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Influence of pre-harvest fruit bagging on quality attributes of fruit crops – a comprehensive review

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ABSTRACT

Pre-harvest fruit bagging is an emerging horticultural technique that enhances fruit quality while promoting sustainable pest and disease management. By enclosing developing fruits in protective bags, this method shields them from biotic and abiotic stresses, resulting in improved external attributes such as uniform coloration, smoother texture, and increased size as well as internal qualities like balanced sugar-acid ratios, enriched aroma, and superior flavour retention. The practice reduces reliance on synthetic pesticides, minimizes mechanical damage, extends shelf life, and lowers post-harvest losses, aligning with integrated pest management strategies. Despite challenges including labour intensity, cost, and environmental concerns over conventional bagging materials, advancements in biodegradable and crop-specific solutions offer promising alternatives. It is widely adopted in various fruits globally, including mango, banana, guava, grape, apple and litchi. As global demand for high-quality, residue-free produce grows; pre-harvest bagging presents a viable approach to enhancing both productivity and sustainability in modern fruit production. Continued interdisciplinary research and innovation are essential to optimize its adoption and impact.

Keywords: *Pre-harvest fruit bagging, Fruit quality, Biotic and abiotic stresses, Mechanical damage, Viable approach, Biodegradable and bagging materials.*

INTRODUCTION

Pre-harvest fruit bagging is a widely practiced horticultural method known for its substantial impact on enhancing fruit quality, visual appeal, and post-harvest performance. The primary aim of fruit bagging is to establish a controlled microenvironment around developing fruits, effectively reducing their exposure to various biotic and abiotic stresses. Serving as a physical shield, the bags offer protection against insect pests, fungal pathogens, mechanical damage from wind or hail, and physiological disorders such as sunburn and russeting [1], [2]. This barrier function helps lower the incidence of pests and diseases, thereby decreasing reliance on chemical pesticides and enabling the cultivation of residue-free fruits that align with consumer safety standards [3],[4]. Additionally, fruit bagging modulates microclimatic conditions such as light exposure, humidity, and temperature around the fruit, contributing to enhanced surface coloration, smoother skin texture, and more uniform shape and size, all of which are highly desirable traits in commercial fruit production [5].

Recent studies have shown that fruit bagging also improves the resilience of fruits during storage, helping to reduce the occurrence of common post-harvest disorders such as chilling injury, sunscald, and bruising. This added protection contributes to an extended shelf life and minimizes storage-related losses [6], [7]. In practice, fruit bagging involves enclosing developing fruits on the tree using bags made from materials such as kraft paper, Butter paper, News paper bags, polyethylene films, non-woven fabrics, or biodegradable composites [8]. The selection of bagging material, timing of application typically during early fruit development and removed before ripening, are crucial and vary based on crop species, climatic conditions, and market demands [9]. It is a cost-effective and environmentally friendly technique that aligns well with Integrated Pest Management (IPM) strategies and Good Agricultural Practices (GAP), offering the dual benefits of pest suppression and improved fruit quality [10], [11]. In addition to its protective role, this method enhances the visual appeal and nutritional value of fruits, meeting the rising expectations of consumers and complying with food safety standards [12], [13]. Its increasing global adoption highlights its importance in sustainable horticulture and reinforces the broader movement toward reducing dependence on synthetic agrochemicals.

ORIGIN AND EVOLUTION OF PRE-HARVEST FRUIT BAGGING TECHNIQUE

Fruit bagging technique is a time-honored horticultural technique that traces its origins to East Asia, particularly ancient China and Japan. Early farmers in these regions used simple materials such as paper, cloth, and bamboo used in the cultivation of premium fruit crops such as apples (*Malus domestica*), pears (*Pyrus communis*), peaches (*Prunus persica*), and mangoes (*Mangifera indica*) [14], [15], [16] to shield developing fruits from environmental and biological threats [17].

Historical accounts from the Ming Dynasty detail the use of bamboo sleeves and oiled paper as protective coverings, demonstrating an early understanding of how microclimate regulation and physical barriers could enhance fruit quality [2].

