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Pre-harvest fruit bagging for quality improvement in fruit crops: A review

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Abstract
Fruits play a major role in the daily diet of the human and are major sources of various vitamins and minerals as well as they provide a very good income to the farmers. Several environmental factors have a significant role during fruit growth and their development. Many pre-harvest biotic (diseases, pests, birds) and abiotic (include genetic, environmental and cultural) stresses influence the postharvest quality of the fruits and lead to susceptibility of fruits to diseases and various physiological disorders like cracking and sunburn. To combat these problems, fruit bagging is an effective technique, which improves both physical and chemical quality of the fruits and minimizes the effect of agrochemical residues on the fruit surface. It provides physical protection to the fruits and modifies the micro-environment inside the bag in favour of the fruit development. It minimizes the incidences of many diseases, insect-pests, physical damage, sunburn and cracking of the fruits. Due to its several advantageous effects, it is being used commercially in several fruits such as mango, banana, guava, grape, apple, litchi etc. in many parts of the world.

Keywords: Fruit bagging, advantages, quality attributes and physiological disorders

Introduction
Various methods have recently been employed to improve fruits to avoid losses from various biotic and abiotic factors around the world. It is becoming increasingly important to develop techniques for improving fruit production, appearance, quality and reducing diseases and pests with lesser chemical application due to increased awareness towards safe/ least pesticide load on the produce to confirm the safety of employees, consumer health, and environmental protection (Sharma *et al*. 2009) [66]. Fan and Mattheis, (1998) [24] reported that pre-harvest fruit bagging has become an effective method to combat biotic and abiotic stresses. In this technique, individual fruit or fruit bunches or fruit berries are bagged on the tree for a specific period. This technique offers help in improving the physical appearance as well as the chemical quality of fruits by decreasing the external damaging factors like fruit cracking, sunburn and russeting. Therefore, bagging has been used extensively in many fruit crops to enhance the appearance of fruits (skin colour) and to minimize the insect-pest infestation, occurrence of diseases, mechanical damages, agrochemical residues on fruit surface/ in fruits, bird damage and other many physiological disorders (Amarante *et al*. 2002a, Xu *et al*. 2010, Joshi *et al*. 2016a and Joshi *et al*. 2016b) [4, 42, 43, 115]. Earlier the bags were used for export markets and processing units to improve fruit quality but nowadays it is being used extensively on fruits for domestic consumption also. Bagging technique is commercially used in various fruits *viz*. mango, guava, banana, litchi, grapes, pomegranate, citrus, apple, peach etc.

Bagging
Bagging refers to the covering of fruits with bags to protect them from various biotic and abiotic factors. It is a technique, which provides physical protection to the fruits, which helps in improving their physical and internal quality as well as changes the microclimate inside the bag for proper growth and development (Fan and Mattheis, 1998) [24].

Effect of fruit bagging
For proper growth and development, fruit requires very specific type of climate. Several environmental factors and other biotic factors affect the growth and developmental process of the fruit. Such as, fluctuation in temperature or long dry spell leads to cracking of fruit and reduces its appearance and marketability.

High humidity and low temperature favour the development of various fungal diseases. By the bagging of fruits or berries, it modifies the micro-environment inside the bagged fruit and gives suitable climate to the fruits for their growth and development and minimizes the incidence of various pathogens and physiological disorders with enhancing the postharvest quality of the fruits. Bagging provides protection to the fruit from frost damages by maintaining a relatively good temperature inside the bagged fruit (Santosh *et al*. 2017) [74]. During winter months, it increases the temperature inside the bag by 1-2 °C and in summer or hotter months 3-6 °C (Omar *et al*. 2014 and Santosh *et al*. 2017) [67, 74].

Advantages of fruit bagging

- Reduces the residues of pesticides, improves eating quality of fruit.
- It significantly improves the appearance of the fruit, which facilitates in obtaining a good market price.
- It eliminates fruit fly infestations, restricts bird damages and reduces infectious diseases.
- The paper bags are recyclable and biodegradable.
- It is an integral part of organic fruit production.
- It protects the fruit from cracking and sunburn.
- It is an environment-friendly technology.
- How to bag a fruit?
- Select the fruit plants for bagging.
- Perform the fruit thinning process before bagging as per the fruit species and requirement.
- Cover one fruit or one cluster of berries in each bag, and then close it with a twine or coconut midrib.
- To keep fruit from touching the bag, push the bottom of the bag upward.
- Make 2-3 holes on the bottom to permit water drainage more easily.
- Use a ladder to reach up to the maximum fruits. Fix or tie the ladder securely on large branches if you are working with large and tall fruit trees.

Factors affecting quality of fruits

There are numerous pre and post-harvest factors, which affect the quality of fruits. Quality means “degree of excellence or superiority”. It includes appearance of fruits, fruit shape and texture, fruit colour and chemical quality attributes.

