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ENHANCING SHELF LIFE OF FOOD COMMODITIES: A REVIEW ON ROLE OF NANOTECHNOLOGY

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ABSTRACT : The growing demand for healthy and safe food, strategy against an increasing risk of biotic factors such as disease, and threats to agricultural and food productivity due to changing climatic conditions and human interventions has created a strong demand for emergence of an alternative technology which promises solution to these problems. Nanotechnology is a promising field of interdisciplinary research and works with the smallest possible particles which raise hopes for improving methods of food preservation and processing by encountering problems unsolved conventionally. This review discusses the potential of nanotechnology for their uses in the food industry in order to provide consumers a safe and contamination free food with extended shelf life.

Keywords : *Shelf life, Nanotechnology, Nanosensors, Packaging, food commodities.*

Food is perishable by nature and changes will take place naturally in all food while it is being handled and stored. The changes can be rapid e.g. raw meat and fish or spoilage and deterioration can take place over a period of days or weeks. For some foods, e.g. very dry foods, nuts, dry fruits, the deterioration in the quality may not become apparent until after months or even years of storage.

Shelf life of a food is the length of time a food can be kept before it begins to deteriorate or, in some cases, before the food becomes less nutritious or unsafe. Food commodities including fruits and vegetables are metabolically active, perishable that have a shorter shelf life. Varied range of traditional methods for extending the shelf life of foods have been successfully used for decades, and in some cases thousands of years. The ultimate aim of shelf life is to help consumers make safe and informed use of products so that they are aware about the time limit up to which the consumption of the food is considered as safe.

Even if food items look similar *i.e.* they belong to the same category e.g. fruits, vegetables etc, their shelf life can be quite different. It is not safe to take the shelf life from one and apply it to the other. There are many factors that may affect the shelf life of a product. Some factors relate to the food itself *i.e.* intrinsic factors, while others are external to the product names as extrinsic factors (Table 1).

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By understanding, which are the most important factors impacting the shelf life of a food, it may be possible to manipulate these factors to extend the shelf life. This article is divided into three sub sections based on traditional, ongoing and nanotechnology related methods for enhancing shelf life of food commodities.

Table 1 : Intrinsic and extrinsic factors effecting shelf life of food commodities

Intrinsic factors	Extrinsic factors
pH/total acidity	Storage temperature
Natural micro flora	Relative humidity of environment
Availability of oxygen	Exposure to light
Reduction potential (Eh)	Moisture contents
Added preservatives (e.g. salt, spices, antioxidants)	Various processes through which the food commodities are passed e.g. washing, cooking etc.
Physiological changes	Packaging & handling methods
	Microorganism contamination

1.TRADITIONAL METHODS

Food by its nature begins to spoil the moment it is harvested. Therefore, for making food available all the time as and when required for fulfilling his hunger, the man started persevering food by making nature its preserving medium.

1.1 Drying

In ancient times, sun and wind were used to dry foods naturally, which is quite evident from studies (Shephard 78), mentioning that during the prehistoric age, fruits and vegetables were preserved by drying whereas meat and fish were first salted and dried then upon. Evidence shows that Middle East and oriental cultures actively dried foods in hot sun as early as 12,000 B.C. (Shepherd 79)

1.2 Smoking

Early humans probably discovered by accident that certain foods exposed to smoke seem to last longer than those that are not. In the first century A.D. Columella mentioned about the flavor of a variety of Roman cheese which was hardened in brine and then smoked (Wilson, 93). Various evidences lead down to indicate that the Romans probably utilized smoking. In colonial times, many households had smokehouses which were used to smoke beef, ham and bacon (Earle 28). Smoking is still sometimes used to preserve fish and meat (Forbes, 31).

1.3 Freezing

Freezing was also an obvious preservation method to the appropriate climates. People living in geographic area that had freezing temperatures for some part of a year made use of the temperature to preserve foods. In the areas having extremely low temperature, ice-houses were very popular for storage.

1.4 Fermentation

Fermentation was also used in some parts of the world. It was not invented, but rather discovered. The first beer was discovered when a few grains of barley were left in the rain. It is believed that mankind settled down from nomadic wonderers into farmers to grow barley to make beer roughly as early as 10,000 B.C (http://www.pwnn., 43). Cheese making was also used in colonial times to lengthen the time that milk could be used.