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By the early 20th century, fruit bagging in Japan had undergone notable advancements, particularly with the introduction of double-layered paper bags in apple orchards. Over time, the materials used for bagging evolved from basic paper and cloth to plastic, and eventually to sophisticated breathable fabrics and mesh bags. These modern materials help regulate internal humidity, reduce fungal growth, and further improve fruit quality and safety [8], [18]. Amid the challenges posed by climate change; including unpredictable weather patterns, heightened pest pressure, and increased sun-related disorders, fruit bagging emerges as a climate-smart strategy. Recent advancements have introduced biodegradable and sensor-equipped "smart" bags that enhance environmental adaptability and sustainability [19].

BAGGING MATERIAL SELECTION AND ITS CHARACTERISTICS

The effectiveness of pre-harvest fruit bagging largely depends on the inherent characteristics of the materials used. Key properties such as gas permeability, light transmission, water resistance, and thermal insulation collectively determine the bag's ability to create a favourable microenvironment, directly influencing fruit development and ripening.

- **Paper Bags:** Paper bags are particularly suitable for temperate and humid climates due to their excellent breathability, which facilitates air circulation and minimizes internal condensation [20]. By maintaining a drier internal environment, they help prevent fungal growth. Their semi-opaque nature reduces exposure to excessive solar radiation, thereby preventing sunscald while still allowing enough photosynthetically active light to support normal pigment formation.

- **Plastic Bags:** Plastic materials are effective at retaining moisture and regulating temperature around the fruit, creating a stable, humid microclimate. However, without proper ventilation, they can trap excess humidity, leading to physiological disorders. To mitigate this, modern plastic bags often feature micro-perforations or breathable film layers that allow controlled airflow while offering strong protection against rain, insects, and pathogens.

- **Cloth-Based Bags:** Cloth bagging options, including loosely woven cotton and advanced non-woven fabrics, strike a balance between breathability and protection. Their lightweight and flexible structure cushions fruits from mechanical injury, making them ideal for sensitive varieties like peaches and mangoes. The porous nature of these fabrics ensures consistent airflow and moisture release, reducing the risk of heat accumulation and microbial contamination [21].

Fig 1: Various bagging material used in fruit crops

Steps for Pre-Harvest Fruit Bagging

- Choose the appropriate fruit plants intended for bagging.
- Carry out fruit thinning based on the specific crop and its requirements before initiating the bagging process.
- Enclose individual fruits or clusters (such as berries) in separate bags, securing each with twine or a coconut midrib.
- Gently push the bottom of the bag upward to prevent direct contact between the fruit and the bag.
- Create 2–3 small holes at the bottom of each bag to allow for proper water drainage.
- Use a ladder to access higher fruits, ensuring it is safely fixed or tied to sturdy branches when working with tall or large fruit trees.

POSITIVE EFFECTS OF PRE-HARVEST FRUIT BAGGING IN FRUIT CROPS

a. Protection against abiotic stresses: Fruit bagging serves as an effective strategy for protecting fruits from various environmental stresses, particularly in areas frequently exposed to intense sunlight, high winds, and heavy precipitation. This technique is especially beneficial for fruits with thin or delicate skins such as apples, pears, peaches, and grapes which are highly vulnerable to sunburn. Sun damage not only diminishes the fruit's aesthetic quality but also negatively impacts its nutritional value [22]. By acting as a physical shield, the bag reduces direct exposure to solar radiation and lowers the fruit's surface temperature, thereby mitigating the risk of sunburn blemishes [23] and also effectively guards against mechanical injuries caused by wind, such as abrasions, bruises, and surface deformities.

b. Temperature & Humidity normalization: Beyond functioning as a protective barrier, fruit bagging modifies the immediate microenvironment around the fruit, thereby aiding in the regulation of temperature and humidity. During episodes of high ambient heat, the shading effect provided by the bag helps lower the fruit's surface temperature, effectively alleviating thermal stress, a critical factor for species and cultivars sensitive to elevated temperatures [24]. This thermal regulation not only prevents heat-induced physiological disorders but also promotes uniform sugar accumulation and proper pigment formation.