Pre-harvest factors

Several pre-harvest biotic and abiotic factors such as genetics, cultural practices and environmental factors influence fruit growth, development, maturation as well as have physical effect on fruit quality. Latent diseases, pathological and physiological conditions and insect damage result from poor orchard management and field sanitation. The quality of fresh fruits develops during their growing period and after harvest, there is no possibility for further improvement in their quality. This is because of the fact that the fruits have been detached from its source of water, carbohydrates and nutrients supply. Therefore, it is essential to consider the pre-harvest factors that affect the harvested produce, quality and shelf life, as well as the consumers' decision to buy it. The different pre-harvest factors affecting postharvest qualities and shelf life are as follows:

1. Biotic factors

Many biotic factors are involved in affecting of fruit quality such as insect-pests, diseases and other microorganisms. These insect-pests and diseases deteriorate the fruit quality and reduce marketability of fruits thereby resulting in losses to the producer. By bagging of individual fruit or berries, the damages caused by various insect-pests and diseases can effectively be controlled. The major ones are listed below:

- Insect-pests - Apple codling moth, lemon butterfly, pomegranate butterfly, mango fruit borer, fruit fly, aphid, litchi nut borer etc.
- Diseases - Anthracnose, fruit rot, brown spot of apple, stem-end rot of mango etc.

2. Abiotic factors

Abiotic factors include genetic factors, environmental factors and cultural practices.

A. Genetic factors

Cultivars

The first factor which determines the various quality parameters of fruit such as colour, shape, size and weight with biochemical composition is the cultivar and species. Several quality parameters are genetically determined. The quality attributes of different fruit cultivars varied, which is thought to be due to the genetic composition of the species as well as differences in total fruit development and ripening time. The level and chemical composition of bioactive compounds differ according to cultivar, so quality factors said to be more or less genetically regulated (Scalzo and Mezzetti, 2010) [78] but can be improved by adopting recommended pre-harvest management practices.

Rootstocks

Generally, fruit trees are grafted on different rootstocks, which also have significant influence on quality attributes. Higher acid content was observed when ‘Allen Eureka’ lemon was grafted on Cleoptera mandarin, however, when it was grafted on sour orange (*C. aurantifolia*) rootstock, its TSS content was found increased. The fruits produced from ‘Jonagold’ apple grafted on M-26 rootstocks had lower ethylene production which delayed ripening and enhanced shelf life of fruits (Asrey and Barman, 2020) [6]. The composition of bioactive compounds and antioxidant activity is also influenced by rootstock. Besides this, post-harvest flavour and susceptibility to diseases are also influenced by rootstock (Asrey and Barman, 2020) [6]. Rootstock affects the accumulation of sugar content, acidity, anthocyanin, polyphenol, minerals and vitamins in cherry plants (Spinardi *et al*. 2005) [98].

B. Environmental factors

Temperature and light

Temperature plays a vital role in deciding growth, development, maturity and also post-harvest quality attributes of fresh fruits (Asrey and Barman, 2020) [6]. Fruit crops are relatively sensitive to higher temperature, and many crops having unique temperature requirements for optimum yield and quality. The absorption and metabolism of minerals and nutrients by plants influenced by temperature (Tyagi *et al*. 2017) [107]. The rate of transpiration increases as the temperature rises, while the flower sex and fruit set affected by the lower temperature. Variations in temperature and climate can affect the processes of photosynthesis, respiration, aqueous connections and membrane stability as well as plant hormone levels during the developmental stage of fruit (Tyagi *et al*. 2017) [107]. Higher temperatures can accelerate

biochemical reactions catalysed by a variety of enzymes, as well as affect mineral deposition. In case of apple, when fruits exposed to direct sunlight developed dark red colour than those fruits which did not receive sunlight (Saure, 1990) [77]. On other hand, exposure of produce to excessively high temperature or high intensity of sunlight cause a number of post-harvest physiological disorders like sunburn or sunscald. If the period of exposure of fruit to high temperature or intensity of sunlight is very high, it causes collapse or death of cells and degradation of pigments. Higher temperatures cause sunburn and cracking in many fruits crop *viz*. cherry, citrus, grapes, apple, pomegranate, bael, litchi etc. (Kumar and Kumar, 2007) [50].

Wind

High wind velocity during growth may cause damage to the fruits. It causes damage due to rubbing of fruits against twigs, which causes development of tan to silver colour that increases in size with advancement of maturity (Asrey and Barman, 2020) [6].

Rainfall

Rainfall has a direct impact on fruit development and harvesting time. Fruit splitting/cracking disorders as seen in many of the fruit crops such as cherry, apple, litchi, citrus and grapes are more prevalent when there is a heavy rain after drought period (Opara *et al*. 1997) [68].

C. Cultural factors

Mineral nutrition

Nutrients play a crucial role in commercial fruit production. They have a direct effect on the quality of the fruits. Effects on fruit colour, texture, disease resistance, juice composition, and the emergence of physiological disorders closely related to nutrients concentration in plants (Singh *et al*. 2013) [96].

Nitrogen

Higher nitrogen level in fruits increases the respiration rate and ethylene evolution rate (e.g. mango, apple etc.), decreases the firmness and vitamin C content (mandarin orange and grapefruit), delays maturity, increases susceptibility to physiological disorders and generally reduces the post-harvest life (Asrey and Barman, 2020) [6].

Phosphorus

High phosphorus content in fruit increases firmness, soluble solid contents and decreases fruit size, dry matter content and incidence of diseases and pests. However, low temperature breakdown and senescence breakdown might be there due to low phosphorus content in fruits (Asrey and Barman, 2020) [6].

