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Influence of packaging material and storage temperature on the shelf life and quality of broccoli: A review

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Abstract
Broccoli (*Brassica oleracea* L. var. italica) is a member to 'cole crop group' closely related to cabbage, cauliflower, kale and mustard. The word broccoli comes from Italian word broccolo, which means 'flowering crest of a cabbage". High intake of broccoli reduces the risk of cancer and prevents heart disease (Allen and Allen, 2007). Broccoli is a highly parishable crop, for which it is recommended to be precooled as soon as possible after its harvesting. Temperature plays a very important role in extending the shelf life and indirectly delays the losses of quality parameters during postharvest storage. Most of the quality losses occurs due to improper packaging material. Packaging prevents the produce from drying and preserves nutritive values, texture, flavor, color. Packaging delays color changes and prolongs storage life as it reduces the respiration and ethylene production.

Keywords: Packaging, broccoli, shelf life, precooling, ethylene, edible coating

Introduction
Broccoli (*Brassica oleracea* L. var. italica) having chromosome no. 2n=18 belonging to family Brassicaceae (Cruciferae). India is the 2nd largest producer of broccoli after China. Broccoli is native to Mediteranean region. Broccoli is a cultivar to wild cabbage. Wild cabbage originated along the northern and western coasts of the Mediteranean (Schery, 1972; Heywood, 1978). It is a highly nutritious crop containing high amount of vitamins (A&C) and minerals (K, P, Ca and Fe). Broccoli has large flower heads usually dark green in color, arranged in a tree-like structure branching out from a thick stalk which is usually light green. The mass of flower heads is surrounded by leaves. India and China combiningly produced 73% (26.0 million tonnes) of world's broccoli and cauliflower crops (2017). The majority of broccoli cultivars are cool-weather crops that do poorly in hot summers. Broccoli grows best when exposed to an average daily temperature between 18-23 ^{0}C (64 and 73 ^{0}F). Broccoli is one of the most prominent vegetables grown all over the world.
Fruit quality is the key concern for the consumers. It is highly nutritious crop but due to its perishable nature it can deteriorate very fast at inappropriate temperature. So temperature plays the major role in post harvest storage and handeling of broccoli. Products undergo various biological changes even after its harvesting. The loss of green color of broccoli is an important quality feature for the consumers. The loss of green color in broccoli florets occurs due to breakdown. Packaging is one of the viable options to extend shelf-life of the produce and to slow down the respiration rate and ethylene production. A proper packaging and its gas exchange can be helpful in extending shelf life to a considerable amount of time.

Packaging practices
Packaging is good for food preservation. It protects the food from environmental factors, dust, microbes, and other infections. It helps to keep broccoli from drying out and preserves its nutritive value, flavor, color, texture. Different kinds of packaging material used by different researchers to enhance the shelf life of broccoli.
Besides providing a uniform-size package to protect the produce, there are other requirements for a container:

- It must provide proper ventilation for commodities during transport and storage
- It must be cost-effective in relation to the market value of the commodity for which used
- It must be readily available, from more than one supplier
- Thickness of polythene varies with the purpose of plastic and type of vegetable (25-30 microns for LDPE).

Advantages of using plastic packaging bags for food packaging

With the growing population and the rising demand for consumer goods, food and beverage manufacturers are constantly looking for ways to enhance their practices and create additional value. They are also required to ensure that the food product is well-preserved using appropriate packaging till the point of sale.

