

## ADVANCEMENT IN PROTECTIVE PACKAGING SYSTEMS FOR FRUITS AND VEGETABLES

### Abstract

Packaging technology is vital in scientific handling of fruits and vegetables due to its perishable nature. These perishable commodities require both retail and bulk package containers to meet supply chain requirements. Conventionally and contemporarily wide range of material is used for packaging and transportation. Shrink packaging with different engineering properties are offering benefit of bulk and single unit packaging. Bio based material as package base is gaining importance due to environmental concerns posed by non-degradable hydrocarbon material. Many derivatives of bio origin are successively developed and used in packaging industry. In addition to meeting static needs, packaging material is expected to meet dynamic needs and be active for changes in local package environment. Modified Atmosphere Package (MAP) with its active and passive approach is proven to be good in meeting package dynamics on commodity specific approach. To keep package active and responsive, active packaging approach gaining significance in fruit and vegetable packaging. Scavengers and scrubbers of different groups have proved their ability in keeping packaging micro-atmosphere neutral for bio activity. This review is compilation of basic information about packaging and perishable commodities along with their interaction in transit and marketing. This will help in giving basic understanding of necessities of package and techniques in practice for preserving commodity for long time. Research scholars and academicians can benefit by this content in understanding available techniques in fruit and vegetable marketing.

**Keywords :** Quality, handling, storage, material, damage.

### Authors

#### **Dr. Rajesh. K**

Assistant Professor  
Department of Food Process Engineering  
College of Food Science and Technology  
Pulivendula, India.  
k.rajesh@angrau.ac.in

#### **Dr. M. Sai Srinivas**

Teaching Associate  
Department of Food Process Engineering  
College of Food Science and Technology  
Pulivendula, India.  
saisrinivas194@gmail.com

#### **Dr. T.V.N Padmavathi**

Assistant Professor  
Department of Food Safety and Quality Assurance  
College of Food Science and Technology  
Rudrur, India.  
padma\_avn@yahoo.co.in

## I. INTRODUCTION

Packaging performs significant role in keeping the quality of fruits and vegetables as they hover through the supply chain. Packaging shields the produce from transport jerking and abrasion damage during handling and from disclosure to chemical, physical and microbiological perils that could compromise safety. Packaging simplifies the movement of produce, while prolonging its keeping quality. Packaging materials and integrated system followed plays a significant role in preventing the losses on farm and the supply chain. Packaging minimises wastes, helps in value addition and makes the product qualitatively and quantitatively satisfactory.

Fruits and vegetables are considered as living organisms as they remain fresh even after harvest due to metabolic activity. During its metabolic activity, oxygen is used to break down carbohydrates into water and carbon dioxide. In case of dearth in oxygen, the pattern of chemical reaction changes leading to formation of small quantities of alcohol which leads to development of off flavours. The kind of spoilage prevailing in fruits and vegetables due to presence of surface moisture is by bacteria, yeast and molds. These organisms start acting on the surface by utilizing surface moisture and subsequently invade into internal structure through surface bruises and cuts.

The scenario of vegetable and fruit crops in India has become very encouraging. The percentage share of horticulture output in agriculture has become 33% (includes all horticultural crops). The production of vegetables has increased by 82.21% and fruits by 91.25% since 2004-05 to 2017-18 (NHB, Horticultural Statistics at Glance; Ministry of Health and Family Welfare). Fruits and vegetables together account for 90% of total horticulture production in the country. India is now the second largest producer of fruits and vegetables in the world and is the leader in several horticultural crops, namely mango, banana, papaya, cashew, areca, potato and okra. The Ministry of Food Processing Industries (MFPI) estimate losses of 23 million tons of grains, 12 million tons of fruits and 21 million tons of vegetables from India (MOFPI. Annual Report 2019-20).

Post-harvest losses are of greater concern in case of fruits and vegetables due to its instinct features like high moisture and metabolic activity. Post-harvest losses are classified according to their primary causal agent which includes following.

**1. Direct Causes of Post-Harvest Losses:** Under this group the product is subjected to physical abuse, biological, physiological and biochemical activities which leads to deteriorative reactions.

- **Physical and Ambient Factors:** This factor encompasses product response when subjected to excessive or insufficient heat, cold, gases or humidity. The change in rate and kind of biochemical reactions under such influencing factor leads to unwarranted changes in fruits and vegetables.
- **Mechanical Injuries:** This group includes impact injury, abrasion injury, transmission vibration, compression injury, puncture injury. They are caused due to unscientific handling of produce after harvest, during transport and storage.

- **Biological and Microbiological Losses:** This factor refers to damage or consumption of produce by bacteria, yeast, mold, insects, rodents and birds. Selection of improper package, storage ambience and unscientific pest control are major cause for damage.
  - **Bio-Chemical and Physiological Losses:** Undesirable reactions between chemical compounds and contamination with harmful substances are major reason for such losses. Improper harvest, unscrupulous usage of pesticide is attributed for these losses.
2. **Indirect Causes for Post-Harvest Losses:** They are not directly associated with any chemical or biological activity but related to managerial aspect of produce. Lack of marketing strategy, inadequate market system, lack of infrastructure, policy change, ill equipped man power is some of the responsible for indirect post-harvest losses (Mauriello *et al.*, 2005).

For both direct and indirect causes, selection of proper protective packaging systems plays an important role in minimizing losses. The packaging system adopted for fruits and vegetables facilitates ambience to minimise direct causes for post-harvest losses. In addition, it mitigates the contribution of unscientific management practices in post-harvest losses.

The role of adopting protective packaging system has greater scope in expanding packaging technology in safeguarding product quantity and quality in supply chain. Many advance packaging systems are now being adopted for fruits and vegetables to facilitate good storage and transport (Idah *et al.*, 2007). The advent of super markets has also added advantage for promoting packaging system in more effective way. Package system is turning into dynamic component by changing its operational features based on external factors inviting attention of safe product consumers.

## II. PACKAGING SYSTEM FOR FRUITS AND VEGETABLES

Packaging as an enclosure of products performs one or more of the following functions: containment, protection, preservation, communication, utility and performance (Packaging Institute International definition). As defined for food products, the packaging system for fruits and vegetables primary function includes containment, protection, communication and convenience. Though communication function does not have significant role in fruit and vegetable distribution but the remaining three functions have greater role in scientific distribution of produce. Unlike processed food, fruits and vegetables being respiring entity needs greater attention in transport and storage. The unit size is much higher than that of processed food products and adds to bulk of product handling in supply chain.

Number of ways can be used to classify packaging of fruits and vegetables. Based on stage of distribution, primarily intended packaging system is classified into i) consumer or retail packaging ii) transport or bulk packaging

1. **Consumer or Retail Packaging:** These are small size packaging material used to pack 6 to 12 fruits or up to 2 kg vegetables (Camelo, 2004). Commercial value and the consumer

needs decide the quantity of produce to be added to each unit. These are the units where consumer handles in households by preserving them in domestic refrigerators. Any communication intended to convey to the consumer should be prescribed properly on this packaging material. Following are some of the packaging types used for retail marketing.

