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ARTICLE

# Nanotechnology-Based Advancements in Postharvest Management of Horticultural Crops

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## ABSTRACT

Horticulture is a branch of Agricultural science where it is defined as the science and art of cultivating and handling fruits, vegetables, ornamental plants and several plants having unique medicinal and aromatic values. Horticultural crops provide farmers with high income and have good export quality, but they have a concern about postharvest losses. Hence, increasing productivity and decreasing post-harvest losses by using scientific studies and techniques like biotechnology and nanotechnology could be the simplest possible solution to the above-mentioned problems. Using nanotechnology which is having the characteristics of nanoparticles is proven to be very useful in science and technological applications. Nanotechnology-based formulations increase the product quality and the shelf life of horticultural products and provide multiple ways of inhibiting the growth and development of microorganisms. It is precisely a new edible packaging coverage (film) that controls the exchange of gases and prevents damage from harmful rays such as ultraviolet radiation to a greater extent. Increasing strength by using nano biosensors for labeling products is considered a fundamental process to automated control of storage products. Postharvest rotting of vegetables is recognized to be an oxidative reaction and microbial deterioration as well. This review will address all such nanotechnology-based advancements for minimizing post-harvest losses of horticultural crops and enhancing the socio-economical progress of growers in particular.

**KEYWORDS**

Nanotechnology; horticultural crops; post-harvest; fruits; vegetables

## 1 Introduction

Most of the horticultural crops and their products are imperative in our everyday diet. This is because they supply macro-and micronutrients which are needed for maintaining the proper health of individuals and they are highly perishable. The diseases which occur especially after the harvest of the crops are mainly caused by plant pathogenic microorganisms like fungi and bacteria, which cause serious losses during storage and transportation. Many scientific methods are adopted for preservation with physical and chemical methods to avoid crop infestation with diseases and pests, and even the process of ripening after harvesting the crops. For instance, the edible coating is one of the important methods for reducing respiration, and use of metals to stop the attack of diseases and pests cause various postharvest decays of products. Many preservatives are mostly prepared by chemical methods, but silver nanoparticles (SNPs) synthesized from plant extracts of different plants are considered as a recent technology which inhibits the growth of microorganisms, improves water uptake of cut flowers and their vase life, is considered eco-friendly, can be used at a large scale and, most importantly, less harmful compared to their synthetic counterparts. Nanotechnology can be very useful in the spices and aromatic industries and to preserve the aroma, colour and flavour of spices. Using gold nanoparticles-antibody label, contamination of conjugate harmful aflatoxins causing impaired growth can be significantly reduced. Packaging with silver nanoparticles aluminium foils can be useful as it eventually becomes biofilms which allow conservation of the quality of spices, and they can be conserved and served to consumers with the same quality as they have at harvesting [1].

Nanotechnology has become an emerging technology in all fields of science, including medicine and agriculture. Distinct properties of nanomaterials and nanoparticles are also being applied proficiently to transform our farming into a sustainable agriculture in general, and a sustainable horticulture in particular; this is the result of minimizing postharvest diseases of vegetables and fruits at the scientific and industry levels [2]. Postharvest losses in fruits and vegetables are from 4.58% to 15.88%. About 10%–15% of shrink and decay on fresh fruits and vegetables lower their market value and consumer acceptability. Among these losses, 18% comes from animals and pests, and 16% are due to diseases where 72%–85% of the losses are caused by fungi [3]. The economic losses are mainly due to fungal diseases. Postharvest production is variable and ranges from 30%–50% which mainly depends on good agricultural or cultural practices and locations [4–6]. The Food and Agriculture Organization identified that 33% of the food delivered worldwide for human consumption is lost after crop harvesting [7]. These losses were distributed throughout the production network as a result of pathogen-initiated diseases that cause most of the food wastage. Minimizing these losses will ultimately increase their supply and reduce the overall cost.

## 2 Controlling Growth and Development of Microorganisms

There are many pathogens causing diseases but an important postharvest pathogen around the world is Botrytis cinerea which causes the grey mould disease. It causes decay on a large number of economically important horticultural crops, especially on vegetables and fruits, and even on ornamental flowers like marigolds. It affects the flowers at the pre- and postharvest stages. It is also a major problem on long distance transport and storage. This pathogen infects leaves, stems, flowers, and fruits, either by primary or secondary infection [8].