1. It is a very flexible and adaptable form of packaging, which allows manufacturers to customize its shape, size and style as per their customers' requirements.
2. It is an extremely light-weight storage option that doesn't require a lot of storage space either. Since they don't take up much storage space, they are also extremely easy to transport, thus reducing the carbon footprint during transportation.
3. Plastic packaging can survive extreme environments and don't easily degrade in hot and cold temperatures, thus preserving the integrity of the food or beverage inside it. It also protects your products from moisture, oxygen, dust, light and odours.
4. Since plastic is extremely durable and resistant to external influences, you can ensure your product is well-preserved at all times. This in turn, helps you avoid losses due to wastage of inventory and also helps you bring about consistency in product delivery, thus increasing brand value.
5. The high versatility of plastic allows for ease of reuse and recycling. In fact, these days' companies are creating specialized plastic bag making machines that help you optimize on the recyclability of plastic.
6. The durability offered by plastic packaging also allows manufacturers to print eye-catching, high-quality custom designs, and thereby increase product visibility in a retail setting.
7. Plastic packaging is highly economical and can be used by all industries irrespective of their scale of operations. The cost-effectiveness of plastic food packaging is especially beneficial to small-scale product manufacturers as it allows access to standardised packaging options in spite of lower budgets.
8. As mentioned above, plastic bags are easily recyclable and require lesser energy to produce in comparison to the other packaging alternatives available. According to a study conducted by United States EPA, plastic bags use 40% less energy to produce and generate 80% less solid waste than paper. The study also revealed a pound of plastic takes 91% less energy to recycle as compared to a pound of paper.
9. Polythene is widely used as a single bag to protect almost any food from dust or dirt over a short period. It is also widely used in combination with other flexible packaging such as paper or cellulose to make these materials heat sealable.
10. Thicker films are stronger and have better barrier properties to moisture and air, but thicker films are also less transparent and less flexible.

Types of packaging material used for broccoli packaging majorly

1. Oriented polypropylene (OPP)
2. PVC-Polyvinyl chloride
3. LDPE-Low-density polyethylenes

1. Oriented polypropylene (OPP): Flexible packaging plastic known as OPP and BOPP (Biaxially Oriented Polypropylene) is a very shiny plastic, often perfectly clear or brightly coloured, and not stretchy at all. It is commonly used for packaging and presentation e.g. the outer packaging on cigarette boxes, greetings cards, pasta bags, confectionery and pastries.

It has the following qualities

1. Low cost
2. Good clarity
3. Good machinability
4. High gloss
5. High speed
6. Ease of printing

Polypropylene can be white or pearlised to give an enhanced depth of colour when printed, whilst the low temperature seal film is ideal for faster machine running speeds. National Flexible has the UK's largest slitting facility dedicated to slitting and perforating of polypropylene.

OPP is a very common single-use plastic found all over the world, and among the least recycled.

2. Polyvinyl chloride (PVC): forms of card and paper. Some of the key reasons for its success compared to traditional materials are highlighted below:

1. PVC is lightweight compared with glass, with the added benefit of reduced transport emissions.
2. It is shatter resistant which was seen as an immense benefit as it would reduce the number of accidents in the home and outside.
3. PVC has excellent organoleptic properties which means that it imparts no taint or taste to foodstuffs.
4. PVC has excellent barrier properties for the preservation of food.
5. Innovative designs and product shapes can be achieved and all with excellent clarity and transparency.

There are various options for PVC packaging at end-of-life. Like any other thermoplastic, PVC can be mechanically recycled and recycling programmes have been established throughout Europe for both bottles and trays. Other options are possible.

In summary, PVC packaging plays an important role in the protection of a variety of foodstuffs, from specialised tamper-proof packaging to commodity food display trays. Ceasing the use of PVC in packaging would reduce the freedom of choice to the consumer with no added benefit to the environment.

3. Low-density polyethylene (LDPE): resins are used to produce a range of general-purpose and high-performance applications, which include blown and cast film, extrusion and coating, and rotational and injection molding.

LDPE is transparent and glossy. Its barrier properties to moisture and air are relatively poor and the film has little strength to resist puncturing, although it does not tear easily. Because like other films, it does not protect foods against mechanical damage, these packages require outer cartons or boxes for transport and distribution.

Jacobsson, A., Nielsen, T. & Sjöholm, l. in their article, said that broccoli stored in LDPE results in longer storage or provide longest shelf-life and broccoli stored in PVC deteriorated faster than packaged in other materials. The

influence of packaging material was greater at the higher temperature.