- **Flexible Plastic Films:** They are predominantly used in most of fruit and vegetable marketing because of its ease of handling. Different groups of thermosetting plastic in the form of pouches are used to make retail pouches. As the produce is respiring, properties like O<sub>2</sub>, CO<sub>2</sub> and water vapour transmission rates of flexible package plays an important role in its selection. For marketing of onion, garlic and citrus fruits net bags are used instead of continuous film of plastics. For the convenience of leafy vegetables handling in retail units, wrapping of bundle of leafy vegetables with suitable plastic film is common.
- **Trays with Overwrap:** Pulp and plastic material based trays are common for retail packaging. The trays are engineered to absorb mechanical shocks during produce movement. They are available with plane base and cavity indented base to accommodate individual fruit. This feature of fruit helps in securing fruit in position and avoids handling abuse during distribution. The overwrap film covered above tray is a transparent, food-grade, odourless plastic film with the property of clinging to the product packed when stretch wrapped. The choice of overwrap depends on commodity nature and storage condition.
- **Plastic Punnets:** These are hard packaging material customized to produce size. The advantage over flexible package is its ability to bear compression load when units are stacked one over other. Strawberry, kiwi fruits and other commercially valued produce is packaged in such containers.
- **Foam Sleeve:** Polyethylene foam in the form of plastic tubular film is intertwined to act as an elastic container. The intent of this unit package is to provide cushioning along with minimising produce contact with other packaging and manual handling. Individually foam sleeve protected produce is again packaged in corrugated boxes for meeting consumer demand.
- **Cartons and Corrugated Boxes:** In retail sales, corrugated boxes containing 12-15 fruits are common. Mangoes, apple, grapes are packed in such containers due to its availability at cheaper cost and ease of disposal. The advantage of this kind of unit package is its mechanical strength and bulk space.
- **Shrink Wrap:** Alternate to stretch wrapping, this type is useful in accommodating produce according to surface contours. By selecting proper packaging material, transpiration of produce can be brought down by 5-20 times. Individual or group of fruits are loosely covered with flexible packaging material and passed through heat shrunk tunnel to obtain shrink wrap produce.

**2. Transport or Bulk Packaging:** They are designed to transport produce for long distance in bulk quantity in a package which is convenient to handle. The capacity of this group packaging ranges from 10-50 kgs. The package is predominantly chosen by considering convenience of handling rather than protection because it is temporary nature. It comprises flexible and rigid package and the option depends on produce nature and economic value.

- **Wooden Boxes:** Includes natural wood and industrially manufactured wood based sheets. The wood used in manufacturing of boxes are well dried, easily machinable, free from knots, cracks, insect attack, bad odour. Plywood, hard board and particle board are some of industrially manufactured wood material. Wood used in making boxes are selected based on the surface features of produce. Tomatoes, capsicum, cauliflower, guards are commonly transported by using wooden boxes. In case of long distance transport, produce filled box will be covered using wood sheets by striking nails.
- **Plastic Crates:** HDPE and polypropylene injection moulded plastic crates are manufactured as plastic trays (Schirp *et al.*, 2014). They are rigid, impact and compression resistant, less weight with provisions for respiration. Collapsible plastic crates are also available to reduce the space required for transporting empty crates. As the crates are moulded using polymer material, different size and shapes can be manufactured based on commodity. Capacity of plastic crates ranged from 10 to 50 kg. Internal surface of boxes is smooth; also it facilitates easy handling provision during loading and unloading.
- **Corrugated Fibre Board/Plastic Boxes:** These boxes are user friendly and need not be returned once the product is transported. Their strength is not comparable to wooden boxes or plastic crates but facilitate better exterior printability and internal smooth surface. Due to its poor wet strength, they are laminated with plastic film like LDPE, PP or PVC. Proper sealing mechanism has to be adopted to seal open ends of corrugated fibre board to make package unit intact.
- **Bamboo Baskets:** Bamboo is used in weaving basket of required shape and size. The weaving requires skill as it involves careful cutting, stripping, drying and intertwining of bamboo strips to required size and shape. Berries such as grapes, jamoon, and blueberry are transported in bamboo basket using leaves as inner covering material. Baskets own good compressibility, stakability and impact resistant.
- **Sacks:** This is flexible package used for bulk transport made by cotton, jute and plastics. The material is made by intertwining thread of aforesaid material to different degree of closeness to facilitate aeration of produce. They are easy to handle during loading and unloading and weigh very less compared to rigid packaging material. Sacks can be stacked one above the other if the produce is having good compression resistance. However, they have low protection against puncture, compression, vibration and impact injuries.

### III. SHRINK PACKAGING OF FRUITS AND VEGETABLES

Shrink wrapping is a kind of technique which reduces the loss of moisture and keeps freshness of produce for longer periods. Reduction of transpiration loss to the tune of 10-20% is possible by shrink packaging (Ben-Yehoshua, 1985). Shrink package forms barrier for moisture loss to a greater extent. It prevents secondary infection, provides barrier for the spread of microbial infection, maintain firmness, delay ripening, control chilling injury.

**1. Methods of Shrink Packaging:** Individual fruit or vegetable is first loosely covered or sealed in a suitable polymeric film and then exposed to hot blown air for few seconds. In case of unit/tray wrap packaging, the produce sealed in a suitable package in convenient size and passed through the hot tunnel to form a tight wrap. In both the cases, the produce should be exposed to minimum possible time to avoid temperature impact. Following parameters are to be considered while selecting suitable film for shrink packaging.

- High barrier for water vapour diffusion.
- Film should strike balance between thickness and tensile strength.
- Selective permeability to facilitate exchange of gases when off flavours is developed.
- Film should be adaptable to specific requirements of packaging machine and produce.
- Film should be glossy and more transparent for effective produce presentation.
- Good sealing property and abrasion resistance for better handling.

**2. Effects of Shrink Packaging on Fruits and Vegetables:** Physiological parameters like respiration, transpiration and ripening are better controlled by shrink packaging than low-temperature storage.

- **Weight Loss Reduction:** Shrink wrapping reduces moisture loss of fruits and vegetables to the tune of 5-20 times. Fruits or vegetable having large surface to volume ratio are vulnerable to moisture loss where shrink package could be used to extend shelf life. Kinnow mandarins, Nagpur mandarins, pomegranates, papaya and mangoes are studied for the loss of moisture by shrink wrapping. After shrink wrapping, the produce was stored at different relative humidity ranging from 25-90%. Only 2-8% weight loss (moisture) was observed across different relative humidity whereas, 25-30% weight loss was reported for same storage condition at different storage durations.

Miller *et al.*, (1986) has reported loss of weight due to moisture as 3% for non-wrapped pepper compared to 0.3% weight loss in wrapped pepper. Cucumber fruits were shrink wrapped and stored at both ambient and refrigerated storage by Sudakar *et al.*, (2000). It was reported that 1% weight loss was observed in case of wrapped cucumber and 5.6-8.28% weight loss in non-wrapped cucumbers.