c. Better Skin Colour: Fruit bagging significantly influences skin colour development by regulating light exposure and alleviating environmental stress during the maturation phase. In apple production, for example, bagging is employed to shield fruits from direct sunlight, thereby reducing the incidence of sunburn and encouraging the formation of more consistent and visually appealing skin coloration [25]. The partial shading provided by the bag creates a favourable microclimate that enhances the synthesis of anthocyanins - the pigments primarily responsible for the red and purple hues observed in apple varieties [26].

d. Effects on overall shape, size and improved texture: Fruit bagging plays a vital role in shaping fruit morphology by protecting developing fruits from insect predation, mechanical damage, and wind abrasion. The controlled microenvironment within the bag supports uniform cell division and expansion, leading to the development of fruits that are typically larger, more symmetrical, and consistent in appearance [27]. This morphological uniformity is particularly evident in crops like grapes, where bagging has been shown to improve the proportion of marketable fruit by ensuring even size and shape distribution and minimizing deformities. Improvement of Flavour and Aroma: The microclimate established through fruit bagging also significantly influences the development of flavour and aroma - two critical sensory attributes that drive consumer preference. Studies have shown that bagging can enhance the natural sweetness of fruits like apples by fostering optimal ripening conditions and protecting the fruit from environmental stresses [28], [29]. Additionally, bagging has been associated with increased synthesis and retention of volatile organic compounds (VOCs), which are essential contributors to the characteristic aroma profiles of fruits such as peaches and grapes [1].

e. Presence of higher vitamins, minerals and antioxidants: It has also been linked to notable enhancements in the nutritional quality of fruits, particularly in terms of vitamin content and antioxidant capacity [30]. Research on crops such as kiwifruit indicates that bagged fruits often contain significantly higher concentrations of vitamin C than their unbagged counterparts, a result likely attributed to diminished oxidative stress due to reduced ultraviolet (UV) radiation exposure [31].

f. Enzymatic activities: Fruit bagging also influences the activities of main enzymes, which plays a significant role in biochemical changes. 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 [32].

g. Protection against Insects-Pests infestation: By enclosing individual fruits, bagging significantly limits contact with common agricultural threats such as fruit flies (*Bactrocera* spp.), codling moths (*Cydia pomonella*), and frugivorous birds. This protective measure reduces the reliance on chemical insecticides, thereby promoting safer, residue-free produce while simultaneously improving yield and fruit quality [33].

h. Significant decline in Bacterial and Fungal Diseases: Pre-harvest fruit bagging also provides effective protection against a variety of fungal and bacterial pathogens. The physical barrier formed by the bag minimizes direct exposure to external infection sources, particularly in regions where rain splash and high humidity significantly contribute to disease proliferation [34]. For example, studies in pear orchards have shown that pre-harvest bagging substantially lowers the occurrence of fungal diseases such as scab (*Venturia pirina*) and gray mold (*Botrytis cinerea*) by reducing surface moisture on the fruit.

i. 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. Many such disorders have been identified in different fruit crops i.e. apple, mango, pear, loquat etc. all of which have an impact on fruit yield and quality, and several management strategies have been implemented to overcome them [35].

j. Improving Shelf Life of fruits: Bagging plays a crucial role in mitigating the effects of temperature fluctuations, dehydration, and mechanical damage, all of which are major contributors to post-harvest fruit deterioration [36]. By protecting fruits from these environmental stressors during the growth phase, bagging helps preserve their physiological integrity, resulting in delayed ripening and extended freshness after harvest .

k. Post-Harvest Loss reduction: Mechanical damage, pest infestations, and latent infections are significant contributors to post-harvest fruit loss. By providing physical protection during critical stages of fruit development, bagging helps mitigate these issues, thereby reducing post-harvest decay and bruising [37]. Studies comparing bagged and nonbagged fruits in grape and apple production have shown that bagged fruits experience significantly lower rates of post-harvest losses, both in terms of physical damage and microbial spoilage, compared to those grown under conventional open-field conditions [38].