There are many benefits of using edible coatings which can eventually reduce water loss, slow the rate of ripening, reduce chilling and mechanical injury, reduce decay and add shining to the coated products. Edible coatings can be used as antimicrobial composites, antioxidants or anti-ripening compounds which ultimately induce changes in flavour due to late ripening or result of anaerobic changes. Coatings can be made from proteins, lipids, polysaccharides or can be made from those biomacromolecules [9]. Different edible coatings can be used on fruits and vegetables as shown in Tab. 1.

Chitosan is a biopolymer derived from chitin (a polysaccharide constituent of crustacean shells). It also exhibits antimicrobial properties reduce postharvest decay of Horticultural crops [10–13]. The application of Chitosan has been widely used to control pre-harvest and postharvest diseases. It can also control the quality of fruits and vegetables as it have low toxicity, is safe for human consumption and is environmental friendly [14,15]. Chitosan also improves the resistance of tomato fruit against grey mould disease caused by *B. cinerea*, and is highly promising as a natural composite to partially substitute the utilization of synthetic fungicides. When the coating of chitosan of 102.4–370 nm diameter was combined with 1% of gum arabic and applied on banana fruit, the ripening process of fruits is reduced and the shelf life is increased for a few days compared to uncoated banana [16].

A nanotechnological coating based on pullulan and polymeric nanocapsules of a range of 153.9 nm containing an essential oil extracted from thyme (*Thymus vulgaris* L.) was applied to increase the shelf life of table grapes. Grapes coated with the formulated nanocapsules maintained their colour, firmness, and total soluble salts (TSS) content for a longer period compared to untreated grapes. Coated grapes had a lower incidence of gray mould compared to untreated ones. The nanocapsule coating avoided quicker evaporation of volatile compounds and increased their persistence on the grape surfaces, thus delaying ripening and extending the shelf life [17] as shown in Fig. 1.

*Colletotrichum gloeosporioides* is a serious pathogen in various horticultural crops like mango and guava after the harvest of a crop. Silver nanoparticle composite with size 10–15 nm inhibited fungal growth by especially inhibiting the conidial germination [18].

A clay-chitosan nanocomposite was prepared against *Penicillium digitatum* which attacked ‘Valencia Late’ sweet orange. It showed complete inhibition of the pathogen and suppressed branching of hyphae at a concentration of 20 $\mu g.mL^{-1}$ [19].

**Table 1:** Different edible coatings used on fruits and vegetables

| Edible coating | Fruits/ vegetables | Action | References |
|---|---|---|---|
| Chitosan/ Tripolyphosphate (TPP) | Banana | Slower rate of ripening process | [20] |
| Gelatin-Fiber/titanium dioxide($TiO_2$) | Melon | Effective for controlling mold and yeast population growth | [21] |
| Gelatin-Chitosan/ (Ag/ZnO) | Okra/lady’s finger | Antimicrobial polyethylene packaging for the preservation of quality of vegetable | [22] |
| Chitosan-methyl Cellulose/Silica($SiO_2$) | Loquat fruit | Effective in enhancing chilling tolerance | [23] |
| Chitosan/silica nanocomposite | Table grapes | Antifungal | [24] |

(Continued)

**Table 1 (continued)**

| Edible coating | Fruits/ vegetables | Action | References |
|---|---|---|---|
| Gelatin/Kafirin | Vegetables | Rate of respiration and reducing water loss | [25] |
| Silica nanoparticles | Grapes | Antifungal | [26] |
| Nanocomposite-Aloe vera gel | Mango | Increasing titratable acid and elongation | [27] |
| Microencapsulated ascorbic acid | Guava | Decrease the respiration rate | [28] |
| ZnO nanoparticles | Cucumber | Carotene, zinc and iron increase in cucumber observed | [29] |
| Se nanoparticles | Tomato | Tomato yield increased by 21% with 10 mg/L Se nanoparticles | [30] |
| Chitosan nanoparticles | Grapes | Delayed the ripening process, increased moisture retention | [31] |
| Chitosan-silver NPs composite | Mango | Higher antifungal against *Colletotrichumgloeosporioides* | [32] |

### *2.1 Silver Nanoparticle for Increasing Vase Life of Cut Flowers*

Cut flowers are used to show gratitude, affection and many people used them to express emotion on numerous occasions. The two most important aspects of a cut flower are vase life and quality. The customers get satisfied and repeat the purchase for these appealing factors throughout the world in almost all the ornamental markets. When cut flowers are harvested they do not have a prolonged shelf life, due to interrupted inflow of water because of microbial proliferation.