- **Firmness:** Firmness of fruits is affected due to loss of moisture which in turn influence consumer acceptance. Polyolefin shrink wrapped pomegranates maintained firmness of 102 N compared to 78.5 N in non-wrapped after 60 days of storage as reported by Abd-elghany *et al.*, (2012). Pal *et al.*, (2004) had observed significant difference in guava softening when tested for firmness after 2 weeks of storage at ambient condition. Change in firmness was 2.8 folds when compared between

wrapped and unwrapped films. Tomatoes were tested for firmness after 4 weeks of storage and higher firmness value (21 N) was observed for wrapped compared to non-wrapped (15 N) tomatoes (Risse *et al.*, 1985).

- **Shelf Life Extension:** Heaton *et al.*, (1990) had reported acceptability of apples for 38 weeks when shrink wrapped and stored at 26°C under 40–42% RH. High-density polyethylene of 15 µm was shrink wrapped on lemons and stored at ambient condition reported acceptable shelf life up to 75-90 days. Cryovac (9 µm), polyolefin (13 µm) and LDPE (25 µm) were used to shrink wrap kiwifruits and stored at 22–28°C and 62–68% RH by Sharma *et al.*, (2012). Among the films studied, Cryovac (9 µm) reported as effective by retaining good total soluble solids (TSS) and ascorbic acid content.
- **Decay Control:** Sporulation and drip from rotten produce contaminates adjacent by causing unacceptable produce quality. Fungicide treated fruit retains its effectiveness on fruit or vegetable due to film wrapping as compared to non-wrapped fruits.
- **Mitigating of Chilling Injury:** Singh & Sudhakar Rao (2005) reported that shrink wrapped papaya stored at 13°C could be stored till one month without chilling injury. The reduction in chilling injury in shrink wrapped films was related to modified and water saturated atmosphere produced by sealed packaging.
- **Reducing Blemishes:** Blemishes are commonly found on fruits and vegetable surfaces based on harvested technique adopted on field. Blemishes lead to secondary infections by the activity of microorganisms. Shrink film wrapped produce isolate fruit surface contact with adjacent produce when packed individually by minimizing chances of transfer of microorganism.
- **Delay of Ripening and Fruit Senescence:** Ethylene produced by fruits hastens process of ripening by accelerating biochemical reaction. When fruits are wrapped individually, they minimize spread of ethylene in the batch of produce by safeguarding fruits by accelerated biochemical reactions. Matured green papaya were shrink wrapped with cryovac D-955 film by Singh & Sudhakar Rao (2005). They observed that the ripening process was prolonged to 15 days compared to 7 days in non-wrapped films when they were stored in ambient conditions.

#### IV. ENGINEERING PROPERTIES ESSENTIAL FOR PACKAGING

Packaging material is considered as “silent seller”, because it performs all functional activities without external influence. Apart from primary functionalities, from engineering perspective, packaging films should possess some properties to sustain different external atmosphere. Mechanical, barrier, optical, and surface properties plays significant role in establishing produce shelf life and consumer choice.

1. **Mechanical Properties:** Mechanical stresses such as compression and tensile stress are common in transportation and storage of produce. Elastic (Young’s) modulus, tensile

strength and elongation at break are three important factors obtained in stress-strain plot of packaging material. Elastic modulus expressed in MPa is slope linear part of stress-strain plot. It exhibits elastic behaviour of material and considered as intensive property.

Tensile strength is very important from package handling point of view. It is the indication of maximum bearable stress that the package can withstand before failure. Under tensile strength, yield (tensile strength in the elastic region), breaking (tensile stress at the breaking point) and ultimate (highest stress point along the stress-strain curve) strengths are considered to understand packaging capability at different loading conditions. Tensile strengths are calculated by subjecting packaging material to elongation forces whereas, compressive strengths by compressive forces. Puncture test is performed on packaging material to analyse capability of packaging material in resisting external handling conditions such as protruded contact parts, shelf sharp edges, display racks.

Coefficient of friction (COF) is another important mechanical test to quantify resistance of surface to slide on other surface. “Polymer-to-Polymer” and Polymer-to-metal” values of COF were to be found to know packaging material ability in resisting external surface handling.

2. **Transport Properties:** Quality decay of product is arrested when package is engineered to suit fruits and vegetable ambience which facilitate sustainable environment. Permeability of packaging for oxygen, carbon dioxide, nitrogen and water vapour is important from packaging ambience point of view. Permeation of gasses is a three sequential process including adsorption, diffusion and desorption. These sequential operations are gradient driven process from high to low concentration region. Permeability coefficient of package is product of solubility and diffusivity. The parameter used to quantify the barrier property of package is transmission rate. Packaging material is chosen based on transmission rates of package to oxygen, carbon dioxide and nitrogen gases predominantly. As the transmission rates of each gas differ with kind of polymer, co-extruded polymers are common for fruits and vegetables to tailor-made the package. External factors such as, temperature and relative humidity plays significant role in altering transmission rates of different gases.
3. **Optical Properties:** Protection of produce from cosmic waves to radio waves in electromagnetic spectrum is paramount for packaging material. Packaging alters the quantum of absorbance, transmittance and reflectance of incident rays. Chlorophyll, pheophytins, porphyrins, riboflavin, myoglobin, and synthetic colorants in produce absorb light energy to transfer atmospheric oxygen into triplet oxygen. This triplet oxygen triggers detrimental reaction such as discoloration and oxidation. Aluminium foil and metalized films act as total barrier against electromagnetic radiation especially in preventing UV and visible light.

Apart from acting as barrier, package is also intended to perform some of consumer perspective attributes such as transparency, haze and gloss. While selecting packaging for consumer retail units, there should be balance between barrier and hedonistic property.



## V. BIO-BASED PACKAGING

As environmental concerns are erupting in all fields, packaging is no exception in throwing challenge on alternatives for polymers. Bio-degradable package offers advantages like renewable source, lesser cost, abundant and eco-friendly. Biopolymer based packaging finds its origin from naturally available renewable sources such as polysaccharides, proteins and lipids or in combination. Alternatively, bio-based packaging offers variable CO<sub>2</sub> and O<sub>2</sub> selectivity and moisture permeability giving an opportunity to engineer package to product specific needs. Some of the commonly used bio-based packaging films and material is enlisted below.

**1. Biomass/Plant Origin:** these are plant based material subjected for direct extraction resulting in development of starch, protein and cellulose.