Fig 2: Effects of Pre-harvest fruit bagging in fruit crops

Table 1: Fruit crops improved through bagging

S.No.	Fruit crop	Advantages in fruit Bagging	Reference
	Mango	Improves fruit coloration, size and shape	[39]
1	Peach	Minimizes insect damage and enhances flavor profile	[40]
2	Banana	Provides protection from thrips, beetles, and sunburn	[41]
3	Guava	Decreases scarring and pest incidence	[42]
4	Apple	Enhances fruit colour and size while reducing susceptibility to pests and diseases	[43]
5	Litchi	Reduces fruit cracking and deters fruit borer infestation	[44]
6	Dragon fruit	Protects against sunburn and bird damage	[45]
7	Grape	Shields from sunburn and contributes to superior wine quality	[46]
8	Pear	Enhances overall quality and reduces surface blemishes	[47]
9	Fig	Protects fruits from bird and insect attacks	[48]
10	Cherry	Prevents bird damage and intensifies colour development	[49]

Table 2: Effect of Pre-harvest bagging on quality attributes

S.No.	Fruit crop	Quality Attribute	Reference
1	Apple	Improvement in soluble solids and ascorbic acid contents	[50]
2	Mango	Significant effects on SSC, TA, SS/TA ratio, vitamin C	[51]
3	Banana	Significant improvement in all quality attributes	[52]
4	Guava	Increase in soluble solids concentration, ascorbic acid (SSC)	[53]
5	Litchi	Significant improvement in TSS/acid ratio	[54]
6	Grapes	Significant effect on sugar accumulation in the berries	[55]

Table 3: Impact of fruit bagging on the incidence of insect-pests and diseases in different fruits

S.No.	Fruit crop and cultivar	Bagging date/time	Bagging material	Insect-pest/disease controlled	Reference
			Incidence of insect-pests		
1	Apple cv. Imperial Gala	40 days after flowering	Transparent micro-perforated plastic or non-textured fabric bags	Reduction in fruit fly, Oriental fruit moth and woolly apple aphid	[56]
2	Apple cv. Royal Delicious	30 days before harvesting	PP non-woven bags	Reduction in the incidence of San Jose Scale	[57]
3	Guava cv. Allahabad Safeda	At marble stage	PP non-woven bags	100% reduction on the incidence of fruit fly	[53]
4	Pomegranate cv. Mridula	60-70 days before harvesting	Parchment paper bags	Nearly 90% reduction in the incidence of fruit borer	[58]
5	Mango cv. Alphonso	30 days before harvesting	Black polybag, transparent polybag, brown paper bags	100% reduction in the incidence of fruit fly	[51]
6	Litchi cv. Shahi	Bagging after 1 week of fruit set	Biodegradable cellophane paper bags, brown and news paper bags	Reduced incidence of stalkend and stone borer	[54]
			Incidence of diseases		
1	Apple cv. Royal Delicious	30 days before harvesting	PP non-woven bags	Reduction in scab, flyspeck and sooty blotch	[57]
2	Guava cv. Allahabad Safeda	Marble stage	PP non-woven bags	Reduction in anthracnose disease	[53]
3	Mango cv. Nam Dok Mai #4	45 days after full bloom	Plastic bags with wavelengthselective characteristics	Reduction in the incidence of most of the postharvest diseases	[39]
4	Pear cv. Huangguan	During fruit development	3 layered bags	Increase in the incidence of browning spot	[59]