Various nanotechnological products, like Nano-silver, are used as anti-microbial agents and ethylene inhibitors. Using Silver Nanoparticles for extending the vase life of cut flowers not only inhibit the growth of bacteria but also enter into the vascular tissues of the stem and limits synthesis of ethylene which suppresses ethylene synthesising genes ACO1 (Musa acuminata oxidase 1) and ACS1 (Musa acuminata synthase 1). Moreover, it also increases the uptake of the solution thereby ultimately increasing the vase life of cut flowers [33].

The use of this preservative solution for extending the vase life of cut flowers has been widely applied. These silver nanoparticles are harmless, easy to apply with no side effects and with high stability [34]. Different concentrations of silver nanoparticles are having various applications in improving and maintaining the quality of cut flowers (Tab. 2).

**Table 2:** Silver nanoparticles concentrations for different cut flowers to improve vase life

| Cut flower | Application method | Silver nanoparticles concentration | Improved results | References |
|---|---|---|---|---|
| Carnation | Vase solution | 5 mg $L^{-1}$ | Suppressed ethylene synthesis | [35] |
| Chrysanthemum | Pulse treatment | 10 mg $L^{-1}$ | Reduced vascular occlusion and prevented water stress | [36] |

(Continued)

**Table 2 (continued)**

| Cut flower | Application method | Silver nanoparticles concentration | Improved results | References |
|---|---|---|---|---|
| Gerbera | Pulse treatment | 10 mg $L^{-1}$ | Maintained water content and hydraulic conductance | [37] |
| Lisianthus | Vase solution | 40 mg $L^{-1}$ | Increasing quality and vase life | [38] |
| Mokara Red orchid flower | Pulse treatment | 5 mg $L^{-1}$ | Increasing the vase life | [39] |

### *2.2 Methods for Silver Nanoparticles Synthesis*

Nanoparticles are generally prepared using chemical methods which may be difficult in separation and purification from nanoemulsions and their utilization on a large number of surfactants. Similarly, nanoparticles can be prepared using plant extracts which will be eco-friendly, and usage of toxic chemical substances can be reduced [40]. Silver Nanoparticles can be synthesized on a very large scale compared to chemically prepared Silver Nanoparticles on a small scale. Different Silver Nanoparticles were prepared using different plant extracts which are shown in Tabs. 3 and 4. Basil, banana, geranium leaves, pomegranate, Aloe vera, *Centella asiatica*, *Murraya koenigii*, *Alternanthera sessilis*, *Piper nigrum* and many other crops have been reported in this context [41]. SNPs prepared using both plant extracts and microbial synthesis are very eco-friendly in nature. The SNPs act as antimicrobial agents by reducing infection from bacteria which blocks water transportation through the stem. SNPs prepared with green synthesis will be easy for application and this will have a large surface area and good stability. All these properties make SNPs an excellent medium for the preservation of cut flowers, medicinal and aromatic plants. Spices contaminated by aflatoxin can also be safeguarded by using nanoparticles to avoid contamination.