- **Chitosan:** Chitin is a major skeletal substance of invertebrates and also found in cell wall constituents of fungi and green algae. Among the different methods of extraction of chitin and chitosan, chemical extraction process is commonly practiced due to cost economics. Ahvenainen, 1996 had reported that chitosan can be formed into semi permeable membrane which modify internal atmosphere leading to delayed ripening and decreased transpiration rate.
- **Cellulose:** Cotton fibre and wood are important raw material used in production of cellulose. Viscous paste is produced when plant fibre is dissolved in alkali and carbon disulphide. Subsequently, cellophane forms are obtained by sulphuric acid bath and sodium sulphate treatment. Cellulose needs modification, plasticization and blending due to inherent processing problems associated with it.
- **Starch:** It has a unique feature of staying in granular form in plastic matrix. It is a mixture of linear amylose and highly branched amylopectin and highly water soluble. Starch is also used in blends with synthetic polymer and enhances biodegradability.
- **Protein Films:** They have good hydrophilic features, helps in good adhesion on fruits and vegetables. Protein films are good barriers for gases but do not resist water diffusion. Soy protein, whey protein, fibrinogen, wheat gluten, egg albumin and corn zein are some of the bio-origin material used in manufacture of protein films. Many research findings have suggested that protein with blend of lipids or polysaccharides are good at exhibiting better package property by combining individual component properties. Vegetable oils, glycerin, citric acid and antioxidants are used in making composite film that led to moisture barrier, restricted oxygen transport and carrier of antioxidant to other foods (Cutter & Sumner, 2002).

**2. Classical Chemical Synthesis**

- **Lactic Acid:** It is produced by subjecting substrate for anaerobic fermentation by different groups of microorganisms. Lactic acid is also used in synthesis of poly lactic acid as new bio degradable or bio-based plastic.

- **Polylactic Acid (PLA):** It is mainly obtained by lactic acid, which is having its origin to renewable bio based resources like sugar beets and corn. Structurally it is comprised of linear aliphatic polyester, a high strength thermoplastic possessing biodegradability and compostable. PLA finds its limitation by possessing features like high polarity, brittleness, stiffness and low deformation at break limit. This can be overcome by using suitable blend of material having good barrier and mechanical properties. Addition of maleicanhydride to PLA chain enhances better mixing and filler properties thereby proving better package for different produce.

### 3. Bio based Polymer from Micro-Organisms/GMO

- **Polyhydroxyalkanoates (PHAS):** These are produced by bacterial fermentation which replaces hydrocarbon based polymer. The process of production involves fermentation of substrate constituting of feed stock including vegetable oil, municipal waste, organic waste, fatty acids along with carbon source. After 48 h of fermentation with suitable bacteria, broth will be subjected for isolation and purification.
- **Bio-Polyethylene:** It is derived from bio-renewable feedstock such as maize, wheat, corn, wood through biological fermentation process. Ethanol is produced by anaerobic fermentation further; azeotropic mixture of hydrous ethanol is obtained through distillation process. Though it is biological origin, the product is not inferior to petrochemical polyethylene. It is extensively used in packaging of agricultural produce including fruits and vegetable due to its competitive packaging features and low cost.
- **Bacterial Cellulose:** Bacterial cellulose differ with cellulose obtained by chemical process through high degree of polymerization due to gradual chemical changes brought by bacterial fermentation under ambient conditions. Major challenge in utilizing bio-cellulose in large scale is high cost of production despite having good barrier properties.

### 4. Polymers from Petroleum Sources

- **Polycaprolactone (PCL):** It is a biodegradable polyester synthesized from petrochemical having very low melting point. It is used in manufacture of speciality polyurethanes which imparts good water and solvent resistance. Due to its low melting point, it gets mixed well with other resins to bring desirable changes in polymer properties. A blend with other bio-origin material will cut the cost of polymer making it more biodegradable and cost effective.
- **Polyesteramides (PEA):** Hydrolysable ester groups ( $-\text{COO}-$ ) is placed as backbone in this product which imparts high tensile strength and thermal stability. It finds its application as package in pharmaceutical and food industry due to presence of hydrolytically cleavable ester bonds which helps in altering material crystallinity.

- **Bio-based Fibers:** They are animal or plant origin encompassing cotton, jute, hemp, wool silk. Advantage of minimal weight, lower cost and waste minimization can be found in such bio-fibers. Natural composite fibers can be formed by using blend of different bio-origin raw material.

## VI. MODIFIED ATMOSPHERIC PACKAGING

Storing of fruits and vegetable in a package needs dynamic ambience as the produce undergo respiration by changing gaseous composition inside package. This necessitates the altering of package ambience either directly or indirectly to extend shelf life of fruits and vegetables. Product undergoes different degree of respiration which is influenced by temperature, relative humidity, gaseous composition and permeability of gases. Thus, it is very important to optimise these parameters to improve shelf life of product. When package is made dynamic to respond the changes brought out due to action of produce, the effectiveness of packaging system improves.

Respiration is considered as an important detrimental factor to bring down product shelf life by hastening physiological process of produce. It is an aerobic process which demands oxygen for changing forms of biochemical constituents. Respiration provides energy required to carry many biochemical reactions. Decreasing rate of respiration by modifying package gas composition is the main aim of modified atmospheric packaging. Altering gas composition like CO<sub>2</sub> and O<sub>2</sub> to retard the rate of respiration through choice of packaging having different permeations are practiced in MAP.

1. **MAP Technique:** It is a method of creating passive means of altering gas composition within package by choosing appropriate packaging material. The success of this technique stands on balance between produce respiration rate and gas exchange between produce and external atmosphere through package (Farber et al., 2003). MAP slows down rate of biochemical changes by inhibiting rate of oxidation and additionally helps to check amount of ethylene produced in the storage. MAP differs with CAP with the fact that in controlled atmosphere, the package ambience is precisely controlled throughout storage period through appropriate action whereas; MAP is dynamically attaining required gas composition through respiration activity of produce during storage.

Following are sequence of operations in packaging fruits and vegetables under MAP

- Fruits or vegetables are introduced into package having desired barrier properties followed by flushing of gas mixture of specific modified atmosphere compositions.
- Closure of packaging with appropriate sealing mechanism to contain modified atmosphere.
- Refrigerated storage of container for first few days, during this period the oxygen present in package atmosphere is converted into carbon dioxide through respiration in slow rate.
- Package is transferred to ambient atmosphere; the package micro-atmosphere is now enriched with carbon dioxide and depleted with oxygen which retards rate of respiration.

The above said phenomena are termed as commodity generated modified atmosphere package or passive MAP as the modification of local gases happened due to produce activity. On the other hand, vacuumization and back flushing of desired gas composition helps in attaining required gas ambience at faster rate. The process is called active modified atmosphere package. In addition to the above technique, O<sub>2</sub>, CO<sub>2</sub> scavengers and water vapour adsorbers are also used inside package to improve the time gap for establishing favourable atmosphere.

- 2. Gasses used in MAP:** Nitrogen, oxygen and carbon dioxide are extensively used in MAP. Properties such as solubility and diffusivity of these gases in package play an important role in its effectiveness inside micro atmosphere. Purified gases having tag of “food grade” gases are majorly used in composition. MAP demands low proportion of oxygen and comparatively high proportion of carbon dioxide in order to reduce rate of respiration. Also, higher proportion of CO<sub>2</sub> is detrimental in maintaining freshness of produce working for phytotoxic effect. Therefore, N<sub>2</sub> is used as filler gas due to its inert nature and non-toxic property.