2.5 Dehydration, Salting & Pickling

Salting, also known as curing, removes moisture from foods. The earliest curing was actually dehydration, which was used for food preservation in ancient time. Early cultures used salt to help desiccate foods. Salt has been used to preserve fish since ancient times, possibly even before meat was cured. The early Mesopotamian civilizations relied on a staple diet of salt fish and barley porridge.

Retaining the quality of food from field to fork is a challenge for the food industry but new methods have been developed to preserve products without compromising on look and taste.

2. ONGOING METHODS

Fruits and vegetables are widely used as an excellent source of micronutrients and phytochemicals. Habitual inclusion of fruits and vegetables in the diet may prevent or reduce the risk of several chronic diseases (Cooper, 26; Bermejo, 11). However, as they are perishable products that contain living tissues, the quality retention and prevention of postharvest loss during handling, storage and retailing is critical (Asrey 8). It is estimated that more than 20-22% of the total production of fruits is lost due to spoilage at various post-harvest handling stages (Sandhya, 75).

Postharvest treatments are used to minimize the loss of fresh produce as well as to maintain the quality by controlling various factors (as mentioned in Table 2), thereby increase the shelf life (Artes *et. al.,* 6). They can be divided in to three main categories as chemical, physical and gaseous treatments.

Table 2 : Available technologies based on the intrinsic and extrinsic factors for extending shelf life.

Factors	Main problems	Technologies available	Technologies and information needed
Natural Properties	Physiological changes like respiration and transpiration	Coating, packaging, MAP, CA	Type of coating materials, cost, fermentation risks
External conditions	High temperature and relative humidity	Cool storage, CA, MAP	Chilling injury, fermentation risks, cost, temperature, relative humidity, CO_2, O_2 requirement for some produce, physiological disorders, and alternate storage methods
Microbial contamination	Tropical climate is the host for microorganisms and disease	Pre-cooling, heat treatment, irradiation, MAP, coating	Physical treatments, non-chemical treatments, adaptation of available technology, fruit sensitivity

Handling methods	Improper postharvest handling, resulting in bruise and damage	Packaging	Type of retail pack, improve package performance

2.1 PHYSICAL

2.1.1 Freezing and refrigeration

Freezing is one of the oldest and most widely used methods of food preservation, which allows preservation of taste, texture, and nutritional value in foods better than any other method. Exposure of microorganisms to low temperatures reduces their rates of growth and reproduction. Refrigeration and freezing, the most popular forms of food preservation in use today, reduces water activity and stops many biochemical processes and bacterial, fungal growth.

Water, which makes up over 90 percent of the weight of most fruits and vegetables, is held within the fairly rigid cell walls which give support to structure, and texture. When the water freezes, it expands and the ice crystals cause the cell walls to rupture. Sometimes freezing may cause changes in foods that make the product unacceptable such as destabilization of emulsions, flocculation of proteins and loss of textural integrity. The chemical change occurring is development of rancid oxidative flavors through contact of the frozen product with air.

2.1.2 Radiation

Radiations, in the form of ultra violet rays are used in storage facilities to reduce surface contamination. Gamma rays are also used for some meat products.

2.1.3 Pulsed Electric Field (PEF)

Pulsed Electric Field (PEF) utilizes brief pulses of a strong electric field for processing. PEF, being performed at low temperature, holds potential as alternative pasteurization process for sterilizing food products. In this method, a substance is placed between two electrodes, and then the pulsed electric field is applied, which enlarges the pores of the cell membranes resulting in killing cells and release of their content. Industrial applications of PEF processing for the pasteurization of fruit juices has been reported. (Bentley, 10)

2.1.4 Edible coatings

Edible coatings provide a barrier to moisture, oxygen and solute movement for the food, can also act as a gas barrier and slow down the respiration, senescence and enzymatic oxidation (Mohebbi *et al.,* 64; Ghasemnezhad *et al.,* 33). It can be a complete food coating or can be disposed as a continuous layer between food components (Gol *et al.,* 34). In addition, edible coatings help to preserve colour, texture and volatile compounds of fresh fruits and vegetables. It also maintains the structural integrity and protects against mechanical damages (Dhall, 27). Polysaccharides, lipid-based substances and protein films are commonly used as edible coatings (Bourtroom, 12).

