable product in shredded papers or tissues is the most economical and eco-friendly packaging solution for safe transport over long distances. In Mango, paper cuttings are also used as a cushioning material inside the box and the quantity will vary depending upon the size and the capacity of the boxes.

Agricultural waste

Agricultural waste such as paddy and wheat straw, leaves of many plants, coconut fiber and coconut husk, cotton and rice hulls, are compostable and sustainable. Coconut fiber, rice hulls and straws of wood are in use from various decades to prevent damage from mechanical injury to fruits like papayas and mangoes during the distribution (Castro et al., 2012). Chandra and Kumar (2012) reported the use of Teak and Banana leaves as cushioning materials for guava fruits during storage. Some agricultural waste commodities used as a cushioning material for fruits and vegetables are discussed below:

Paddy straw

Paddy straw is a natural cushioning material widely used for packaging of fruits and vegetables for near or in country markets. Cushioning by paddy straw is done by keeping the cushioning materials between rows of fruits and layers of fruits inside the boxes. The function of paddy straw is to fix the fruits and vegetables inside the packages and prevent them from damaging by vibration and impact. It also serves as a cushion during unloading the produce on the ground.

CFB boxes with the paddy straw as the cushioning material has been found to be the best packaging material for packing & the transportation of kokum fruits (Raorane, 2003). In a report released by ICAR (2009), it was reported that Khasi mandarin packed within cardboard boxes lined with cushioning material as and 2% $CaCl_2$ solution dip, along with recorded better shelf life (33.7 days) with better fruit quality (ICAR, 2009).

Coconut fiber

Coconut fiber is becoming one of the most used eco-friendly cushioning material among all as it is a reinforcing composite, acoustic and has very good thermal insulation properties. Coconut fiber is extracted from the husk of coconut and applied as a cushioning material for perishable produce. It is the fibrous material found between the internal and the external shell of the coconut. Coconut fiber along with the wood straw, is used to prevent damages to fruits during the transport of the produce at different destinations. (Castro et al., 2014).

Leaves
Leaves of various plants (particularly Cassia, Polyalthia, Litchi and Mango) are used as cushioning materials. Chandra and Kumar (2012) used the leaves of banana and teak as wrapping materials for guava fruits. Chauhan and Babu (2011) conducted a study on apple and used leaves of *Azadirachta*, mentha, melia, banana, walnut, basooti, and camphor as cushioning materials. The study brought forth that camphor leaves were the best cushioning material and were able to maintain the best fruits characteristics. This effect of camphor leaves can be ascribed to volatile generated by the camphor leaves which can destroy any budding incipient infection on fruit, which destroys the fruit during storage by creating rotting (Saxena et al., 1981).

Rice hulls
Rice hulls are natural and environmental friendly waste commodities which are very light, completely bio-degradable, difficult to burn and resistant to moisture as also preventing its spread. These are of two types- loose rice hulls and bagged rice hulls. The problem with loose one is that when it is exposed to moisture, it becomes denser, thus losing its efficacy of shock absorption and become harder to handle due to lightweight and small grain size. They also stick to the produce inside the packages. Rice hull in bag increase the shock absorption capacity is easier to handle and provide double protection when compared to loose rice hulls. In study rice hulls efficacy was tested against a bubble wrap (3/16-inch) and an anti-vibration rubber pad (0.129-inch), respectively. It was reported that 1-inch thick rice hulls sealed in plastic bag decreased reduced impact abrasion by 41% as compared to 39% by bubble wrap and 42% by anti-vibration pad of the same thickness, respectively which was be attributed to enclosed air inside the plastic bag. Malasri et al. (2015) also reported that rice hulls had good insulating property against heat and is an important in protecting some temperature-sensitive commodities at the time of transport and distribution which can be effectively utilized by covering boxes on all sides with bagged rice hulls placing bagged rice hulls in all sides of a box. Garcia (1982) used rice hull ash of different particle sizes and moisture content as cushioning for tomatoes.

Diseases management
In different stages of growth, horticulture crops produce a number of inducible aromatic and flavour compounds which have a wide range of application in disease management (Tripathi & Shukla, 2007). These are secondary metabolites which are generally produced in crops during the ripening stage providing resistance against microbes during the post-harvest stage. These compounds have distinctive properties of low solubility and volatility. Due to the natural occurrence in horticulture crops and as potential fungicide, their evanescent nature and easy bio-degradability ensure low toxic residues and associated problems. These combinations can be taken out from source crop for the application on the other harvested perishable produces. Some of the volatile aromatic components of significant importance are discussed below:

Aldehydes
Some organic compounds i.e., aldehydes, acetaldehyde, benzaldehyde, cinnamaldehyde, benzyl alcohol and ethanol and are proven as powerful growth inhibitors of microorganisms. These are deadly to the fungal spores and also their mycelia of fruit and vegetable pathogens like *R.stolonifer*, *P. digitatum*, and *Colletotrichum* species during lab trials. These compounds can effectively be used to control storage diseases of perishables.