Potassium

High potassium fertilization increases vitamin C content and decreases development of physiological disorders (Cruz *et al*. 2017) [19]. The deficiency of potassium resulted in smaller fruit size, poor fruit colouration, abnormal ripening and reduced phenolic content. Embleton and Jones (1968) [23] reported that application of potassium influenced the quality of lemon fruits and rind thickness, juice, acidity and vitamin C content were related to leaf potassium content.

Calcium

Low-calcium fruits are prone to several of physical, physiological and pathological problems as well as having a limited postharvest storage life. Calcium is essential for the fruits to retain their textural consistency (Asrey and Barman, 2020) [6]. Bitter pit in apples, cork spot in pear and blossom end rot in grapes were caused by Calcium deficiency (Freitas *et al*. 2010) [26]. Pre-harvest spray of calcium chloride and boric acid as well as fully packed poly bags helped to extend the shelf life of ber fruits (Singh *et al*. 2013) [96].

Other nutrients

Pre-harvest deficiency of boron reduced fruit size and lead to development of physiological disorders as lumpiness in papaya, fruit cracking in litchi (Wang and Ko, 1975 and Sanyal *et al*. 1990) [75, 108]. The deficiencies of iron and zinc have been found to reduce fruit size (citrus and peach) and colour development (peach). Similarly copper and molybdenum deficiencies have been noticed to cause development of misshapen fruits (citrus and strawberry) and affected kernel filling in walnut (Asrey and Barman, 2020) [6].

Irrigation

Appropriate water management strategy is very important for optimum yield and quality of produce. The quantity and time of its application is also important for getting optimal quality produce. Both excessive and deficit irrigation affect the harvested produce quality (Henson, 2008) [32]. Too much irrigation leads to brittleness and caused easy damage to the fruits and increased the tendency of postharvest decay incidence. On the other hand, lack of irrigation during development stage reduced fruit size, juice content and development of thick skin in citrus (Asrey and Barman, 2020) [6]. Extreme moisture stress reduced yield and quality. A long dry spell followed by heavy irrigation leads to cracking of fruits (litchi, pomegranate, apple and cherry) as suggested by Kumar and Kumar, (2007) [50]. Moisture stress at the end of the growing season has been found to increase fruit colour, total soluble solids, firmness, dietary fibre, protein, vitamin C and mineral nutrients like calcium, magnesium, manganese but decreased fruit size.

Pruning and thinning

Pruning improves penetration of sunlight inside the canopy thereby improves postharvest quality of fruits (e.g. apple, peach, plum and grape). Judicious pruning increases fruit size, soluble solid content, anthocyanin accumulation, phenolic content, flavour and reduces titratable acidity in fruits. At initial stage of fruit growth, fruitlet-thinning leads to increase in fruit size but it reduces yield. Therefore, it is recommended to maintain a balance between fruit size and yield. Asrey *et al*. (2013) [8] suggested that, in ripe mango fruits, the percentage of anthracnose and stem-end rot diseases decreased by pruning. Shoot pruning also provided dwarfness to the plants and advanced the quality of guava fruit (Lal *et al*. 2000) [51].

Plant bio-regulators

When plant bio-regulators (PBRs) used in the right concentration, may provide a major economic benefit to farmers, as they have been shown to stimulate yield and quality parameters. Pre-harvest spray of NAA improves fruit quality of guava by increasing pulp: seed ratio, TSS, total sugars and vitamin C content. Likewise, application of GA3 @ 40-60 ppm increases fruit size in grapes (Sembok *et al*. 2016) [80]. In citrus, GA3 application increases firmness, juice content and delay colour development and senescence of peel.

Gill *et al*. (2012) [27] stated that spray of GA3 advances the fruit set in apple and pear and also observed, spray of GA3 @ 20 ppm minimize the number of seed in pear. Application of gibberellins helps in improving the fruit size and its firmness in peach and cherries Lurie, (2010) [56].

Pollination

The term pollinizer refers to the source plant for compatible pollen that normally blooms at the same time, provides plentiful compatible pollen for pollination, and increases fruit set in the orchards. In horticultural crops, selection of suitable pollinizer is of utmost importance. Such as in case of apple, 33 per cent pollinizer varieties should be present in the orchard for optimum fruit set.

Bagging materials

- Paper bags (Black and Brown)
- White-coated bags
- Net bags
- Plastic Bags
- Leaves (e.g. Banana)
- Cellophane or fabric bags
- Black or blue polyethylene bags
- Transparent polypropylene micro-perforated bags

Effect of bagging on fruits

1. Effect of bagging on physiological factors

a. Fruit size and weight

After the fruit has set, it grows slowly and gradually in size until it reaches maturity. Bagging of fruits at developmental stage can have an impact on their size and growth. The effect of fruit bagging on fruit size and weight has been found to be inconsistent in many studies. This may be due to differences in bag type, bagging time, fruit and cultivar responses and environmental and storage conditions of fruit after harvesting (Zhen *et al*. 2000, Wang *et al*. 2002, Huang *et al*. 2007 and Chen *et al*. 2012) [16, 36, 109, 118]. Thus, fruit bagging might improve, reduce or have no effect on fruit size and its weight.

