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

Maneesh Kumar, VP Singh, Rajkumar Jat, Sajeel Ahamad and Virendra Kumar

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). Fan and Mattheis, (1998) 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 russetting. 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). 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).

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 from 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)[79] 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 Cleopatra 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)[80]. 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)[80]. 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)[80]. 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, baer, 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, 106]. 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) [33]. 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) [58] 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) 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 pollinator 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

<table>
<thead>
<tr>
<th>Fruits/cultivar</th>
<th>Bagging date/time</th>
<th>Bagging material</th>
<th>Effect</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carambola</td>
<td>10 DAFB*</td>
<td>Plastic bags</td>
<td>Increased fruit weight</td>
<td>Xu et al. (2008) [114]</td>
</tr>
<tr>
<td>Mango (Nam Dok Mai)</td>
<td>For 52 days</td>
<td>2 layer paper bags (black &amp; brown)</td>
<td>Increased fruit weight</td>
<td>Watanawan et al. (2008) [111]</td>
</tr>
<tr>
<td>Longan</td>
<td>-</td>
<td>Paper bags</td>
<td>Larger-sized fruit</td>
<td>Yang et al. (2009) [116]</td>
</tr>
<tr>
<td>Date palm (Khalas &amp; Sukari)</td>
<td>-</td>
<td>Blue bag</td>
<td>Increase fruit size and bunch weight</td>
<td>Harhash et al. (2010) [113]</td>
</tr>
<tr>
<td>Litchi</td>
<td>Two months prior to harvest</td>
<td>Brown and butter paper bags</td>
<td>Increase in fruit size and weight</td>
<td>Joshi et al. (2016a) [42]</td>
</tr>
<tr>
<td>Mango (Langra and Pant Sinduri)</td>
<td>40 days after fruit set</td>
<td>Brown paper bag</td>
<td>Increase in fruit weight and volume</td>
<td>Joshi et al. (2016b) [43]</td>
</tr>
<tr>
<td>Guava</td>
<td>20 DAFB</td>
<td>White polyethylene</td>
<td>Increases the fruit weight and size</td>
<td>Meena et al. (2016) [59]</td>
</tr>
<tr>
<td>Guava (Bari Peyara-2)</td>
<td>-</td>
<td>White polyethylene</td>
<td>Increases fruit weight and size</td>
<td>Rahman et al. (2017) [70]</td>
</tr>
<tr>
<td>Guava (Swarupkathi)</td>
<td>-</td>
<td>White polyethylene</td>
<td>Increases fruit weight and diameter</td>
<td>Rahman et al. (2018) [71]</td>
</tr>
<tr>
<td>Papaya</td>
<td>-</td>
<td>Polythene bags</td>
<td>Minimum loss in weight of fruit</td>
<td>Mia (2003) [90]</td>
</tr>
</tbody>
</table>

b. Fruit maturity

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

Table 2: Reduction in fruit size & weight

<table>
<thead>
<tr>
<th>Fruits/cultivar</th>
<th>Bagging material</th>
<th>Effect</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pear (Conference)</td>
<td>Paper bags</td>
<td>Reduced fruit weight</td>
<td>Hudima and Stamper (2011) [38]</td>
</tr>
<tr>
<td>Loquat (Baiyu)</td>
<td>-</td>
<td>Reduced fruit weight</td>
<td>Xu et al. (2010) [115]</td>
</tr>
</tbody>
</table>

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.