Prasad and Stadelbacher (1974) reported that acetaldehyde vapours are used to control *Botrytis cinerea*. It is also active against *Botrytis cinerea* and *Rhizopus stolonifer*, which causes strawberry fruits rot (Avissar & Pesis, 1991). Several scientists have reported that the use of benzaldehyde to fumigate peaches for protection against *Rhizopus* rot. The use of benzaldehyde hinders germination of spore of *Botrytis cinerea* totally at 25 µl/l and at 125 µl/l *Monilinia fructicosa* (Wilson et al., 1987).

Hexanal (E)-2-Hexenal and hexanal are two important volatile flavouring complex components which produce hexanal vapours having numerous properties that are natural resource measures to combat perishable diseases with very few toxic residues by inhibiting myceliala growth on apple slices (Song et al., 1996). (E)-2-Hexenal is recognized to have higher antifungal activity in nature and many scientists has proved its activity against *Botrytis cinerea* in vitro and in vivo (Fallik et al., 1998). It has been shown that (E)-2-hexenal proved as an efficient fumigant in controlling fungal mould growth on 'Crimson Seedless' table grapes (Archbold et al., 1999). The study reports that by treatment of 'Conference' pear by trans-2-hexenal at 12.5 µl l^{-1} at 20°C for 24 or 48 h after inoculation reduces its decay by reducing pautlin content of blue mould disease (*Penicillium expansum*) and improves fruit quality (Neri et al., 2006).

Acetic acid

Acetic acid occurs naturally in fruit crops and is an important metabolic intermediate. It is found all over the biosphere and poses little or no residual hazard. Using acetic acid fumigation is advantageous in many ways. The acetic acid in the air in low concentrations i.e., 2.0-4.0 mg l^{-1}, have been found to be very effective to control *Botrytis cinerea* conidia on fruit apple cv. Red Delicious. Scientists have reported the commercial application of acetic acid as a fumigant in fruits, i.e., apricot and plums (Liu et al., 2002), sweet cherries (Sholberg & Gaunce, 1995).

Jasmonates

Jasmonates includes both methyl jasmonate (MJ) and jasmonic acid (JA), are naturally occurring plant hormones vigorously distributed throughout the kingdom *Plantea*. They are recognized to control many activities of plant growth and development and also their responses to environmental pressures which creates stress (Creelman & Mullet, 1995; Sembdner & Parthier, 1993). These, when applied at low concentrations for post-harvest treatment, have the potential to increase natural resistance and to declines decay in fruits. The post-harvest usage of jasmonates declines the decay caused by gray mould (*Penicillium digitatum*) both in natural or artificial inoculation of 'Marsh Seedless' grapefruit (Droby et al., 1999). Jasmonates can serve as environmental friendly means to reduce chemical usage as it is naturally occurring compounds used in low doses.

Glucosinolates

Glucosinolates are another natural occurring class of compound, including approximately hundred compounds produced by plants of family Cruciferae (Brassicaceae) and have scientifically proven antifungal properties (Fenwick et al., 1983). The chemical reaction produces sulfate ion, glucose, and some compounds like thiocyanate, isothiocyanate, and nitril. The glucosinates have been tested for antifungal activity both in vivo and in vitro on several storage pathogens, namely *Botrytis cinerea, Rhizoctonia stolonifera, Penicillium expansum* and *Mucor piriformis*. A natural flavouring compound Allyl-isothiocyanate (AITC) in mustard and horseradish also have well-documented antimicrobial activity. Proper controls of blue mould, including a TBZ resistant strain on pears, have been reported on the exposure of fruit to an AITC-enriched atmosphere (Mari et al., 2002).

CONCLUSIONS

It is clear from the above-presented review that the antagonistic impact of synthetic chemicals and pesticides on soil, human and environmental health from the food safety aspect are well recognized and now scientifically proven which has enunciated the interest of the scientist for finding an alternative techniques to control phytopathogens, pests, improving produce quality and shelf life.

A wide variety of plant-based botanicals have potential to be used as cushioning materials, washes for fruits and vegetables, as anti-microbial in edible coatings, fumigants, anti-fungal and antibacterial agents and as preservatives, relating to their anti-microbial properties against a wide range of foodborne microorganisms. Their protective property makes them a suitable and potentially viable alternative against synthetic chemicals.

Although successful uses of many of these products have been demonstrated their large scale adaptation is still not visible as compared to synthesized chemicals; therefore, it is high time to explore, understand and develop cost-effective, human and eco-friendly plant-based products for post-harvest management of produce as the mainstream products and study their application on specific fruits and vegetables. These products require extensive research to demonstrate their exact mode of action and implementation to make their applications practicable and economically sustainable. Also, if proven effective and suitable concentrations have been determined, they can serve as an effective mechanism for easy control of various processes of crop post-harvest management.

CONFLICT OF INTEREST

The authors have no conflict of interest to report.

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