Table 1: Effect of bagging on increasing in fruit size and weight

Fruits/cultivar	Bagging date/time	Bagging material	Effect	Reference
Carambola	10 DAFB*	Plastic bags	Increased fruit weight	Xu *et al*. (2008) [114]
Mango (Nam Dok Mai)	For 52 days	2 layer paper bags (black & brown)	Increased fruit weight	Watanawan *et al*. (2008) [111]
Longan	-	Paper bags	Larger-sized fruit	Yang *et al*. (2009) [116]
Date palm (Khalas & Sukari)	-	Blue bag	Increase fruit size and bunch weight	Harhash *et al*. (2010) [31]
Litchi	Two months prior to harvest	Brown and butter paper bags	Increase in fruit size and weight	Joshi *et al*. (2016a) [42]
Mango (Langra and Pant Sinduri)	40 days after fruit set	Brown paper bag	Increase in fruit weight and volume	Joshi *et al*. (2016b) [43]
Guava	20 DAFB	White polyethylene	Increases the fruit weight and size	Meena *et al*. (2016) [59]
Guava (Bari Peyara-2)	-	White polyethylene	Increases fruit weight and size	Rahman *et al*. (2017) [70]
Guava (Swarupkathi)	-	White polyethylene	Increases fruit weight and diameter	Rahman *et al*. (2018) [71]
Papaya	-	Polythene bags	Minimum loss in weight of fruit	Mia (2003) [60]

*DAFB- Days after full bloom

Table 2: Reduction in fruit size & weight

Fruits/cultivar	Bagging material	Effect	Reference
Pear (Conference)	Paper bags	Reduced fruit weight	Hudima and Stamper (2011) [38]
Loquat (Baiyu)	-	Reduced fruit weight	Xu *et al*. (2010) [115]

b. Fruit maturity

Although bagging has been shown to affect fruit maturity, opposite results have also been recorded.

Table 3: Effect of bagging on fruit maturity

Fruit/cultivar	Bagging date or time	Bagging materials	Effects	References
Banana	-	Polyethylene bags	Enhance fruit maturity	Johns & Scott (1989) [41]
Litchi	-	Cellophane paper (CP) bags	Delayed maturity	Debnath and Mitra (2008) [20]
Apple (Delicious)	-	White paper Bag	No effect on fruit maturity	Ju (1998) [44]
Guava	1 month before harvest	Simple news paper	Enhance fruit maturity	Singh *et al*. (2007) [92]

c. Fruit ripening

- Fruit ripening can be improved through bagging of "Helali" cv. of datepalm (Awad. 2007) [9].
- Harhash and Al-Obeed (2010) [31] reported that blue colour bags were found superior for promoting fruit ripening in date palm cv. "Succary" and "Khalas", however, yellow and white polythene bags were also found effective.
- Signes *et al*. (2007) [91] reported that the ripening in 'Perla' (black cultivar of grape) can be delayed by bagging.
- Fruit bagging of guava with white polybag or newspaper enhances the early ripening (Singh *et al*. 2007) [92].

d. Fruit appearance

Fruit is prone to several physical defects and damages during harvesting, processing, packaging and transportation. As a result, people found it less appealing. Consumers prefer fruit that is free from blemishes, abrasions, and wounds. Pre-harvest fruit bagging reduces/prevents the mentioned mechanical damages along with enhanced colouration and thus augments its market value (Han *et al*. 1999) [30].

Table 4: Effect of bagging on fruit appearance

Fruit/cultivar	Bagging material	Effect	Reference
Mango	Paper bag	Reduce incidence of black spots, improve physical quality, light-green skin colour	Sarker *et al*. (2009) [76]
Litchi	-	Minimum incidence of cracking and sunburn and fruits free from blemishes, superior appearance	Debnath and Mitra, (2008) [20]
Banana	-	More attractive fruits, free from skin blemish	Muchui *et al*. (2010) [64]
Persimmon (Fuyu)	-	Reduces fruit blemishing	Katagiri *et al*. (2003) [46]
Pear (Doyenne du Comice)	-	Reduces bird damage and skin blemishes, increases marketability	Amarante *et al*. (2002a) [4]
Papaya	Polyethylene plastic-black bags	Increases the fruit appearance and good firmness	Tran *et al*. (2015) [104]

e. Fruit colour development

The main parameter that draws customers' attention is the colour of the fruit. The physical appearance of the fruit is improved by an attractive colour, which aids in obtaining higher prices in both domestic and international markets. Pre-harvest fruit bagging has shown to encourage or inhibit fruit colouration in many researches.

Table 5: Effect of bagging on fruit colouration

Fruit/cultivar	Bagging material	Effect	Reference
Litchi	Semi-transparent CP bags	Excellent skin colouration on fruit	Hu *et al*. (2001) [35]
Pear	-	Attractive green colour	Amarante *et al*. (2002a) [4]
Grape (Perla)	Cellulose bags	Increased uniformity of the fruit colouration	Signes *et al*. (2007) [91]
Mango	Two-layer paper bag	Development of greenish-yellow skin colour	Watanawan *et al*. (2008) [111]
Apple (Grany Smith)	-	Enhances development of red colour in green apple	Wang *et al*. (2010a) [110]

f. Colour inhibition

Ju (1998) [44] and Amarante *et al*. (2002b) [5] suggested that pre-harvest fruit bagging has the primary effect of inhibiting rather than promoting colour development but it depends on the stage of development of the fruit at the time of bagging, the bagging date, the type of bag used, the date of bag removal and the environmental conditions of the region.