Other techniques used to enhance shelf-life\\ of broccoli- Role of temp

MAP: Modified atmospheric packaging is a technique used by the different scientists for prolonging the shelf-life of broccoli and other vegetables and fruits. MAP can be defined as an alteration in the composition of gases inside the product and in the environment around the fresh produce (Thompson 2003) [37]. Composition of gases changes inside the pakage by the exchange of gases process i.e respiration of fruits, O_2 level is decreases while CO_2 level decreases. Broccoli stored in MAP reduces weight loss and respiration rate, maintains ascorbic acid, total antioxidant activity, glucosinolate contents and visual quality and thus increases the shelf-life in a controlled ambient storage (Nath *et al.* 2011, Serrano *et al.* 2006, Jia *et al.* 2009) [23, 36, 14].

1-MCP-1-methylcyclopropane: is a synthetic plant growth regulator used to maintain the quality and to prolong the strorage shelf-life of produce. It can delay TSS, sofetening, color, and aroma development (Ratanachinachorn *et al.*, 2007; Manning *et al.*, 2011). It is commercially used to slow down the ripening. Some Scientists used it to enhance the shelf-life of freshly harvested broccoli. Different chemicals were used to prevent yellowing of broccoli (Wang 1977, Aharoni *et al.* 1985) [40]. Recently it has been used widely by the scientists to maintain postharvest quality of the produce. It is an ethylene action inhibitor that binds to the ethylene receptors and thereby delays ripening of products and extending storage life (Blankenship and Dole 2003). Its treatment inhibited the increase of respiration ratio and ethylene production (Ku and Wills 1999, Fan and Mattheis 2000) [17], delayed yellowing and extended storage life of broccoli (Forney *et al.* 2003, Yuan *et al.* 2010) [7]. Research workers in their research used alone 1-MCP or using 1-MCP and MAP combiningly for better results. They both significantly helps in reducing weight loss, TSS, ascorbic acid maintainance, retains green color and prevents breakdown of chlorophyll.

Ecofrost (A cold room): Temperature plays an important role in maintaining the quality of fresh cut produce and increases its shelf-life by reducing weight loss, chlorophyll loss, TSS, ascorbic acid. The broccoli florets should be compact and firmly closed, and dark green in color during harvesting. At high temperature florets results in off flavour and at temperature below -1º C could result in chilling injury. Experiments done by the researchers using a cold room for storing the broccoli harvest. They kept the produce at 4^0C with best ventilation used. Samples were kept in shrink wrap, cling wrap and vaccum packed. Very low rate of loss of weight occurred in vaccum packed florets compared to shrink wrap, cing wrap. Vaccum pack in combination with low temperature significantly helpful in maintaining quality of broccoli heads. Storage at low temperatures reduces metabolism, and delay senescence during storage.

Shrink wrap: Is an emerging technique for post-harvest handling of vegetable. It is also useful in transport also. It prevents the produce from getting bruises, abrasion and damage by pathogens and other insects and makes the produce more attractive. The technology delays physiological deterioration and prevents condensation of droplets within the packaging itself. Shrink wrap provides optimum gas and humidity to maintain the quality of produce and prevents postharvest losses of broccoli. Broccoli stored in shrink wrap loses roughly 3.7% of its original weight.

The best packaging method for vegetables is with a heat-shrinking film, that is a protective film that shrinks when it is heated by the packaging machine. In this way the film adheres effectively to the product to be packed. The most immediate benefits are lower costs than other types of packaging and reduced consumption. But do not underestimate the aesthetic reasons, which are particularly important in direct sales of fruit and vegetables to the consumer.

Plastic bag: It is good for packing broccoli as it can maintain good moisture content in broccoli. And it also protect the food from external environment during transport. It helps in keeping the food contamination free as more number or laborers or workers are involved from field to consumer.