**Table 3:** Plant-derived metallic nanoparticles and their applications

| Plants used | Nanoparticles | Parts of plant | Size (nm) | Shapes | Plant metabolites involved in bioreduction | Pharmacological applications | References |
|---|---|---|---|---|---|---|---|
| *Acalyphaindica* | Ag, Au | Leaves | 20–30 | Spherical | Quercetin, plant pigment | Antibacterial | [42] |
| *Aloe vera* | $In_2O_3$ | Leaf | 5–50 | Spherical | Biomolecules | Optical properties | [43] |
| *Alternantherasessilis* | Ag | Whole | 40 | Spherical | Amine, carboxyl groups | Antioxidant, antimicrobial | [44] |
| *Andrographispaniculata* | Ag | Leaves | 67–88 | Spherical | Alkaloids, flavonoids | Hepatocurative activity | [45] |
| *Boswelliaserrata* | Ag | Gum | 7–10 | Spherical | Proteins, enzymes | Antibacterial | [46] |
| *Carica papaya* | Ag | Fruit | 15 | Spherical | Hydroxyl flavones, catechins | Antimicrobial | [47] |
| *Cassia fistula* | Au | Stem | 55–98 | Spherical | Hydroxyl groups | Antihypoglycemic | [48] |
| *Cinnamomumzeylanicum* | Ag | Leaves | 45 | Spherical | Water-soluble organics | Antibacterial | [49] |

(Continued)

**Table 3 (continued)**

| Plants used | Nanoparticles | Parts of plant | Size (nm) | Shapes | Plant metabolites involved in bioreduction | Pharmacological applications | References |
|---|---|---|---|---|---|---|---|
| *Citrulluscolocynthis* | Ag | Calli | 5–70 | Triangle | Polyphenols | Antioxidant, anticancer | [50] |
| *Citrus sinensis* | Ag | Peel | 35 | Spherical | Water-soluble compounds | Antibacterial | [51] |
| *Dilleniaindica* | Ag | Fruit | 11–24 | Spherical | Biomolecules | Antibacterial | [52] |
| *Dioscoreabulbifera* | Ag | Tuber | 8–20 | Rod, triangular | Diosgenin, ascorbic acid | Antimicrobial | [53] |
| *Euphorbia prostrata* | Ag | Leaves | 52 | Rod, spherical | Proteins, polyphenols | Antiplasmodial | [54] |
| *Lippiacitriodora* | Ag | Leaves | 15–30 | Spherical, | Isoverbascoside compound | Antimicrobial | [55] |
| *Menthapiperita* | Au, Ag | Leaves | 90–150 | Spherical | Menthol | Antibacterial | [56] |
| *Mirabilis jalapa* | Au | Flowers | ~100 | Spherical | Polysaccharides | Antimicrobial | [57] |
| *H. canadensis* | Ag | Whole | 113 | Spherical | Phenolics, proteins | Cytotoxicity | [58] |
| *Iresineherbstii* | Ag | Leaves | 44–64 | Cubic | Biomolecules phenolic compounds | Biological activities | [59] |
| *Meliaazedarach* | Ag | Leaves | 78 | Irregular | Tannic acid, polyphenols | Cytotoxicity | [60] |
| *Tinosporacordifolia* | Ag | Leaves | 34 | Spherical | Phenolic compounds | Antilarvicidal | [61] |
| *Trigonella-foenumgraecum* | Au | Seed | 15–25 | Spherical | Flavonoids | Catalytic | [62] |
| *Withaniasomnifera* | Ag | Leaves | 5–40 | Irregular, spherical | Methyl 7-oxooctadecanoate | Antimicrobial | [63] |

Source: Kuppusamy et al. [41].

Apart from the green synthesis of Silver Nanoparticles, they can also be prepared using biological substances likebacterial species (e.g., *Alcaligenes faecalis*). These were effective in suppressing the growth of microbes, decreased the production of ethylene, and reduced stomatal conductance which showed improved vase life of roses [64].

**Table 4:** Different Plant extracts used for the preparation of silver nanoparticles

| Flower | Plant extract | Improved quality | References |
|---|---|---|---|
| Rose | Saffron petal extracts | Inhibited the growth of Bacillus and Pseudomonas | [65] |
| Carnation | Saffron petal extracts | Increasing water uptake and decreased leakage of ions from petal tissues | [66] |
| Chrysanthemum | Mexican tea | Promoted flower opening and extended vase Life | [67] |
| Gerbera | Carvacrol essential oil extracted from oregano (*Origanum vulgare)* | Antimicrobial | [68] |

### *2.3 Applications of Nanotechnology in Aromatics and Spices Industries*

Spices are the best products used for food flavouring as they enhance flavour, taste and also change food colour and prolong the shelf life of foods by suppressing microbes and protecting food deterioration. Aflatoxins are mycotoxins produced by the fungi *Aspergillus flavus* and Aspergillus *parasiticus*. These toxins may cause impaired growth, reduce immunity in the body and its harshness may also cause liver cancer. The conjugated antibodies and NPs were used as labels for identifying aflatoxins B and G and Aflatoxin M1 using gold NPs-antibody label conjugate [69].