Nobel gases such as argon found beneficial effect on preserving freshness of coffee beans but, purification and handling adds to the cost. When oxygen levels of micro atmosphere reach very low level (<1%) aerobic respiration turns into anaerobic respiration which leads to formation of acetaldehyde and subsequently ethanol. Additionally, the sensitivity of fruits and vegetable reduces when it is exposed to very low oxygen levels.

- 3. Microbiological Safety:** As many MAP systems are developed to change the micro atmosphere with elevated carbon dioxide content, all aerobic spoilage microorganisms are inhibited. There is a threat by attack of anaerobic pathogens. Some of the studies have established that food borne pathogens get inhibited when optimal gas composition is available in micro atmosphere. Placing of oxygen scavengers, moisture adsorbers and antimicrobial package has synergetic effect on controlling the growth of pathogenic organisms. Experiment conducted by many researchers has established that incorporation of antimicrobial agents in MAP material has brought down spoilage microorganisms.

#### 4. Factors Considered for Designing MAP

- **Respiration:** Higher is the respiration rate greater is deterioration and also faster is the ripening. Individual fruit differs in respiration rate based of surface area, degree of maturity and ambience of storage. Too much restriction of oxygen in MAP is detrimental to produce because it leads to production of alcohol, off flavour and odour development that subsequently leads to decay. The dynamics of respiration of produce needs to be studied thoroughly while designing MAP for better results. Horticulture produce are categorised into various groups based on respiration rate viz., very low (< 5 mg CO<sub>2</sub> /Kg-hr), low (5-10 mg CO<sub>2</sub> /Kg-hr), moderate (10-20 mg CO<sub>2</sub> /Kg-hr), high (20-40 mg CO<sub>2</sub> /Kg-hr), very high (40-60 mg CO<sub>2</sub> /Kg-hr) and very high (>60 mg CO<sub>2</sub> /Kg-hr). Suitable micro-atmosphere and packaging material has to be opted to make MAP susceptible for these commodities.

- **Moisture:** Horticulture produce comes under high moisture group and leads to loss of weight due to physiological process. Relative humidity of ambient atmosphere influences the loss of moisture from product after harvest. MAP design has to account the rate of moisture loss under different gaseous composition to mitigate moisture loss during storage.
  - **Microorganism Load:** Since most of fruits and vegetable are harvested on field, the threat of initial microorganism load is inevitable. Exposure of produce surface to handling containers, storage area also contributes to microbe load. MAP, to certain extent control the growth of microorganism inside package due to skewed oxygen. Further, carbon dioxide rich atmosphere is detrimental for growth of many organisms. To the extent possible, MAP design should consider reducing cross contamination by package during its handling and storage.
  - **Temperature:** this factor facilitates or retard many biochemical reactions based on reaction kinetics at different temperature. Many enzymatic reactions can be curtailed by choosing appropriate storing temperature. Ambient and slightly higher temperature is favourable for many enzymatic reactions and respiration. Storage temperature also influences the permeability of gases from package in MAP.
  - **Pre-Cooling:** commodities subjected to pre-cooling before packing in different packages fare better than those packaged without pre-cooling. This step in post-harvest operation reduces enzymatic activity, respiratory activity, ethylene production and water loss. Pre-cooling primarily removes field heat hidden in produce at the time of harvest. Methods like hydro cooling, forced air cooling and vacuum cooling are commonly practiced for pre-cooling of fruits and vegetables.
5. **Packaging Material used in MAP:** Barrier properties of packaging material are important from MAP design point of view. The dynamics of gas present in micro atmosphere depends on permeation of gases from micro atmosphere to ambient conditions. Package is required to exhibit different ingress and egress rates for CO<sub>2</sub> and O<sub>2</sub> in order to maintain safe MAP atmosphere. Plastic package material dominates in meeting most of the MAP requirement compared to other group of packages. Some of the packages used in MAP are enlisted and discussed below.
- **Low Density Polyethylene:** It has low permeability to water vapour and high permeability to gases. It is considered as most versatile group of polymer due to its adoptability for many packaging features. It also acts as very good blending material in development of customized co-extruded polymer to suit different needs of product.
  - **Linear Low-Density Polyethylene (LLDPE):** this group possess better impact strength, tear resistance, tensile strength. Plastic films are manufactured by using blends of LDPE and LLDPE. The blend composition shifts from one design to another which is dependent of marketing needs of MAP market.

- **High Density Polyethylene (HDPE):** It has better barrier properties than LDPE and LLDPE. Comparatively this material is good barrier extensively used in closures of liquid containers. In design, HDPE blends are used to bring strong barrier properties in packaging material based on commodity needs.
- **Polypropylene (PP) and Oriented Polypropylene (OPP):** Isostatic resins are best suited for MAP and also possess lowest density. It is thermal resistant material due to its high melting point. Polypropylene is a good chemical resistant, transparent and durable than polyethylene.
- **Polystyrene:** It is poor barrier to moisture and gases but has excellent transparency and higher tensile strength. Due to its low barrier property, it is used in MAP when breathable film is required to exchange large quantities of gases from produce. As polystyrene alone is brittle, it is blended with other plastic material to obtain required characteristics in package.
- **Polyethylene Terephthalate:** PET is available in amorphous (transparent) and semi crystalline (opaque and white). Barrier properties of PET can be enhanced by blending with PVDC (McKeen, 2013). It finds its application in MAP due to its better barrier properties to gases and transparency. For retail units in marketing chain, this packaging material meets both product presentation and good barrier property.
- **Polyethylene Naphthalate (PEN):** Barrier property of PEN is comparable to PET in addition; it facilitates good functionality at high temperature. As the packaging material is temperature stable, its use in higher temperature of operation is predominant.
- **Polyvinyl Chloride:** It is stiff, heavy, ductile and strong packaging material suitable for handling voluminous produce. With the addition of plasticizers, they can be converted into package of varied degree of flexibility. PVC can also be blended with other material to obtain desirable character.
- **Ethylene-Vinyl Alcohol:** EVOH is very crystalline material and a co polymer of vinyl alcohol and different proportions of ethylene. Due to the presence of -OH groups, it exhibits strong intermolecular hydrogen bonding. It is good barrier to O<sub>2</sub>, odour, flavour but the presence of hydrogen bonds makes it moisture-sensitive when exposed to high humidity.

## VII. ACTIVE PACKAGING

As discussed in MAP, package is turned into a favourable micro atmosphere to retard unwanted reactions thereby extending shelf life. In case of active packaging, the package tends to turn into an active material responding to the internal changes in package in order to continuously act and keep a steady atmosphere for product. Scavengers of oxygen and carbon dioxide added inside the package helps in controlling the proportion of gases inside packaging.