2.1.5 Canning

Canning of food items is a process which involves placing foods in jars or containers and subjecting them to high temperature that kills micro-organisms that cause food to spoil. During this process, the air is forced out of the jar and vacuum seal is formed, as it cools.

2.2 CHEMICAL TREATMENTS

2.2.1 Antimicrobial and anti-browning agents

Post-harvest quality and consumer safety is dependent on magnitude of enzymatic factors and microbial growth in fruits and vegetables (Lamikanra, 55). Different anti-microbial and anti-browning agents, such as sorbic acid, benzoic acid and propionic acid, hydrogen peroxide (H_2O_2), peroxyacetic acid (PAA), organic acids, and electrolyzed water, are used to maintain post-harvest quality (Sandhya, 75).

Sorbic acid is used for preservation of syrups, salads, jellies and some cakes while benzoic acid is used for beverages, margarine, apple, cider, etc, Propionic acid is used in bread and bakery products. Sulphur dioxide, as gas or liquid, is used for dried fruits, molasses and juice concentrates. Whereas, ethylene oxide is used for spices, nuts and dried fruits (Bentley, 10; Shephard, 80).

Due to its very strong oxidizing properties and cost effectiveness, chlorine-based solutions are commonly used as a disinfectant. H_2O_2 with bactericidal, sporicidal and inhibitory ability based on oxidation of fungi and bacteria, was successfully used to control vegetable pathogens during storage (Afek, 2). Organic acids have been used judiciously to slow down enzymatic and non-enzymatic browning, deterioration of texture and microbial growth on fresh produce (Aguayo *et al.,* 3).

3.2.2 Nitric oxide

Nitric oxide (NO) acts as a multifunctional signaling molecule in various plant physiological processes, such as fruit ripening and senescence of fruits and vegetables (Wendehenne *et al.,* 91). Application of NO in postharvest is a potential new technology, to reduce losses of fruits and vegetables during handling and marketing (Pristijono *et al.,* 70). Exogenous application (gas fumigation or dipping in a solution) of NO has demonstrated beneficial effects like reduction in the production of ethylene, lower rate of respiration, reduced ion leakage resulting from better maintenance of cellular integrity; reduction in oxidative stress through reduced lipid oxidation and enhanced activity of a range of antioxidant enzymes (Singh *et al.,* 82).

2.2.3 Calcium chloride

Calcium chloride is widely used in the food industry to reduce chilling injuries, suppress senescence, enhance the storage and marketable life of fruits by maintaining their firmness and quality. Its application also delays aging or ripening, reduces postharvest decay, reduce the incidence of physiological disorders and increase the resistance to diseases. The post-harvest application of $CaCl_2$ extend the storage life of pears, up to 2 months, plum up to 4 weeks and apple up to 6 months at 0-2ºC with excellent color and quality (El-Ramady *et al.,* 29).

2.3 GASEOUS TREATMENTS

2.3.1 Ozone

Activated oxygen (Ozone) is the best available technology that can replace traditional sanitizing agents (Huyskens-Keil *et al.,* 46; Hassenberg *et al.,* 40). It is a strong and ideal, germicide, sanitizer, sterilizer, anti-microbial, fungicide and deodorizer and detoxifying agent (Graham, 35). Various studies have shown that shelf life of fruits and vegetables can be increased when they are subjected to ozonation (Perez *et al.,* 68).

3.3.2 1-Methylcyclopropene

1-methylcyclopropene (1-MCP), asynthetic cyclic olefins, acts by blocking the access to ethylene-binding receptor resulting in inhibition of action of ethylene (Sisler and Serak 83). Avocado treated with 1-MCP showed significantly less weight loss and retained greener color than control fruit at the full-ripe stage in various studies (Jeong *et al.,* 48).