Table 6: Effect of bagging on colour inhibition

Fruit/cultivar	Effect of bagging in fruits	Reference
Delicious apple	Reduces the anthocyanin development on the skin	Ju (1998) [44]
Plum	Found poor red colour development in bagged fruits in comparison to unbagged fruits	Murray *et al*. (2005) [65]
Apple (Red Fuzi)	Anthocyanin content was recorded lower in bagged 'Red Fuji' apples	Wei *et al*. (2006) [112]

2. Biotic factors influenced by fruit bagging

a. Pest control

Fruit bagging before harvest is a safe way to keep the climate and the produce physically separate. Protection from insect pest damage has been one of the most important effects of fruit bagging. Bagging has been shown to minimise the incidence of fruit fly in guava, mango, and codling moth in apple, woolly aphid in apple, fruit borer in litchi, San Jose scale in apple and fruit borer in pomegranate.

Table 7: Effect of fruit bagging on insect infestation

Fruit/cultivar	Bagging date or time	Bagging materials	Insect-pest control	References
Litchi	Bagging done after one week of fruit set	Brown and cello phone paper bags, newspaper bags	Minimized the infestation of stone borer and stalk-end borer	Debnath and Mitra (2008) [20]
Pomegranate (Ganesh, Mridula, Jyothi, Ruby, Jalore Seedless)	60-70 days prior to harvesting	Parchment paper bag	Minimized the infestation of pomegranate butterfly around 90%	Bagle *et al*. (2011) [11]
Mango (Langra)	30 days prior to harvesting	Black polybag, brown paper bags	Fruit fly control (100%)	Sarkar *et al*. (2009) [76]
Guava	42-63 days before harvesting	Biodegradable film. Waxed paper	Control on fruit fly and guava weevil	Bilck *et al*. (2011) [13]
Apple (Imperial Gala)	Transparent plastic perforated bag	Fruit fly, codling moth, woolly apple aphid	Teixeira *et al*. 2011	
(Apple) Royal Delicious	30 days prior to harvesting	yellow coloured bags	Control san jose scale attack	Sharma *et al*. (2013) [82]

b. Disease control

Fruit bagging often keeps pathogens out of the growing fruit, protecting it from a variety of diseases that can cause significant losses.

Table 8: Effect of fruit bagging on the incidence of diseases in fruit crops

Fruit/cultivar	Bagging date or time	Bagging materials	Diseases occurrence	References
Guava	30 days prior to harvesting	Newspaper bags	Reduces incidence of anthracnose and black spot disease	Martins *et al*. (2007) [57]
Mango (Carabao & Keitt)	60 and 100 days before harvesting respectively	Brown and white paper bags	Reduces occurrence of stem-end rot and anthracnose	Hofman *et al*. (1997) [33] and Buganic *et al*. (1997) [14]
Apple (Royal Delicious)	One month before harvesting	Yellow (light) coloured bags	Reduces sooty blotch and fly speck problem	Sharma *et al*. (2013) [82]
Mango	During fruit development	White bags	Control anthracnose	Senghor *et al*. (2007) [81]
Loquat	During fruit development	Plastic bags	Reduces fruit rot	Ko *et al*. (2010) [49]
	After fruit setting	White plastic bag	Minimizes the rust	Gong *et al*. (2002) [28]

c. Bird damage

Birds are major pests during fruit development and ripening such as in bananas, mangos, apples and dates, causing significant losses. To manage birds, various methods are used, such as beating drums, extending reflective ribbons in the field, and so on, but the birds quickly become accustomed to these methods (Sharma, 2009) [66]. As a result, fruit pre-harvest bagging has helped in the reduction of bird damage to various fruit crops.

3. Physiological and biochemical factors influenced by bagging

a. Physiological disorders

Physiological disorders are abnormalities in plants, which are associated to non-pathogenic factors. These may be incited by deficiency or excess of nutrients, hormonal imbalance, abnormal growing condition etc. (Singh, 2002) [93]. Many such disorders have been identified in different fruit crops, all of which have an impact on fruit yield and quality, and several management strategies have been implemented to overcome them. Fruit bagging have been shown in studies to reduce the occurrence of some fruit disorders.