Table 3: Effect of bagging on fruit maturity

<table>
<thead>
<tr>
<th>Fruit/cultivar</th>
<th>Bagging date or time</th>
<th>Bagging materials</th>
<th>Effects</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana</td>
<td>-</td>
<td>Polyethylene bags</td>
<td>Enhance fruit maturity</td>
<td>Johns &amp; Scott (1989) [91]</td>
</tr>
<tr>
<td>Litchi</td>
<td>-</td>
<td>Cellophane paper (CP) bags</td>
<td>Delayed maturity</td>
<td>Debnath and Mitra (2008) [104]</td>
</tr>
<tr>
<td>Apple (Delicious)</td>
<td>-</td>
<td>White paper Bag</td>
<td>No effect on fruit maturity</td>
<td>Ju (1998) [49]</td>
</tr>
<tr>
<td>Guava</td>
<td>1 month before harvest</td>
<td>Simple news paper</td>
<td>Enhance fruit maturity</td>
<td>Singh et al. (2007) [92]</td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th>Fruit/cultivar</th>
<th>Bagging material</th>
<th>Effect</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mango</td>
<td>Paper bag</td>
<td>Reduce incidence of black spots, improve physical quality, light-green skin colour</td>
<td>Sarker et al. (2009) [76]</td>
</tr>
<tr>
<td>Banana</td>
<td>-</td>
<td>More attractive fruits, free from skin blemish</td>
<td>Muchui et al. (2010) [64]</td>
</tr>
<tr>
<td>Persimmon (Fuyu)</td>
<td>-</td>
<td>Reduces fruit blemishing</td>
<td>Katagir et al. (2003) [46]</td>
</tr>
<tr>
<td>Pear (Doyenne du Comice)</td>
<td>-</td>
<td>Reduces bird damage and skin blemishes, increases marketability</td>
<td>Amarante et al. (2002a) [4]</td>
</tr>
<tr>
<td>Papaya</td>
<td>Polyethylene plastic-black bags</td>
<td>Increases the fruit appearance and good firmness</td>
<td>Tran et al. (2015) [104]</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Fruit/cultivar</th>
<th>Bagging material</th>
<th>Effect</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Litchi</td>
<td>Semi-transparent CP bags</td>
<td>Excellent skin colouration on fruit</td>
<td>Hu et al. (2001) [55]</td>
</tr>
<tr>
<td>Pear</td>
<td>Cellulose bags</td>
<td>Attractive green colour</td>
<td>Amarante et al. (2002a) [4]</td>
</tr>
<tr>
<td>Grape (Perla)</td>
<td>Cellulose bags</td>
<td>Increased uniformity of the fruit colouration</td>
<td>Signes et al. (2007) [91]</td>
</tr>
<tr>
<td>Mango</td>
<td>Two-layer paper bag</td>
<td>Development of greenish-yellow skin colour</td>
<td>Watanawan et al. (2008) [111]</td>
</tr>
<tr>
<td>Apple (Grany Smith)</td>
<td>-</td>
<td>Enhances development of red colour in green apple</td>
<td>Wang et al. (2010a) [110]</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Fruit/cultivar</th>
<th>Bagging material</th>
<th>Effect</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delicious apple</td>
<td>Bagging done after one week of fruit set</td>
<td>Reduces the anthocyanin development on the skin</td>
<td>Ju (1998) [44]</td>
</tr>
<tr>
<td>Plum</td>
<td>Found poor red colour development in bagged fruits in comparison to unbagged fruits</td>
<td>Murray et al. (2005) [65]</td>
<td></td>
</tr>
<tr>
<td>Apple (Red Fuzi)</td>
<td>Anthocyanin content was recorded lower in bagged ‘Red Fuji’ apples</td>
<td>Wei et al. (2006) [112]</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Fruit/cultivar</th>
<th>Bagging date or time</th>
<th>Bagging materials</th>
<th>Insect-pest control</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Litchi</td>
<td>Bagging done after one week of fruit set</td>
<td>Brown and cello phone paper bags, newspaper bags</td>
<td>Minimized the infestation of stone borer and stalk-end borer</td>
<td>Debnath and Mitra (2008) [20]</td>
</tr>
<tr>
<td>Pomegranate (Ganesh, Mridula, Iyothi, Ruby, Jalore Seedless)</td>
<td>60-70 days prior to harvesting</td>
<td>Parchment paper bag</td>
<td>Minimized the infestation of pomegranate butterfly around 90%</td>
<td>Bagle et al. (2011) [111]</td>
</tr>
<tr>
<td>Mango (Langra)</td>
<td>30 days prior to harvesting</td>
<td>Black polybag, brown paper bags</td>
<td>Fruit fly control (100%)</td>
<td>Sarkar et al. (2009) [76]</td>
</tr>
<tr>
<td>Guava</td>
<td>42-63 days before harvesting</td>
<td>Biodegradable film. Waxed paper</td>
<td>Control on fruit fly and guava weevil</td>
<td>Bilck et al. (2011) [113]</td>
</tr>
<tr>
<td>Apple (Imperial Gala)</td>
<td>Transparent plastic perforated bag</td>
<td>Fruit fly, codling moth, woolly apple aphid</td>
<td>Teixeira et al. 2011</td>
<td></td>
</tr>
<tr>
<td>(Apple) Royal Delicious</td>
<td>30 days prior to harvesting</td>
<td>Yellow coloured bags</td>
<td>Control san Jose scale attack</td>
<td>Sharma et al. (2013) [82]</td>
</tr>
</tbody>
</table>

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.
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

### b. Fruit nutrient concentration
Fruits contain 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.
Antioxidants are those compounds, which inhibit the oxidation process and protect the damaging of cells from free radicals. Phenolic compounds are mainly responsible for aroma and flavour in fruits.