Nanocoatings containing metallic particles with NPs or biopolymers offer various ways of colour enhancement, extending shelf life, reduction of browning, enhancing flavour, improving availability of anti-oxidants from spices, etc. The quality of spices and aromatic products can be improved using nanotechnology. Spice lumping is a serious problem in reducing shelf life and market quality. The NPs Nano $SiO_2$, Nano $Ca_2SO_4$ Si, Nano Sodium aluminosilicate and dicalcium phosphate are having a wide range of scope in reducing the lumping and free-flowing nature of spices [70].

## 3 Nanotechnology for Packaging

Nanotechnology has the potential to generate new fruit packaging. The new technology of nano-packing materials with lower relative humidity, oxygen transmission rate, and high strength was synthesized by blending polyethylene with nano-powder (nano-Ag, kaolin, anatase $TiO_2$, mineral $TiO_2$), and it enhanced the preservation quality of fruits throughout storage at 40°C [71]. Nano-packaging can maintain the sensory properties and chemical and physiological qualities of strawberry fruits at a better level compared with the conventional packing (polyethene bags) [72]. Also, nano packaging is more efficient than the normal polyethene packaging concerning a reduction in decay rate, and anthocyanin and malondialdehde contents (Tab. 5).

**Table 5:** Comparison of packing with nano packing and conventional packing and their effect on reduction in decay rate, Anthocyanin and Malondialdehde contents

| Contents | Nano packaging | Conventional packaging |
|---|---|---|
| Decay rate | 16.7% | 26.8% |
| Anthocyanin | 26.3 mg/100 g | 31.9 mg/100 g |
| Malondialdehde | 66.3 micromol/g | 75.4 micromol/g |

Polyphenoloxidase (PPO) and Pyrogallic acid oxidase (POD) activities were considerably lower in nano-packing than conventional management. These showed that nano-packaging may offer a beneficial role to enhance the preservation quality of the fruits throughout extended storage [73].

In the United States, apples are marketed with a waxy coating, which prevents fruit from loss of moisture content and shrinking. Currently, edible coatings are 5 nm for fruit, vegetables, and baked products. The edible coating blocks gas exchange, prevents water loss, maintains colour, flavours, and antioxidants, and can preserve products even after the opening of packing [74]. Fuji apples that were coated with Nano-SiOx/chitosan composite preservation agents had a better quality than without coating [75]. Green tea which was packed with nano-packing had better maintenance of vitamin C, chlorophyll, polyphenols and amino acids than compared with normal packing [76]. As mentioned above for various uses, nano packaging is also exploited for food packaging as shown in Tab. 6.

Packaging of spices is a complex issue as the technique should not only enhance shelf life but also retain its aroma, colour, flavour and reduce infection of microbes. Electrochemical anodisation was used to produce cylindrical nanopores between 15 and 100 nm diameter on an aluminium surface of packaging foil. These surfaces were then incubated with cultures of *E. coli* and Listeria innocua. The surfaces covered with nanopores of 15–25 nm diameter significantly inhibited both attachment and biofilm formation which are safe for spices packaging [77].

**Table 6:** Applications of nanomaterials in food packaging

| Nanomaterial packaging material | Fruits and vegetables used for packaging | Properties of packaging | References |
|---|---|---|---|
| $TiO_2$-Chitosan | Grapes | It acts as a preservative and prevents entry of microbes | [78] |
| Ag-Cellulose films | Tomato | Prevents bacterial growth and infection | [79] |
| TiO-Polyacrylonitrile | Tomato | Reduces ethylene rate | [80] |
| ZnO-Chitosan | Apple and mango | Antioxidant and prevents microbes attack | [81] |