Table 9: Effect of fruit bagging on the physiological disorders of fruit crops

Fruit/cultivar	Bagging date or time	Bagging materials	Disorders	References
Mango (Apple)	40-45 days before harvesting	White bags	Reduces lenticels discolouration	Mathooko *et al*. (2011) [58]
Litchi	Two months prior to harvesting	Brown paper bag	Reduces sun burning and fruit cracking	Joshi *et al*. (2016a) [42]
Apple (Royal Delicious)	One month prior to harvesting	Light yellow colour bags	Reduces incidence of brown core, bitter pit and cork pit	Sharma *et al*. (2013) [82]
Apple (Granny Smith)	At golf-ball fruit size	Brown paper bags	Reduces sun-burn	Bentley and Viveros (1992) [12]
Carambola	10-17 days after flowering	Plastic bags	Minimizes fruit dropping	Xu *et al*. (2008) [114]
Date palm (Zaghloul)	during pollination	Transparent blue polyethylene bags	Reduces fruit cracking	Kassem *et al*. (2011) [45]
Pear (Conference)	Fruit developmental stage	Plastic bags	Reduces sun-burn	Amarante *et al*. (2002b) [5]
Pear (Doyenne du Comice)	One month after full flowering	Perforated Polyethylene bags	Reduces fruit cracking and russeting	Amarante *et al*. (2002a) [4]

b. Fruit nutrient concentration

Fruits contains a variety of nutrients that contribute to the overall quality of the fruit. Fruit bagging, which is typically performed in the orchard during the fruit development stage, can have an effect on the nutrient composition of the fruit. For instance, Apple fruits covered with paper bags had the lowest calcium (Ca) concentration, but other bags increased it (Dong *et al*. 2007) [22]. Bagging had no effect on the concentrations of Nitrogen and phosphorus in pear fruits, but it reduced the concentrations of potassium, calcium, and magnesium by 9.6%, 38.9%, and 6.7 percent, respectively (Lin, 2008) [52]. Likewise, calcium level in bagged apple fruits were greater than in unbagged apples (Wang *et al*. 2010a) [110]. Therefore, Bitter pits were less common in bagged fruits than in unbagged ones (Sharma *et al*. 2013) [82].

c. Enzymatic activities

During fruit development, many biochemical changes occur, and several enzymes play an essential role in these changes. Fruit bagging also influences the activities of main enzymes, which plays a significant role in biochemical changes. Hu *et al*. (2001) [35] found that bagging 'Feizixiao' litchi fruit improved colour and growth, which they related to phenolic and flavonoid metabolism, as well as the activities of PAL and polyphenol oxidase (PPO). The activities of superoxide dismutase (SOD), peroxidase (POX), catalase (CAT), and ascorbate peroxidase (APX) in bagged apple fruit were higher than in unbagged fruit, as per Wang *et al*. (2010a) [110].

d. Fruit quality

The ultimate goal of a fruit grower is to produce high-quality fruit. Fruit quality is determined by many factors such as total TSS, acidity, and other quality attributes. Fruit bagging has been shown to affect the eating quality of fruits.

Table 10: Effect of bagging on fruit quality parameters

Fruit	Quality attributes affected	References
Pear	Reduction in total soluble solids and increase in titratable acidity	Lin *et al*. (2008) [52]
	Opposite effect on sorbitol and sucrose content	Hudima and Stamper (2011b) [38]

Apple	Increases sweetness of the fruits	Bentley and Viveros (1992) [12]
	Reduces TSS content	Chen *et al*. (2012) [16]
	Increases TSS and vitamin C content	Sharma *et al*. (2013) [82]
Banana	Not adverse effect on total soluble solids, acidity and fruit firmness	Muchui *et al*. (2010) [64]
	Improves finger length and finger quality and also provide protection from mechanical damage	Turner *et al*. (1984) [106]
Mango	Increases TSS, ascorbic acid, titratable acidity	Watanawan *et al*. (2008) [111]
	Increases internal quality of the fruit with acidity, sugar and carotenoid contents in cultivar Zill	Hongxenia *et al*. (2009) [34]
	Bagging with newspaper bag and brown paper after 30 days fruit set enhances the fruit quality like TSS, fruit retention, total sugars	Haldanker *et al*. (2015) [29]
	Bagging with green polyethylene bags showed maximum TSS, sugars, ascorbic acid with minimum acidity	Joshi *et al*. (2016b) [43]
Litchi	Improves TSS:acidity ratio	Debnath and Mitra (2008) [20]
	Bagging with green polyethylene bags showed maximum TSS, sugars, ascorbic acid with minimum acidity	Joshi *et al*. (2016a) [42]
Guava	Increase in TSS content	Singh *et al*. (2007) [92]
Loquat	Increase in TSS with reduced titratable acidity	Liu *et al*. (2004) [55]
Plum	Reduces soluble solid content	Murray *et al*. (2005) [65]
Red pitaya	Bagged fruit (7 days after anthesis) shows positive effect on fruit quality	Tuan *et al*. (2017) [105]
	Increases TSS, peel thickness and acidity	Costa *et al*. (2017) [18]

4. Phenolic compound content and anti-oxidants activities

Phenolic compounds are secondary metabolites that act as antioxidants and protect plants (as well as humans) from a variety of diseases. Fruit bagging can also affect phenolic compound concentrations and total antioxidant in fruits. Antioxidants are those compounds, which inhibit the oxidation process and protect the damaging of cells from free radicles. Phenolic compounds are mainly responsible for aroma and flavour in fruits.