3. NANOTECHNOLOGY INTERVENTIONS IN FOOD SCIENCE

Nanotechnology is not a separate scientific field, rather it is a new platform for a range of existing disciplines - including chemistry, physics, biology, agriculture, biotechnology, neurology, information technology and engineering— allowing a shift down to the nano scale. According to National Science Foundation and National Nanotechnology Initiative, nanotechnology is defined as the ability to understand, control, and manipulate matter at the level of individual atoms and molecules, as well as at the "supramolecular" level involving clusters of molecules (in the range of about 0.1 to 100 nm), in order to create materials, devices, and systems with fundamentally new properties and thus innovative functionality. Due to unique properties, nanomaterials offer applications in widely varied field of science and technology including food science.

Keeping in view the necessity and demand of healthy food for every living being, research has been initiated throughout the globe for not only enhancing the shelf life of food commodities but also declining the spoilage of food by employing varied class of nanomaterial such as solid nanoparticles, nanofibers, nanocapsules, nanotubes, nanocomposites etc. Role of nanotechnology in food science can be broadly classified in three categories: Nanomaterials based sensors for detection of biological/chemical contamination, nanomaterials based food packaging, and nanoencapsulation & nanoemulsions for food processing.

3.1 Nanosensor

Nanosensors are emerging as a promising tool for applications in the agriculture and food production. They offer significant improvements in selectivity, speed and sensitivity compared to various traditional methods. Nanosensors based on their composition can be classified into chemical nanosensors and biosensors (also known as molecular sensors). Nanosensors can help detect toxic contaminants in foods at high precision levels using various nanomaterials, which have been introduced by environmental contamination during processing or handling. (Jianrong *et al.,* 49; Yang *et al.,* 96). These toxic food contaminants could be naturally occurring toxicants (phytotoxins), residues of pesticides & drugs, microbes and their toxins, preservatives, chemical contaminants from food processing and packaging, and other residues. These compounds as individual can cause serious health issues like illnesses related to drug resistance, that reduces the efficacy of treating drugs (Kim *et al.,* 52) and amalgamation of these, pose difficulties in their detection itself.

3.1.1 Sensors based on Carbon nanomaterials

Carbon nanotubes (CNT's), unique electrical, chemical, mechanical and structural properties, make them excellent amplification platforms to increase the number of signal-generating molecules. Moreover, CNT's metallic, semiconducting and superconducting electron transport, make them extremely attractive for electrochemical biosensors. Graphene is an isolated single atomic layer of graphite which is currently utilized in electrochemical analysis due to its exceptional conductivity. The large surface area, high conductivity and ease of modification with biomolecules have been applied to a variety of biosensing systems (Guo *et al.,* (36,37), Jain *et al.,* (47), Yang *et al.,* (97), Liu *et al.,* (59), Cai and Du (15), Cesarino *et al.,* (18), Bagheri *et al.,* (9) and Promphet *et al.,* (71)] particularly those with electrochemical detection.

3.1.2 Sensors based on Metal & metal oxide nanoparticles

Most widely, nanotechnology-based sensors incorporate noble metal nanoparticles such as gold (Weng *et al.,* 92) and silver (Zhou *et al.,* 105; Sherry *et al.,* 81; Cao *et al.,* 17; Wei *et al.,* 90). AuNPs have been commonly used, because of their unique character *i.e.* to increase surface area and conductivity in electrochemical sensors. A variety of assays based on AuNPs have been reported for the detection of chemical contaminants [Upadhyay *et al.,* (86), Chi *et al.,* (24), Li *et al.,* (56), Zhou *et al.,* (105, 106), Huang *et al.,* (44), Mecker *et al.,* (63), Yun *et al.,* (99)], heavy metal ions [Zhou *et al.,* (103, 104), Chen *et al.,* (20), Wan *et al.,* (89), Kumar and Anthony (54), Zhou *et al.,* (105, 106), Ravindran *et al.,* (73), Farhadi *et al.,* (30)] and for assessment of microbiological food contaminants [Sharma *et al.,* (77), Asao et al (7), Chen et al., (21) and Tang *et al.,* (85)].