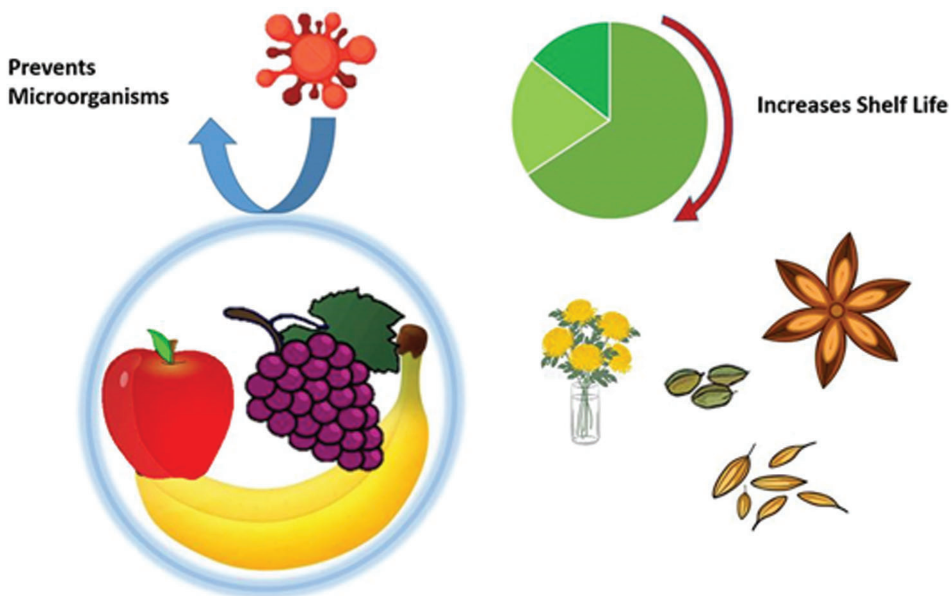


**Figure 1:** Nanotechnological role inedible coatings of horticultural crops

### *3.1 Nanoemulsions*

An emulsion is a combination of two or more solutions that do not combine easily. Nanoemulsions are nano-sized emulsions that lie in the range of nanoscale, which are manufactured for improving the delivery of active pharmaceutical ingredients. These are the thermodynamically stable isotropic system in which two immiscible liquids are mixed to form a single-phase using an emulsifying agent, i.e., surfactant and co-surfactant.

Using Nanoemulsion coating of Carnauba wax of 42 nm diameter (also called Brazil wax and palm wax) is an accepted proposition. This wax was extracted from leaves of the carnauba palm (*Copernicia prunifera*) at 2.4% and it was applied on Papaya fruit. The fruits were stored for 9 days at 22°C and a relative humidity of 60%–70%; it was found that the fruits showed a reduced decaying and loss of mass [82]. Various nanoemulsions are used on fruits for protecting them from deterioration and prevention from microbes attack as shown in Tab. 7.

Nanolaminate is a very thin food-grade film (ranges from 1–100 nm/layer) with physically or chemically bonded dimensions [83]. Nanolaminate has many advantages in preparing edible films. Edible films are present on numerous horticultural produce and chocolate, toffees, baked goods and French fries [84]. These films protect foods from loss of moisture, lipids, and gases. These films improve the textural properties of fruits and also retain colour, flavour, antioxidant and nutrient content.

**Table 7:** Different Nanoemulsions used for edible coatings of different fruits to enhance shelf-life

| Fruits | Nanoemulsion | Method of emulsion | References |
|---|---|---|---|
| Red Delicious-Apple | Tocopherol/nopal mucilage nanoemulsion | Encapsulant | [85] |
| GolabKohanz-Apple | Chitosan-nanoemulsion | Coating | [86] |
| Banana | Chitosan-Nanoemulsion | Coating | [87] |
| Papaya | Chitosan-Nanoemulsion | Coating | [88] |
| Papaya | Wax Nanoemlusion | Coating | [89] |

## 4 Multiple Chips (Nanobiosensors) for Labelling of the Products

Nanotechnology-based biodegradable sensors in the form of small chips such as electronic tongue technology sensors are recently being utilized widely in food products. It changes the colour of the product when its pH changes because of spoilage. A "Release on command" nanobioswitch (Netherlands) operates the preservative packaging [90]. Biological molecules like sugars or proteins are used for nanostructures as biosensors on food [91]. These biosensors (1) function as detectors of food pathogens and other microbes, and (2) act as a device to trace food products. Nanotechnology is also useful in encapsulation systems for protection against environmental factors. Further, it can be used in the design of food ingredients such as flavour and antioxidants [92]. The main objective is to improve the functionality of such ingredients while minimizing their concentration. As the infusion of these innovative ingredients gets into foods, it gains more popularity [93]. It will also occur the greater exploration of delivery controlled release systems for nutraceuticals [94].