Table 11: Effect of bagging on phenolic compound content and anti-oxidant activities

Fruit/cultivar	Effect of bagging in fruits	Reference
Apple (Delicious)	Phenolic compound concentration increases by bagging till 60 days then it declined.	Ju *et al*. (1998) [44]
Grape fruit	Increased the concentration of antioxidants.	Son and Lee. (2008) [97]
Pear (Conference)	Increases phenolic compound contents like caffeic acid and epicatechin in the peel	Hudima and Stamper (2011) [38]
Peach (Wanmi)	Bagging did not affect chlorogenic acid and catechol concentrations in fruit skin or flesh	Wang *et al*. (2010a) [110]
Sweet orange	Increases the chemical quality, phenolic compound and antioxidant activity	Xie *et al*. (2013) [113]

Table 12: Effect of bag types on appearance, insect-pest attack, disorders and quality of fruits

Fruits	Bagging materials	Best recommendation	Positive influences	References
Peach	Black and White bags	White bags	Improves pulp colour	Takada *et al*. (2006) [100]
Litchi	Cellophane paper bag, craft and newspaper bags	Fabric and Cellophane bags	Improves fruit colour	Hu *et al*. (2001) [35]
	Brown and butter paper bags, green polyethylene bags	Brown and butter paper bags	Improves fruit colour and internal quality of the fruits	Joshi *et al*. (2016a) [42]
Mango	Brown paper and black poly bags	Brown paper bags	Reduces incidence of fruit fly, high TSS and physical quality of fruits	Sarkar *et al*. (2009) [76]
	Newspaper bags, black and brown paper bags	Brown paper bags	Improves skin colour	Ding and Syakirah (2010) [21]
Mango (Kesar)	Newspaper, white paper and brown paper bags	Newspaper and brown paper bags	Enhances peel colouration, fruit length, fruit and pulp weight	Kireethi *et al*. (2018) [48]
Mango (Alphanso)	Different types of bags	Plastic bags	Enhances the sensory quality and chemical content of fruits	Tendulkar *et al*. (2018) [103]
Guava	Nylon fabric, Waxed paper and paper bags	Nylon bags	Complete control on fruit fly	Morera-Montoya *et al*. (2010) [63]
Carambola	Plastic bags, newspaper bags, non- woven cloth bags	Plastic bags	Increases fruit size and TSS	Xu *et al*. (2008) [114]
Date palm	Black, blue polyethylene bags and white paper bags	Blue and black colour bags	Increases respiration rate	Awad (2007) [9]
Banana	Different coloured bags	Plastic bags	Increases fruit size and enhances fruit maturity	Stover and Simmonds (1987) [99]
Apple	Different coloured bags	Light yellow coloured bags	Improves colour, fruit firmness and reduces storage disorders	Sharma *et al*. (2013) [82]
		Paper bags	Better calcium absorption by fruit	Dong *et al*. (2007) [22]

Bagging in different fruit crops

Usually bagging is used in various fruit crops for increasing both physical and chemical attributes (Sharma *et al*. 2014) [84]. It protects the fruitsfrom various biotic and abiotic factors.

Bagging on banana bunch

Banana bunch protection by bagging is used in commercial banana growing areas around the world to improve the quality and appearance of the fruits, as well as to ensure a quicker and more uniform harvest, sufficient ripening of the banana and protection from external biotic and abiotic conditions. The use of blue bags to prevent bunches from sunscald has proven to be very successful (Choudhury *et al*. 1997) [17]. According to the several reports, the temperature within the cover rises by 0.5 °C on average over a 24-hour period, and can rise by 7 °C during the hottest hours. Depending on the type of cover and environmental conditions, this microclimate decrease the days from flowering to the harvesting of bunches up to 14 days and increases bunch weight. The temperature of the bunch cover was 1-2 °C higher than the ambient temperature during the winter. The use of perforated bags will minimises the build-up of high relative humidity within the banana bags and prevent fungi growth and fruit decay at low humidity. (Muchui *et al*. 2010) [64]. The use of non-perforated blue polyethylene bags with a thickness of 30-35µ improved bag temperatures and reduced bunch production time (Robinson and Nel, 1982) [73]. Two-three weeks after the fruit set, banana bunch covering helps in controlling the infestation of thrips which causes peel damage and reduces the market appeal reported by (Stover and Simmonds, 1987) [99]. Furthermore, thrips, beetles, pitting, anthracnose, tip end rot, cigar end rot, brown spot, and diamond spot were all protected from the bunches through bagging (Amani and Avagyan, 2014) [3].

Bagging in guava

Highest ascorbic acid content was achieved by white polythene bags even though, most of the bagged fruits of guava shown best results on physical and chemical quality of Lalit cultivar with yellow polyethylene bags (Meena *et al*. 2016) [59]. Fruit bagging of guava also reduced the infestation of fruit fly and diseases like anthracnose and bird damage problems (Mitra *et al*. 2008, Morera-Montaya *et al*. 2010, Abbasi *et al*, 2014, Mondal *et al*. 2015, and Sharma and Nagraja, 2016) [1, 61-63, 88].

Bagging in mango

Bagging of mango through brown paper bag (CISH), 37.5 cm (length) X 30.0 cm (width) in size was observed most effective. The fruits bagging by brown paper bags, newspaper bags and polythene bag minimizes the infestation of fruit fly and mealy bug, and also reduces the occurrence of spongy tissue disorder (Haldankar *et al*. 2015, Islam *et al*. 2017, Islam *et al*. 2019, Ravishankar, 2011) [29, 39, 40, 72]. Exposing of fruits to direct high sunlight intensity as well as due to convective heat resulting spongy tissue disorder (Om Prakash, 2004 and Katrodia, 1989) [47, 66]. In addition, fruit bagging with brown paper bag found more beneficial for increasing the quality attributes like TSS, acidity, total sugars, carotenoid content (Singh *et al*. 2017) [95].