3.1.3 Sensors based on Magnetic & other nanoparticles

Magnetic nanoparticles (MNPs) have been widely utilized as immobilization supports in sensing assays, development of immunomagnetic separations and magnetically loaded and controlled sensoring platforms (Hayat *et al.,* 42). Functionalized MNPs are commonly available, permitting development of different strategies for detection of a variety of analytes (Hayat *et al.,* 41). The advantages of MNPs *i.e.* larger surface area, increased possibilities for enhancing the assay kinetics, control and improve the immobilization efficiency; make them one of the most widely used NPs for detection and removal of food contaminants (Van Dorst, 87).

Nanosensors (mentioned in Table 3), being useful for sensing and reporting real time information regarding the product to the consumer, are far from being simply a passive, information-receiving device. They can be designed to manage this at critical control points in the supply chain - from the point food is produced or packaged; through to the time it is being consumed.

Table 3 : Various nantechnology based sensors for detection of food contaminants.

Class of Nanomaterials	Contaminants	References
Carbon based nanomaterials		
Functionalised SWCNTs	Ochratoxin,	Guo *et al.,* (36,37)
	Salmonella	Jain *et al.,* (47)
	Staphylococcal enterotoxin-B	Yang *et al.,* (97)
	Melamine	Liu *et al.,* (59)
Functionalised MWCNTs	Carbaryl	Cai and Du (15)
	Carbaryl Methomyl	Cesarino *et al.,* (18)
	Pb(II)	Guo *et al.,* (36, 37)
	Pb(II), Cd(II) and Hg(II)	Bagheri *et al.,* (9) Gupta and Solver (38)
Graphene	Pb(II) and Cd(II)	Promphet *et al.,* (71)
Metal & metal oxide nanoparticles		
Au NPs (Gold nanoparticles)	Aflatoxin	Sharma *et al.,* (77)
	Escherichia coli O157:H7	Chen *et al.,* (21)
	Staphylococcal enterotoxin-B	Asao *et al.,* (7)
	Brevetoxins	Tang *et al.,* (85)
	Hg(II)	Zhou *et al.,* (103), Chen et al (20),
	Pb(II) and Cu(II)	Wan *et al.,* (89)
	Paraoxon ethyl, aldicarb & Sarin	Upadhyay *et al.,* (86)
	Melamine	Chi *et al.,* (24), Li *et al.,* (56), Zhou *et al.,* (105, 106), Huang *et al.,*(44), Mecker *et al.,* (63), Yun *et al.,* (99)
Au NPs (Silver nanoparticles)	Pb(II)	Kumar and Anthony (54)
	Cu(II)	Zhou *et al.,* (105, 106)
	Cr(VI)	Ravindran *et al.,* (73)
	Hg2+	Farhadi *et al.,* (30)
	Melamine	Han and Li (39), Liang *et al.,* (58)
Iron oxide nanoparticles	*Campylobacter jejuni*	Huang *et al.,* (45)
	Melamine	Gao *et al.,* (32)
Zinc oxide nanoparticles	Mycotoxin	Ansari *et al.,* (5)
	Cu(II)	Chen and Wu (22)

Magnetic & other nanoparticles		
Magnetic NPs & TiO_2 nanocrystals	Aflatoxin B1 & Ochratoxin	Wu *et al.,* (94)
	Salmonella	Joo *et al.,* (50)
	Melamine	Ma *et al.,* (60)
Quantum dots	Cu(II)	Sung and Lo (84)
	Co(II)	Ngamdee *et al.,* (66)
	Melamine	Peng et al (67), Zhang *et al.,* (101), Zhang *et al.,* (100)
Other nanoparticles		
Glyco-nanoparticles	*Cholera* toxin	Schofield *et al.,* (76)
Liposomic and poly (3,4 ethylenedioxythiophene) coated CNT's	*Cholera* toxin	Viswanathan *et al.,* (88)
Rhodamine/Ag/mesoporous silica	Hg(II)	Cheng *et al.,* (23)
Antibody-competitive nanoparticles	Chloramphenicol	Yuan *et al.,* (98)

3.2 FOOD PACKAGING

Food is an incredible source of essential nutrients such as carbohydrates, proteins, fats, vitamins, and minerals to sustain life, provide energy, and prompt growth. Contamination of food can occur at any stage of food chain from production to consumption. Hence, it is highly imperative that the food must be properly protected at all levels by using good quality of packaging material, which is non-toxic, safe and cost effective.