### 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.

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

<table>
<thead>
<tr>
<th>Fruit/cultivar</th>
<th>Effect of bagging in fruits</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple (Delicious)</td>
<td>Phenolic compound concentration increases by bagging till 60 days then it declined.</td>
<td>Ju et al. (1998) [44]</td>
</tr>
<tr>
<td>Grape fruit</td>
<td>Increased the concentration of antioxidants.</td>
<td>Son and Lee. (2008) [57]</td>
</tr>
<tr>
<td>Pear (Conference)</td>
<td>Increases phenolic compound contents like caffeic acid and epicatechin in the peel</td>
<td>Hudima and Stamper (2011) [38]</td>
</tr>
<tr>
<td>Peach (Wannii)</td>
<td>Bagging did not affect chlorogenic acid and catechol concentrations in fruit skin or flesh</td>
<td>Wang et al. (2010a) [110]</td>
</tr>
<tr>
<td>Sweet orange</td>
<td>Increases the chemical quality, phenolic compound and antioxidant activity</td>
<td>Xie et al. (2013) [111]</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Fruits</th>
<th>Bagging materials</th>
<th>Best recommendation</th>
<th>Positive influences</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peach</td>
<td>Black and White bags</td>
<td>White bags</td>
<td>Improves pulp colour</td>
<td>Takada et al. (2006) [100]</td>
</tr>
<tr>
<td>Litchi</td>
<td>Cellophane paper bag, craft and newspaper bags</td>
<td>Fabric and Cellophane bags</td>
<td>Improves fruit colour</td>
<td>Hu et al. (2001) [15]</td>
</tr>
<tr>
<td></td>
<td>Brown and butter paper bags, green polyethylene bags</td>
<td>Brown and butter paper bags</td>
<td>Improves fruit colour and internal quality of the fruits</td>
<td>Joshi et al. (2016a) [42]</td>
</tr>
<tr>
<td>Mango</td>
<td>Brown paper and black poly bags</td>
<td>Brown paper bags</td>
<td>Reduces incidence of fruit fly, high TSS and physical quality of fruits</td>
<td>Sarkar et al. (2009) [76]</td>
</tr>
<tr>
<td></td>
<td>Newspaper bags, black and brown paper bags</td>
<td>Brown paper bags</td>
<td>Improves skin colour</td>
<td>Ding and Syakirah (2010) [21]</td>
</tr>
<tr>
<td>Mango (Kesar)</td>
<td>Newspaper, white paper and brown paper bags</td>
<td>Newspaper and brown paper bags</td>
<td>Enhances peel colouration, fruit length, fruit and pulp weight</td>
<td>Kirirethi et al. (2018) [48]</td>
</tr>
<tr>
<td>Mango (Alphanso)</td>
<td>Different types of bags</td>
<td>Plastic bags</td>
<td>Enhances the sensory quality and chemical content of fruits</td>
<td>Tendulkar et al. (2018) [103]</td>
</tr>
<tr>
<td>Guava</td>
<td>Nylon fabric, Waxed paper and paper bags</td>
<td>Nylon bags</td>
<td>Complete control on fruit fly</td>
<td>Morera-Montoya et al. (2010) [65]</td>
</tr>
<tr>
<td>Carambola</td>
<td>Plastic bags, newspaper bags and non-woven cloth bags</td>
<td>Plastic bags</td>
<td>Increases fruit size and TSS</td>
<td>Xu et al. (2008) [114]</td>
</tr>
<tr>
<td>Date palm</td>
<td>Black, blue polye polyethylene bags and white paper bags</td>
<td>Blue and black colour bags</td>
<td>Increases respiration rate</td>
<td>Awad (2007) [9]</td>
</tr>
<tr>
<td>Banana</td>
<td>Different coloured bags</td>
<td>Plastic bags</td>
<td>Increases fruit size and enhances fruit maturity</td>
<td>Stover and Simmonds (1987) [99]</td>
</tr>
<tr>
<td>Apple</td>
<td>Different coloured bags</td>
<td>Light yellow coloured bags</td>
<td>Improves colour, fruit firmness and reduces storage disorders</td>
<td>Sharma et al. (2013) [82]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paper bags</td>
<td>Better calcium absorption by fruit</td>
<td>Dong et al. (2007) [122]</td>
</tr>
</tbody>
</table>
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 fruits from 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 bunches 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) [13].

Bagging in guava

Highest ascorbic acid content was achieved by white polythene bags despite, 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) [80]. 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, 85].

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) [89]. 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) [19].

Bagging is a non-chemical alternative to pesticides (Liu et al. 2015, Sharma and Shani-Kommu, 2018) [84, 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, 15, 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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