Bagging in pomegranate

Fruit bagging of pomegranate prevents the sunburn damages and enhanced anthocyanin contents, phenolic compound and other quality attributes such as ascorbic acid and antioxidant contents (Tehranifar *et al*. 2010; Seeram *et al*. 2005) [79, 101]. White bag is the most efficient way for development of good quality fruits and minimizing sunburn in fruits and provide control on pomegranate butterfly infestation (Sholmo, 2015) [90].

Bagging in litchi

Pink polypropylene and White polypropylene bags Found was very effective. Minimum fruit cracking and sunburn reported in white polypropylene bagged fruit (15 days after fruit set), while other quality attributes recorded maximum in 30 days after pink polypropylene bagged fruits (Chand *et al*. 2020) [15]. It reduces the incidence of attack of birds, moths, fruit flies and reduces the direct penetration of sunlight from the fruits (Singh *et al*. 2019) [94].

Bagging in apple

Pre-harvest fruit bagging of apple with light yellow coloured recyclable cellulytic bags at least 30-40 days before harvesting, develop attractive red colour comparison to non-bagged apples, and have good postharvest quality attributes. In addition, bagged fruits are less prone to diseases (fly speck and sooty mould) and insects like codling moth and woolly apple aphid (Bentley and Viveros, 1992 and Teixeira *et al*. 2011) [12, 102]. Bags should be removed 3-4 days before harvesting. Bagging also provides helps in reducing the storage disorders like bitter pit, brown core and cork pit in apple and it was due to high calcium content comparison to non-bagged fruits (Sharma *et al*. 2013b) [85]. The incidence of these physiological disorders have been reported to have a good relationship with calcium concentration of fruits (Sharma *et al*. 2012b) [83].

Benefit-cost ratio

Fruit fly and other pests affect more than 50 percent of the production volume in the horticulture sector, resulting in significant losses in fruit yield and quality (Badii *et al*. 2015) [10]. Fruit fly damage has been confirmed to cause 70 percent loss in mango yields and 40 percent loss in citrus fruit yields (Badii *et al*. 2015) [15].

Bagging is a non-chemical alternative to pesticides (Liu *et al*. 2015, Sharma and Shani-Kommu, 2018) [54, 87]. It is cost-effective because it lowers production costs and enhances net profit. Bagging technology adopters in mango production using white paper single layer bags, brown paper double layer bags, muslin cloth bags and perforated bags had a significantly higher yield of 10850 kg, gross return of $7031.62, and net return of $5077.79 compared to non-adopters, who had an average yield of 8250 kg, gross return of $3888.45, and net return of $2698.9 (Afsar and Sultana, 2019) [2]. Afsar and Sultana, (2019) [2] stated that Adopters of the bagging technology had a higher profit cost ratio (3.59) than non-adopters (3.26). Abbasi *et al*. (2014) [1] suggested that guava fruits bagged with perforated polyethylene bags had maximum benefit-cost ratio (21.02) compared to newspaper-bagged fruit (4.53) and control (3.65). Perforated polyethylene bagged fruits gave higher net return (508500 Rs) compare to newspaper bagged fruit (476718.75 Rs) and control (47731.2 Rs).

Constraints of fruit bagging (https://ipm-info.org/components-of-ipm/bagging/) [119]

- It requires a lot of labour and it is time taking process.

- When using plastic there is a risk of water getting trapped inside the bag, which can cause fruit damage or encourage the growth of many fungi or bacteria.
- Use of plastic bags are harmful for the environment because they are not recyclable.

Future strategies

- It is a labor-intensive process, and cost is a major deciding factor in its commercial adoption (Feng *et al*. 2014; Liu *et al*. 2015) [25, 54].
- Many researchers have different opinions about the type of bag to use for different fruits, as well as the date of bagging and the date of bag removal (Chen *et al*. 2012, Huang *et al*. 2009) [16, 37].
- Although some researchers have suggested the use of polyethylene bags, but due to environmental concern, development of biodegradable bags is also compulsory (Islam *et al*. 2017; Sharma *et al*. 2013) [39, 82].
- The experiments have shown that paper bags can be profitable, but It might not be possible to use such bags in heavy rainfall zones (Lin *et al*. 2012; Xu *et al*. 2010; Zamora *et al*. 2008) [53, 115, 117].
- Therefore, it is an utmost importance that decomposable bags, which are not harmful to the environment and specific to the fruits to be used as well as advantageous for farmers.

Conclusion

Pre-harvest fruit bagging can be concluded to be an easy, eco-friendly, and environmentally sustainable technology that is safe to use and has many beneficial effects on the physical appearance and quality of fruits. This method is used in the production of fruits in India and other parts of the world. It is a time consuming and laborious process. We should have need to developed the biodegradable bags because of plastic bags are not biodegradable and harmful to the environment.

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