Table 4: Qualitative comparison between non-bagged fruits and bagged fruits

S.No.	Factors	Fruits which were not bagged	Fruits which were bagged	Reference
1	Resistance towards Diseases	Increased susceptibility to diseases like rot, scab, and mildew due to exposure to pathogens	Bags protect fruits from fungal and bacterial spores, rain splash, and humidity, lowering disease risk.	[15]
2	Control of insec-pest	Higher risk of damage from pests like fruit flies and borers, resulting in visible harm and yield loss	Bags provide a physical barrier, reducing direct damage from insects and birds.	[60]
3	Impact on environment	Higher chemical usage for pest and disease control contributes to environmental contamination.	Bagging reduces reliance on chemical sprays, leading to lower pesticide use and a more environmentally friendly approach	[61]
4	Adaptation towards climatic stress	Fruits are susceptible to damage from weather extremes like sunburn, hail, and wind.	Bags shield fruits from sunburn, wind scars, and rain induced cracking.	[62]
5	Extension of storage life	Physical damage, rapid ripening, and higher spoilage rates contribute to a shorter shelf life.	Reduced bruising, slower decay, and less microbial contamination contribute to a longer shelf life	[63]
6	Losses during post harvest	Higher rates of spoilage and physical injuries result in increased post-harvest waste.	Less bruising, rot, and handling damage result in reduced losses.	[28]
7	Quality of harvest	Environmental exposure leads to blemishes, irregular shapes, and decreased visual appeal.	Reduced bruising, slower decay, and less microbial contamination contribute to a longer shelf life	[64]
8	Value in market	Defects reduce consumer appeal, leading to lower market value and pricing	Superior appearance and quality lead to premium prices and higher market value.	[65]
9	Overall Quality in terms of nutrition	UV exposure and mechanical damage accelerate nutrient loss	Less bruising, rot, and handling damage result in reduced losses.	[66]
10	Systematic process of ripening	Variable sun exposure causes inconsistent ripening, with some fruits overripe and others under ripe.	The regulated microclimate inside the bag promotes more uniform and controllable ripening	[9]

CHALLENGES AND LIMITATIONS OF PRE-HARVEST FRUIT BAGGING

While pre-harvest fruit bagging offers notable agronomic advantages, it also presents certain challenges.

i. Economic Constraints: The use of specialized bagging materials and the additional labour required for their application can significantly raise production costs. For small-scale and resource-constrained growers, these upfront expenses may outweigh the benefits in fruit quality, making the practice economically unfeasible.

ii. Labour Intensity: Manually bagging each fruit is a time-consuming task that demands a dependable labour force. In areas where labour is limited or expensive, this process becomes a major barrier to widespread adoption especially in large orchards that lack mechanized solutions [67].

iii. Potential Impacts on Fruit Development: In certain cases, bagging may delay ripening or result in uneven fruit growth. Altered gas exchange and restricted light exposure within the bag's microenvironment can interfere with natural developmental signals, leading to inconsistent maturity and complicating harvest operations [68].

iv. Environmental and Sustainability Challenges: The widespread use of non-biodegradable plastic bags in fruit bagging raises concerns about post-harvest waste and environmental pollution. Although biodegradable options are available, their higher cost often makes them inaccessible to many growers, leading to continued dependence on conventional plastics [69].

v. Climatic Limitations: In tropical or consistently humid regions, bagging can lead to excessive moisture buildup inside the bags, fostering mold growth and fruit rot instead of preventing it [70].

vi. Consumer Perception and Market Acceptance: Consumer attitudes toward bagged fruit vary, without effective outreach and education to communicate the safety and quality benefits, growers may find it difficult to secure the premium prices needed to justify the costs of bagging [71].

Future Scope: The future of pre-harvest fruit bagging is poised to incorporate advanced materials and intelligent technologies, guided by the principles of environmental responsibility and precision horticulture. As global agriculture shifts toward sustainable practices and data-centric management, these bagging systems will transform into versatile platforms that not only protect fruit quality but also reduce ecological impact [72], [73].

- Adapting a long Sustainable and Bio-degradable package
- Integration of Smart Technologies into Fruit Bagging
- Customizable and Adaptive Bag Designs
- Alignment with Consumer-Centric and Eco-Conscious Trends
- Consumer-Focused Packaging and Traceability

CONCLUSION

Effective implementation of pre-harvest fruit bagging requires a thoughtful cost-benefit analysis and careful adaptation to each unique production system. Growers must balance the initial investment in materials and labour against expected improvements in fruit quality and market returns, tailoring bag type, timing of application, and labour strategies to suit their specific agro-ecological and economic conditions. Looking forward, research should focus on developing affordable, biodegradable materials that perform reliably across diverse climates; integrating sensor-based technologies to monitor and optimize microclimatic conditions in real time; and conducting long-term, multi-location studies across various fruit species to better understand physiological responses to bagging. As agriculture moves toward more sustainable practices, pre-harvest bagging emerges as a scalable solution for producing high-quality fruit with minimal environmental impact contribute to a more resilient and sustainable food system.

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