1. **Oxygen Scavenging:** Iron based sachets are effective in rapid depletion of oxygen level in the headspace of package. Ascorbic acid, enzymes and photosensitive polymers are also successfully used to reduce oxygen level below 0.01%. Details of oxygen scavengers and its mode of action are discussed below.

- **Iron Powder Oxidation:** Iron oxide powder, ferrous carbonate and metallic platinum are filled in small sachets to act as oxygen scavenger inside package unit. The content present in sachets undergo simple oxidation reaction by consuming oxygen present in package ambience. These contents are self-reacting in presence of moisture and easy to handle. Cruz et al. (2007) conducted research by exposing oxygen absorbing sachets at 75%, 80% and 85%. They reported that oxygen absorption increased with increase in relative humidity also, quantified 50 mL/day and 18.5 mL/day absorption when stored at  $25\pm 2^{\circ}\text{C}$  and  $10\pm 2^{\circ}\text{C}$ , respectively.
- **Ascorbic Acid Oxidation:** Oxygen scavenging by using ascorbic acid oxidation is very slow process needs catalyst to hasten the process. The principle involves conversion of ascorbate to dehydroascorbic acid. Cruz *et al.*, (2008) has reported that 1 mol of  $\text{O}_2$  requires 2 moles of ascorbic acid. Both sachets and film technology incorporated with ascorbic acid and ascorbate salts used in design of oxygen scavenger. Film is incorporated with transition metal like (Cu, Co) to catalyse reaction in the presence of water.
- **Enzymatic Oxidation:** Glucose oxidase and alcohol oxidase in presence of catalase reacts with substrate to scavenge  $\text{O}_2$ . In the reaction,  $-\text{CHOH}$  group containing two hydrogen of glucose gets transferred to glucono-delta lactone,  $\text{O}_2$  and  $\text{H}_2\text{O}_2$ . Catalase is used in the reaction because,  $\text{H}_2\text{O}_2$  is an objectionable gas and hence, used to breakdown peroxide. Apart from aforesaid enzymes, ethanol oxidase which oxidises ethanol to acetaldehyde is also found to be effective in oxygen scavenging. Enzymes are used as integral part of packaging or packed as sachets. In case of integral packaging material, polypropylene and polyethylene are immobilized by process called adsorption and encapsulation.
- **Unsaturated Hydrocarbon Oxidation:** As scavengers these compounds are best suited for dry produce like nuts. Soybean, cotton seed oil and sesame are sources of linoleic, linolenic and oleic compounds which are considered as polyunsaturated fatty acids. Basically these compounds are in liquid or semi-solid state therefore, transition metal catalyst is added to solidify the compound for convenient handling in package system. Calcium carbonate is one of the common metal catalysts used for solidifying in the form of granule or powder and then filled in sachet. Also, ethylenic-unsaturated hydrocarbons like squalene, polybutadiene, fatty acids were reported to have sufficient oxygen scavenging capacity. These compounds can be mixed with thermoplastics like polyethylene, polypropylene by terminating functional group to obtain films by coinjection or co-extrusion. Disadvantage of this scavenging system is generation of by-products such as aldehydes and ketones due to oxygen scavenging reactions which has very low sensory value. This problem can be overcome by incorporating functional layer in between food product. In some of the commercially

accepted oxygen scavenging system, unsaturated hydrocarbon polymer pellets with cobalt catalyst are used in mechanical closures, metal caps and steel crowns.

- **Immobilization of Microorganisms in Solid Holders:** This is a technique wherein natural or biological oxygen scavengers are entrapped in packaging material to get activated when suitable atmosphere is available. Edens *et al.*, (1992) reported that a patent was registered wherein yeast is immobilising in bottle closure and get activated when moistened to respire and consume oxygen. Altieri *et al.*, (2004) successfully used hydroxyethyl cellulose (HEC) and polyvinyl alcohol (PVOH) to entrap *Kocuriavarians* and *Pichia subpelliculosa* and maintained microorganism's viability for 20 days. Cycle of biological oxygen scavenging film includes entrapment of selected microorganisms in suitable polymeric matrix, film storage, usage by triggering appropriate activation mechanism.
  - **Photosensitive Dye Oxidation:** In this system, photosensitive dye is impregnated onto polymer film which is activated by mechanism (UV light) and transfer O<sub>2</sub> to singlet state to make oxygen removing rate faster. Oxygen in singlet excited state is highly reactive in carrying chemical reaction by scavenging. In this technique photosensitizing dye and singlet oxygen acceptor is sealed in coil of ethyl cellulose film in the headspace of packaging. When film is exposed to appropriate wavelength of illuminated light, oxygen molecule get sensitized by dye molecule then diffuse into singlet state. This singlet molecule reacts with acceptor molecules to act as oxygen scavenger.
2. **Moisture Scavenging:** Increased moisture on surface of fruits and vegetables makes it prone for microbial spoilage and reduces aesthetics of product. Drip loss is also considered as one of the common hurdle in presenting fruits or vegetable in fresh form. Moisture reduction (replace humid air with dry air) and moisture prevention (through barrier properties of package) are two common strategies adopted to reduce moisture in package. Inherently, hygroscopic material such as 100% cellulose based material is useful for former strategy. RH controllers and moisture removers such as desiccants are commonly used in later group.
- **Desiccants:** Silica gel, clay, molecular sieves, sodium chloride, magnesium chloride, calcium sulfate, sorbitol and calcium oxide are some of the common desiccants used as moisture scavenger. These desiccants are placed in the form of sachets, bags and integrated in pads to absorb moisture from package. Vapour sorption isotherms influence the capacity of desiccants as moisture scavengers. Addition of nanozeolites to paper or plastic film to regulate amount of moisture absorbed in packaging is also reported (Ulkapli & Bagheri, 2016).

Optimum humidity in headspace of mushroom packaging is very important as excess RH leads to psychrophilic bacteria whereas, lower RH leads to weight loss. Mahajan *et al.*, (2008) has reported 96% as optimal RH for storage of mushrooms. The same researchers conducted a study on combination of fast absorbing (CaCl<sub>2</sub>, KCl, and sorbitol; 0.91±0.01 g H<sub>2</sub>O per gram) and slow absorbing (bentonite/sorbitol; 0.34±0.02 g H<sub>2</sub>O per gram) moisture absorbers. The study established that scavenger



moisture holding capacity is RH dependent and reported 0.15 to 0.94 g water per gram of desiccant when RH was increased from 76 to 96%.

Tamarind seed galactoxyloglucan polysaccharides from tamarind seeds are proved to be good moisture absorber aerogels. Gracanac, 2015 designed a system comprising of aerogels and galactose oxidase (enzyme) and observed that the moisture absorbing capacity is 40 times their weight. Among the different methods of incorporating scavengers into package sachets, pouches or pads were found to be more effective as they do not interfere with the structure of external packaging materials

- 3. Ethylene Absorbers:** During post-harvest handling and distribution, ethylene acts as growth stimulating hormone. It accelerates ripening and senescence by increasing respiration rate of climacteric fruits. Ethylene scavengers are essential as it also degrade chlorophyll and enhances softening of fruits (Saltveit, 1999; Ozdemir & Floros, 2004).