Food packaging continues to evolve along-with the innovations in material science and technology, as well as in light of consumer's demand. The incorporation of nanomaterials into food packaging offers various advantages to food packaging such as barrier resistance, biodegradable packaging, incorporation of active components to increase functional performance (self healing composites, antimicrobial compounds etc.), regulating the internal packaging environment and sensor based technologies to provide relevant information. These new innovations in packaging, with improved mechanical, barrier and antimicrobial properties enable preserving of taste, color, flavor, texture, consistency and nutrients of foodstuffs.

3.2.1 Barrier Packaging

Despite the best of barriers, processing technologies and controls, foods are susceptible to biochemical and other forms of deterioration and thus there is need for appropriate packaging technology. While materials such as glass and metals are completely impermeable to gases, plastics on the other hand are semi-permeable; which can affect food and drink quality undesirably over relatively short periods of time (e.g. escape of carbon dioxide from carbonated drinks, oxygen sneaking to packaged foods resulting in faster decay, and ethylene spread between fruits and vegetables resulting in faster ripening).

Plastics, however, can be made more impermeable to gases through the addition of nanosccale based coatings or through the inclusion of nano particles (such as nanoclays of montmorillonite, photocataylytically active titanium dioxide nanoparticles and acrylic nanoparticles) within the polymer matrix. These act as small, physical barriers to the progress of gas molecules across the polymer, and if present in sufficient numbers effectively reduce gas transport to negligible levels (Robinson and Morrison, 74).

3.2.2 Antimicrobial packaging

Antimicrobial packaging is done to control or even prevent the growth of undesired or spoilage microorganisms by releasing antimicrobial substances. Most activities to combat this, have centered around nanoparticles of silver, copper, titanium oxide and zinc oxide. Chitosan; a biopolymer derived from chitin (a polysaccharide constituent of crustacean shells) has seen much interest in recent years as a material for the encapsulation, packaging material, as it also exhibits antimicrobial properties (Qi *et al.,* 72). Inclusion of nanoparticles possessing antibacterial property to matrix of chitosan not only enhances its strength but also improves its antimicrobial activity manifolds.

3.2.3 Biodegradable Packaging

Currently, the largest part of materials used in packaging industries, is non degradable petroleum based plastic polymer materials. As a result, this nondegradable food packaging materials, represent a serious problem on the global environmental (Kirwan and Strawbridge, 53).

One way to avoid this, but to still achieve sustainability, is the use of bio-based packaging materials, such as edible and biodegradable films from renewable resources. These are generally proteins or carbohydrates and can be derived from animal or plant origin. However, the use of bio-based materials for food packaging has been very limited currently due to poor barrier and weak mechanical properties. To overcome this, these natural polymers were frequently blended with other synthetic polymers or chemically modified with the goal of extending their applications in packaging (Petersen *et al.,* 69).

When biopolymers (such as cellulose) are mixed with nanoclay particles, the resultant nanocomposites exhibit improved barrier properties compared with the pure polymer, and after their useful life can be composted and returned to the soil. Other biopolymers that have been combined with nanoclays include chitosan, starch, casein, whey, and gelatin (Zhao *et al.,* 102).

3.2.4 Active packaging (AP)

One of the most innovative developments in the area of food packaging is active packaging. The purpose of active packaging is the extension of shelf life of food and the maintenance or even improvement in its quality. AP has subsidiary constituents, which have been deliberately included in or on either the packaging material or the package headspace to enhance the performance of package system. It includes benefits of both barrier as well as antimicrobial packaging systems.

Active packaging can be classified into two main types:

1). Non-migratory active packaging, acting without intentional migration (e.g moisture absorbers, mostly based on adsorption of water by zeolite, cellulose and their derivative)

2). Active release packaging, allowing a controlled migration of non volatile agents or emission of volatile compounds in atmosphere surrounding the food.