Nanomaterials shown are having numerous optical and electrochemical properties in different hot and cold drinks, juices and oils Tab. 8. Different biosensors are utilized based on Nanomaterials used in various agriculture and food industries. There are many applications of nano-biosensors which include virus recognition using antibody sensor arrays on self-assembled nanoscale block copolymer Patterns, and the detection of food-borne toxins using multifunctional nanoparticles. It is also used in the detection of pore-forming toxins, molecularly imprinted polymers for plant and insect virus recognition.

**Table 8:** Applications of Nanobiosensors in different food materials

| Type of sensor used in food | Material used for detection | Food product used | Nanoparticle | Functions | References |
|---|---|---|---|---|---|
| Electrochemical method | Tert-butylhydroquinine | Cooking oils | Au nanoparticles electro deposited on graphene ribbons | Conductivity enhancements due to growth in the surface region on the target sites | [95] |
| | Leftover pesticides | Potato and onion | $TiO_2$ nanostructure | Upgraded electrochemical properties and conductivity | [96] |
| Optical method | Gallic acid | Clove and green tea extracts | Au nanotubes bismuth-based | Morphological changes were observed | [97] |
| | Antibiotics (Sulfonamides) | Honey | Au nanoparticles | Surface plasmon resonance properties | [98] |

### *4.1 Constraints*

Despite numerous potential uses of nanotechnology in various fields like medical, agriculture, space research technology, etc., there are certain safety concerns with the use of this technology in the environment which still need to be discussed. Some key restrictions and threats related to the agricultural application of nanotechnology are as follows:

1. The existing knowledge on nanotechnology is still at the beginning stage; consequently, it is not possible to forecast the effect of the nanoparticles on human health and the environment [99].
2. Interaction of nanoparticles with non-target sites often leads to certain environmental and health issues [100].
3. Higher production costs.
4. Developments in the agricultural sector are significantly limited due to the low investment in research fields, and provision of low-quality training, etc.
5. Public is not aware of many applications of nanotechnology. This is because people generally follows traditional practices and doesn't accept the new technologies.
6. The various products of nanotechnology and their commercial utilization in various fields still need to be controlled just to make sure that they are safe to use in these areas.

Hence, the appropriate knowledge of these nanomaterials and their possible contacts in the human body is always needed to be examined before their commercial application.

## 5 Conclusions

Nanomaterials showed a vital potential in postharvest technology management. Simple postharvest practices like appropriate early harvest, clean washing, sorting, grading, wrapping, pre-cooling, and proper care taken during transportation help to reduce postharvest losses of most of the horticultural crops. Nano edible coatings available with less cost are useful for farmers in maintaining the quality of vegetables and fruits because these coatings delay respiration rate. Nanocoatings which are made with zinc and silver prevent the attack of microorganisms by reducing the postharvest losses. Through this edible coating and active packaging technology, the farmer can also get better prices in the market. It is also necessary that researches illuminate the precise nano-packing system on stored foodstuffs. This will allow the application of nanotechnology over a broader choice. Nanotechnology-based research will act as a novel tool for the management of postharvest losses of horticultural crops in the coming future. Besides this Nanotechnology also has a direct beneficial role for medicine and the environment. However, like all other technologies, it may have unintended effects that can adversely impact the environment, both within the human body and within the natural ecosystem. While taking advantage of this new technology for health, the environment, and sustainability benefits, science needs to examine the environmental and health implications before applying them in a broad form. Determining the toxicity of nanoparticles can be a big problem as not all engineered nanoparticles are more toxic than fine-size particles of the same chemical composition. The surface coatings of particles, exposure to UV radiation, and dispersion properties can change the behavior of the particle, which may adversely affect the environment and human health. As a result, before applying nanotechnology based technologies requires more investigations.

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