Potassium permanganate is one of the most commonly used ethylene scavenger inside package or in packaging film. Reinforcement of  $\text{KMnO}_4$  into inert material matrix like silica gel, alumina will expand surface area available for oxidation reaction. Spricigo *et al.*, (2017) developed scavenging system with Silica gel and alumina nanoparticles impregnated with potassium permanganate that took advantage of colour change to indicate ethylene scavenge. Scully & Horsham, (2007) has reported that 3 to 6.5 L/kg is the capacity of ethylene scavenger presently available in the market.

Minerals finely dispersed in packaging material not only act as ethylene scavenger but also modify gas permeability of package material. Zeolite, active carbon when incorporated in polymer matrix altered polymer property like faster carbon dioxide diffusion and facilitate entry of oxygen more readily than through pure polyethylene (Kruijf *et al.*, 2002; Esturk *et al.*, 2014).

Titanium dioxide oxidises ethylene into water and carbon dioxide and water activated through UV light or visible light. As the metal requires activation light, the detrimental effect of light on product packaged in polymer needs to be considered. Charcoal with palladium as an ethylene absorbent was studied by Abe & Watada (1991). It is reported that the scavenger is effective as sachet than in packaging structure in preventing ethylene accumulation and reduced softening of kiwifruits and bananas. Polyethylene blended with nano-powders of Ag,  $\text{TiO}_2$  and kaolin were used to preserve fresh strawberries by Yang *et al.*, (2010). This combination reduced fruit decay (16.7%) compared to normal packaging (26.8%). Chinese jujube was packed in active packaging produce by blend of nano-Ag, nano- $\text{TiO}_2$ , and kaolin with polyethylene by Li *et al.*, (2009). They reported reduced weight loss, browning, softening during 12 d storage. Ethylene production rate was increased initially and declined later with 17.9  $\mu\text{L}/\text{kg h}$  for control (3<sup>rd</sup> day) against 9.2  $\mu\text{L}/\text{kg h}$  for nano packaging (6<sup>th</sup> day).

- 4. Carbon Dioxide Emitters:** During the year 1990 the concept of  $\text{CO}_2$  releasing device to maintain lower gas to product volume ratio was introduced. The antimicrobial effect is proportional to partial pressure of gas (Blickstad *et al.*, 1981).  $\text{CO}_2$  is highly soluble in liquids and needs to be compensated to avoid collapse of package due to depleted gas

pressure inside package. Many research scholars have quoted that ferrous carbonate is used as carbon dioxide emitter (Rooney, 1995; Sivertsvik *et al.*, 2003; Restuccia *et al.*, 2010). Combination of the active substances like sodium bicarbonate and citric acid is found to be the latest of CO<sub>2</sub> releasing system. Commercially, CO<sub>2</sub> emitters are available in the form of sachets or pads. The active ingredients present inside the package comes in contact with absorbent pads resulting in release of carbon dioxide.

- 5. Carbon Dioxide Scavengers:** Excess CO<sub>2</sub> accumulation inside the package is detrimental from product quality point of view and integrity of package. Hence, CO<sub>2</sub> scavengers are essential to remove excess carbon dioxide from the packaging material to increase the shelf life. Maintaining optimal level of CO<sub>2</sub> and O<sub>2</sub> concentration is essential to prevent unwanted physiological reaction inside package.

CO<sub>2</sub> scavenging material is enclosed inside sachet and placed in the food package. Both chemical and physical absorbers are combined to have a synergetic additive effect of CO<sub>2</sub> scavenging. Calcium hydroxide (Ca(OH)<sub>2</sub>) is considered as safe carbon dioxide scavenger due to its spontaneous action without any activation mechanism. When large volumes of fresh fruits and vegetables are transported through vehicles, calcium oxide is used as CO<sub>2</sub> scavenger. Physical adsorbers like zeolite and activated carbon are considered as good carbon dioxide scavengers. Carbon dioxide adsorption onto physical adsorbent is exothermic reaction with increased adsorption at low temperatures. Apart from porosity and surface area hydrophobicity and affinity to selective gas plays important role in mixed gas condition. Presence of moisture inside the gas mixture greatly influences the CO<sub>2</sub> adsorption.

## REFERENCES

- [1] N.A. Abd-elghany, I. Samah and M. Hassan, "Effect of polyolefin film wrapping and calcium chloride treatments on postharvest quality of wonderful pomegranate fruits," *J Horti Sci Ornam Plants*, vol. 4, pp. 07-17. 2012.
- [2] K. Abe, and A.E. Watada, "Ethylene absorbent to maintain quality of lightly processed fruits and vegetables," *J Food Sci*, vol. 5, pp. 1589-1592. 1991.
- [3] R. Ahvenainen, "New approaches in improving the shelf life of minimally processed fruit and vegetables," *Trends Food Sci. Tech*, vol. 7, pp. 179-187. 1996.
- [4] C. Altieri, M. Sinigaglia, M.R. Corbo, G.G. Buonocore, P. Falcone, M.A.D. Nobile, "Use of entrapped microorganisms as biological oxygen scavengers in food packaging applications," *Lebensm.-Wiss Tech*, vol. 37, pp. 9-15. 2004.
- [5] S. Ben-Yehoshua, "Individual seal-packaging of fruits and vegetables in plastic film - a new postharvest technique," *Hortic Sci*, vol. 20, pp. 32-37. 1985
- [6] E. Blickstad, S.O. Enfors and G. Molin, "Effect of hyperbaric carbon dioxide pressure on the microbial flora of pork stored at 4 or 14°C," *J Appl. Bacteriol*, vol. 50, pp. 493-504. 1981.
- [7] A.F.L. Camelo, "Manual for the preparation and sale of fruits and vegetables: from field to market," *Food Agric Org*, vol. 151 pp. 23-48. 2004.
- [8] R.S. Cruz, N.F.F. Soares and R.M. Geraldine, "Evaluation of the oxygen absorbed by oxygen absorbers at different temperatures and relative humidities," *Sci Agro tech*, vol. 32, pp. 1538-1548. 2008.
- [9] C.N. Cutter and S.S. Sumner, Application of edible coatings on muscle foods In: A. Gennadios (Ed.). Protein-based films and coatings, Boca Raton: CRC Press, 2002, pp. 467-484.
- [10] L. Edens, F. Farin, A.F. Ligtvoet and J.B. Van-Der-Plaat, Dry yeast immobilized in wax or paraffin for scavenging oxygen. U.S. Patent 5,106, 633. Washington, DC: U.S. Patent and Trademark Office. 1992. Pp. 21-45.