Components of the active packaging for food include

(1) Nanocomposites (metal ions of silver, copper, gold and metal oxides of TiO_2, MgO),

(2) Antimicrobial films (antibacterial/antifungal compounds like sodium benzoate and benomyl, acid, silicate, ethanol, zinc, elements (Si, Na, Al, S, Cl, Ca, Mg, Fe, Pd, and Ti), edible clove, pepper, cinnamon, coffee, chitosan, antimicrobial lysozyme, and bacteriophages),

(3) Gas scavengers [TiO_2, iron powder, silicates, sulfites, chlorides, polymeric scavengers, elements (Fe, Si, Ca, Al, Na, Cl, K, Mg, S, Mn, Ti, Co, V, Cr, and P)] (Ahvenainen 4; Brockgreitens and Abbas 14).

Based on the nature of spoilage, various kinds of substances can be used in AP systems which are of three types: scavenging, releasing and "other". Scavengers include those of O_2, ethylene, moisture and taint, whereas emitters include carbon dioxide (CO_2) and ethanol.

3.2.5 Intelligent or smart packaging systems

Smart packaging can be defined as small and inexpensive labels or tags attached onto primary packaging such as pouches, trays, and bottles, or more often onto secondary packaging such as shipping containers to facilitate communication throughout the supply chain (Yam *et al.,* 95).

These systems boost communication aspect of a package and uses different innovative communication methods i.e., Nano-sensors, time-temperature indicators, oxygen sensors, freshness indicators etc. (Kerry *et al.,* 51; Bouwmeester *et al.,* 13; Majid *et al.,* 61) to assess the quality of food commodities. Time-temperature indicators (TTI) are the most used applications in the field of intelligent packaging. TTI is a small measuring device attached to the package surface (usually made of nanosize particles e.g. triangular silver nanoplates), that exploits the change physical or physio-chemical property to produce irreversible changes of having exceeded a predetermined temperature threshold or is used to record the cumulative time-temperature history.

3.3 Nanoencepsulation and Nanoemulsion for food processing

Nanoencapsulation is defined as the technology of packaging of nanoparticles of solid, liquid or gas, also known as the core or active, within a secondary material, named as a matrix or shell, to form nanocapsules (Cano-Sarabia and Maspoch 16). The core contains active ingredient, which can be a drug, biocide, or vitamin etc. while the shell isolates and protects the core from the surrounding environment. Nanoenca- psulation provide several benefits such as ease of handling, enhanced stability, protection against oxidation, retention of volatile ingredients, taste making, moisture triggered controlled release, pH triggered controlled release, consecutive delivery of multiple active ingredients, change in flavour character, long lasting organoleptic perception, and enhanced bioavailability and efficacy (Marsh and Bugusu and Bugusu 62; Chaudhary *et al.,* 19).

Nanoencapsulation based on lipids, can potentially improve solubility, stability, and bioavailability of foods, thus preventing unwanted interactions with other food components. Some of the most promising lipid-based carriers for antioxidants are nanoliposomes and nanocochleates. Nanoliposomes also help in controlled and specific delivery of nutraceuticals, nutrients, enzymes, vitamins, antimicrobials, and additives (Mozafari *et al.,* 65).

Nanoemulsions are colloidal systems that consist of an oil phase dispersed in an aqueous phase, such that each drop of oil is surrounded by a thin interfacial layer made up of emulsifying molecules (Acosta 1). Nanoemulsions present many advantages such as decontamination of equipment and high clarity without compromising product appearance and flavor. Nanosized functional compounds that are encapsulated by the self-assembled nanoemulsions are used for targeted delivery of lutein; β-carotene; lycopene; vitamins A, D, and E_3; co-enzyme Q10; and omega-3-fatty acids (Choi *et al.,* 25). Nanoemulsion coating can be provided on the perishable fruits and vegetables to increase their shelf life.

CONCLUSION

Nanotechnology has proven its competence in almost all possible fields of science and technology. Food is the basic necessity of every living being and the intervention of nanotechnology in food industry is among one of its successful ventures. It is expected that the commercialization of nanotechnology in food science can not only ensure the reduction in post harvest losses but also ensures the enhancement in the shelf life of food commodities by exploring the potential of nanomaterials in sensors, food packaging and processing techniques. Around the globe, many farmers face losses in their annual income due to post harvest losses. The advent of nanotechnology in food science ensures major reduction in post harvest losses thus helping farmers in securing their future. Also, by increasing the shelf life of food commodities, the problem of food shortage in most parts of the world is expected to be solved with a lot of ease.

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