The ultimate goal of packaging practices or post-harvest tachnologies is to protect the produce from harsh external environment, microbes, pathogens and increase their shelf-life. There are many other techniques used by the scientists, like heat treatments, edible coatings, irradiation.

Heat treatments: in past few years instead of chemicals people preferring heat treatments more. But due to its higher cost usage is less. The surface is washed thoroughly to remove spores resting on the surface of the commodity. When hot water is applied to the surface there is a considerable reduction in microorganism such as bacteria fungi. Different types of are used like hot water dip, saturated water vapour heat, hot dry air and hot water rinse with brushing. Heat treatment have shown great impact on delayed ripening as on high temperature enzymes gets deactivated. Control insect attack and fungal activity. It also prevent postharvest disorders in chilling injury in those commodities which cannot withstand the low temperature too long. Time of heat may vary depending upon the commodities demand. Heat treatments have been used to preserve the color of asparagus and to prevent the development of off flavors, to prevent development of overripe flavors in melons and also to preserve the color of broccoli, celery, asparagus, kiwi and green beans.

Edible coatings: It constitute a viable means of incorporating food additives and other substances in order to enhance product color, flavor, and texture, and to control microbial growth. They are lipid-based substances and protein films. When applied as complete food coating or can be disposed as a continuous layer between food components on commodities act as a barrier to moisture, oxygen and solute movement for the food. It minimizes the moisture loss during storage. It also acts as gas barrier and slows down the rerspiration, senescence, enzymatic oxidation. These coating helps retain color and texture. It also makes fruits and vegetables look attractive. However thick layer of it can also restricts the exchange of respiratory gases.

Type of edible coating

Edible coating materials are generally made up of polysaccharides, proteins and lipids. The edible coatings are mainly divided into three classes; these are following-

Hydrocolloids: e.g., polysaccharides, proteins and alginate.

Lipids: e.g., fatty acids, acryl glycerides and waxes.

Composites: e.g., protein/protein, polysaccharides/protein, lipid/polysaccharides.

Gums- Most of these are polysaccharides and consists of sugar. These are used for coating of fruits and vegetables as its texture capability is good.

Three types of gums are there-
1. Exudate gums
2. Extractive gums
3. Microbial fermentation gums

Herbal edible coatings is a new technique evolving in the food industry. Herbs such as such as Aloe vera gel, Neem, Lemon grass, Rosemary, Tulsi and Turmeric are commonly being used. They have antimicrobial properties and also consists of essential oil, vitamins, antioxidants. Ginger essential oil, clove bud oil, turmeric neem extract, mint oil, other essential oil and extracts are also used as they are beneficial for health.

Irradiation: In Food irradiation produce is exposed to speed particles or rays for improving the shelf life. It also acts as a resting period for many fruits and vegetables. Cucumbers, grapes, tomatoes are not suitable for irradiation as they are very sensitive to radiation. Most of the studies revealed that irradiation reduces the firmness of fresh fruits. The maximum doses which can be applied on fruits and vegetables range between 1 and 2 kGy.

Types of irradiation

Radiations like Gamma rays (with Co-60 or Cesium-137 radioisotope), electron beams (high energy of up to 10 MeV), or X-rays (high energy of up to 5 MeV) are being used for food preservation.

Conclusion

Since broccoli is a highly perishable crop and unable to store for more than 3-4 days at normal temperature. In different ways we can enhance the shelf life of broccoli. When it is stored under ambient temperature it shows gradual weight loss then packed ones and refrigerated. Weight loss is closely related to storage conditions and packaging materials. florets stored under packaged material in low temperature have more stability and greater storage life. Different type of practices can be performed to enhance the shelf life like shrink wrapping, heat treatments, MAP, irradiation, edible coatings, ecofrost. Each of them have own potential to protect the food. Researchers also produce new edible coating which are herbal and safe for the health and extends shelf life of vegetables and fruits.

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