- [11] O. Esturk, Z. Ayhan and T. Gokkurt, "Production and application of active packaging film with ethylene adsorber to increase the shelf life of broccoli (*Brassica oleracea L. var. Italica*)," Packag Technol Sci, vol. 27, pp. 179–191. 2014.
- [12] J.N. Farber, L.J. Harris, M.E. Parish, L.R. Beuchat, T.V. Suslow and J.R. Gorney, "Microbiological safety of controlled and modified atmosphere packaging of fresh and fresh-cut produce," Compr Rev Food Sci Food Saf, vol. 2, pp. 142–160. 2003.
- [13] B. Gracanac, Polysaccharide-based aero gels as water absorbent and oxygen scavenger in meat packaging. PhD Diss., University of Helsinki, 2015.
- [14] E.K. Heaton, J.W. Dobson, R.P. Lane, L.R. Beuchat, "Evaluation of shrink-wrap packaging for maintaining quality of apples," J. Food Prot, vol. 53, pp. 598–599. 1990.
- [15] P.A. Idah, E.S.A. Ajisehiri and M.G. Yisa, "Fruits and vegetables handling and transportation in Nigeria," AU J Tech, vol. 10, pp. 175-183. 2007.
- [16] N.M. Julkapli and S. Bagheri, "Developments in nano-additives for paper industry," J Wood Sci, vol. 62, pp. 117–130. 2016
- [17] N.D. Kruijff, M.V. Beest, R. Rijk, T. Sipilainen-Malm, P.P. Losada and B.D. Meulenaer., Active and intelligent packaging: applications and regulatory aspects. Food Addit. Complim, 19(1):144–162. 2002.
- [18] H. Li, F. Li, L. Wang, J. Sheng, Z. Xin, L. Zhao, H. Xiao, Y. Zheng and Q. Hu., "Effect of nano-packing on preservation quality of Chinese jujube," Food Chem, vol. 114, pp. 547-552. 2009.
- [19] P.V. Mahajan, F.A. Rodrigues, A. Motel and A. Leonhard, "Development of a moisture absorbent for packaging of fresh mushrooms (*Agaricus bisporus*)," Postharvest Biol Tech, vol. 48, pp. 408–414. 2008.
- [20] G. Mauriello, E. Deluca, A. Lastoria, F. Villani and D. Ercolini, "Antimicrobial activity of a nisin-activated plastic film for food packaging," Lett Appl. Microbiol., 41(6): 464–469. 2005.
- [21] L.W. McKeen, The Effect of Long Term Thermal Exposure on Plastics and Elastomers. Waltham: Elsevier Inc. pp. 56, 2013.
- [22] W.R. Miller, L.A. Risse and R.E. McDonald, "Deterioration of individually wrapped and non-wrapped bell peppers during long term storage," Trop Sci. vol. 26, pp.1–8, 1986.
- [23] MOFPI. Annual Report 2019-20. [https://mofpi.nic.in/sites/default/files/english\\_2019-20\\_1.pdf](https://mofpi.nic.in/sites/default/files/english_2019-20_1.pdf). Accessed on 14 June 2020.
- [24] B. Muroyiwa, L. Shokopa, P. Likoetla and M. Rantlo, "Integration of post-harvest management in agricultural policy and strategies to minimize post-harvest losses in Lesotho," J Dev Agric Econ. Vol. 12, pp. 84-94. 2020.
- [25] NHB. Horticultural Statistics at Glance. Ministry of health and Family Welfare. <http://nhb.gov.in/statistics/Publication/Horticulture%20Statistics%20at%20a%20Glance-2018.pdf>. Accessed on 25 July 2019.
- [26] M. Ozdemir and J.D. Floros, "Active food packaging technologies," Crit Rev Food Sci Nutr., vol. 44, pp. 185–193. 2004.
- [27] P.K. Pal, M.S. Ahmad, S.K. Roy and M. Singh, "Influence of storage environment, surface coating, and individual shrink wrapping on quality assurance of guava (*Psidiumguajava*) fruits," Plant Foods Hum Nutr., vol. 59, pp. 67–72. 2004.
- [28] D.V.S. Rao, K.P.G. Rao and S. Krishnamurthy, "Extension of shelf life of cucumber by modified atmosphere packaging (MAP) and shrink wrapping," Indian Food Pack., vol. 54, pp. 65–71, 2000.
- [29] D. Restuccia, U.G. Spizzirri, O.I. Parisi, G. Cirillo, M. Curcio, F. Iemma, F. Puoci, G. Vinci and N. Picci, "New EU regulation aspects and global market of active and intelligent packaging for food industry applications," Food Control, vol. 21, pp. 1425–1435. 2010.
- [30] L.A. Risse, W.R. Miller, S. Ben-Yehoshua, "Weight loss, firmness, color and decay development of individual film wrapped tomatoes," Trop Sci, vol. 25, pp. 117-121, 1985.
- [31] M.L. Rooney, "Overview of active food packaging," In: M. L. Rooney (Ed.), Active food packaging. Glasgow, Ireland: Blackie Academic and Professional, 1995, pp. 1–37.
- [32] M.E. Saltveit, "Effect of ethylene on quality of fresh fruits and vegetables," Postharvest Biol Tech, vol. 15, pp. 279–292, 1999.
- [33] Schirp, M. Mannheim and B. Plinke, "Influence of refiner fibre quality and fibre modification treatments on properties of injection-moulded beech wood–plastic composites," Appl. Sci. Manuf, vol. 61, pp. 245-257, 2014.
- [34] A.D. Scully and M.A. Horsham, "Active packaging for fruits and vegetables," Boca Raton Florida: Taylor & Francis. 2007. pp. 36.
- [35] R.R. Sharma, R.K. Pal and V. Rana, "Effect of heat shrinkable films on storability of kiwi fruits under ambient conditions," Indian J Hortic., vol. 66, pp. 404–408. 2012.

- [36] S.P. Singh and D.V.S. Rao, "Effect of modified atmosphere packaging (MAP) on the alleviation of chilling injury and dietary antioxidants levels in 'Solo' papaya during low temperature storage," *Eur J Horti Sci.*, vol. 70, pp. 246–252. 2005.
- [37] M. Sivertsvik, J.T. Rosnes and G.H. Kleiberg, "Effect of modified atmosphere packaging and super chilled storage on the microbial and sensory quality of atlantic salmon (*salmo salar*) fillets," *J Food Sci*, vol. 68, pp.1467–1472. 2003.
- [38] P. Spricigo, M. Foschini, C. Ribeiro, D. Correa and M. Ferreira, "Nano scaled platforms based on SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> impregnated with potassium permanganate use color changes to indicate ethylene removal," *Food Bioprocess Tech*, vol. 10, pp. 1622–1630. 2017.
- [39] F. Yang, H. Li, F. Li, Z. Xin, L. Zhao, Y. Zheng and Q. Hu, Effect of nano-packing on preservation quality of fresh strawberry during storage at 4°C. *J Food Sci*, vol. 75, pp. 236–240, 2010.
- [40] R. S. Cruz, N. F. F. Soares, N. J. Andrade, "Efficiency of oxygen absorbing sachets in different relative humidities and temperatures," *Ciência e Agrotecnologia* vol. 31, pp. 1800–1804. 2007.