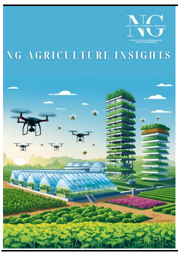

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Pre-Harvest Factor Affecting Composition, Texture, Flavour, Appearance and Post-Harvest Life of Fruits and Vegetables

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A B S T R A C T

Key pre-harvest factors like genetic, environmental, cultural and physiological factors, significantly influence the post-harvest quality of fruits and vegetables, which encompasses market appeal, consumer preferences, visual appearance and nutritional value. Moreover, the pre-harvest factors play a crucial role in plant growth and development. The quality and acceptability of fresh horticulture produce are ultimately determined by a complex interaction of qualities, traits and attributes. The physiological state of the produce and its inherent genetic makeup play an important role in determining its quality and response after harvest. To optimize pre-harvest factors and enhance the production of high-quality horticultural products, there is a need for collaboration between farmers, scientists, and experts in these fields. Understanding deeply the pre-harvest factors affecting post-harvest quality is the main objective of this review. This knowledge will help us manage these factors and maintain high-quality produce effectively.

Keywords: *Quality, Pre-Harvest Factors, Consumer Preference, Nutritional Value, Fruits and Vegetables*

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1. INTRODUCTION

Evidence over the past four decades has shown that in underdeveloped countries, 40-50 percent of horticulture produce is lost prior to consumption, largely due to factors such as water loss, bruising, faulty packing, pests attack and climate change (Kitinoja and Kader, 2002). Post-harvest fruit and vegetable losses have been estimated to be between 20 to 30 percent in certain areas (Bhattarai, 2017). There are various factors that determine the total value of any commodity. The extent to which products rot and spoil depends on the combined effect of these factors (Ahmad, 2015). The pre-harvest factors can cause high post-harvest losses and a significant reduction in product quality if they are not properly controlled (figure 1). Proper planning right at the commencement of farming activities is required in order to achieve maximum post-harvest quality. It is typical to under-appreciate and overlook the effect of pre-harvest factors on post-harvest performance. However, after harvest various processes significantly affect crop quality during growth and development. From harvesting to consumption, horticultural crops are affected by losses in quantity as well as quality. Almost a third of fresh fruits and vegetables are lost before consumption (Kader, 2002). Thus, the primary

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emphasis of the analysis is upon the cause of both quantitative and qualitative losses in horticultural crops. It has a heavy focus on adopting and leveraging advanced technologies to enhance the quality and freshness of the commodities. Enhancing food security and ensuring food availability from existing output relies on reducing post-harvest losses and quality loss. Proper management of pre-harvesting factors are the initial step in post-harvest management of crops. Overall quality of fruits after harvesting can be well maintained but once deteriorated cannot be enhanced. Adoption of proper pre-harvest technology, harvesting and subsequent post-harvest handling practice are critical to the eventual value of the goods in the market and consumer acceptability.

Cultural practices such as application of fertilizer, use of growth regulators and frequency of irrigation are some of the pre-harvest factors with a great influence on post-harvest quality. Natural occurrences such as hailstorms and erratic rainfall, as well as weather conditions such as extremely high or low temperatures, also have a great influence. Additionally, plant traits such as crop duration, penetration of light and pruning and training practices are of very great importance. Collectively, these factors impact the morphology, physiology, chemical composition and quality of the fruit and vegetables, which consequently impacts storability.

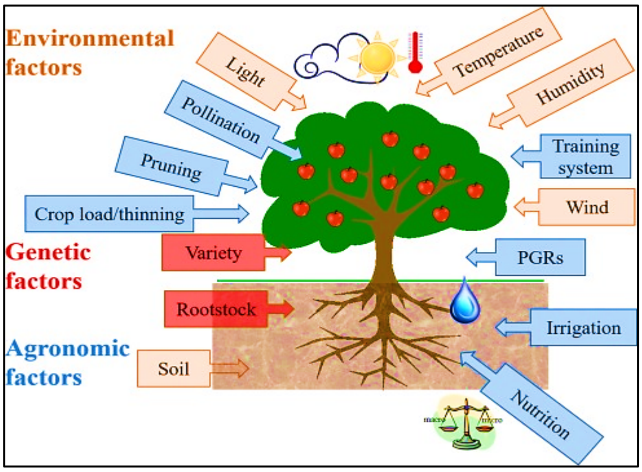

Figure 1. Illustration of pre-harvest factors affecting post-harvest quality in plant

2. PRE-HARVEST FACTORS AFFECTING POST-HARVEST QUALITY

2.1 Growing site

It is a matter fact that soil or any media where the fruit and vegetables are gown has direct impact on its quality as low fertile growing media containing heavy metals toxic chemical with extreme pH ranges may reduce quality of the produce. The media should be analyzed to achieve compositional and physical quality of the harvested produce.

2.2 Genetic factors

Quality of fruits and vegetables is attributed to expression of genes associated with traits. However, the genetic make-up of a genotype or crop variety is not only deciding factor rather the gene expression is regulated by environments and its interaction where crop are raised. Therefore, it is pertinent to mentioned that P = G + E + (G×E), where P represents observed phenotypic performance, G the genotypic component, E the environmental component and G×E the differential response of genotype to environment among which genotype component plays a vital contribution. Earlier researcher validated the concept in many fruits and vegetables (Moharana et al., 2026 in bittergourd; Pramanik et al., 2024 in French bean; Alam et al., 2024 in sweet potato; Dia et al., 2018 & Odor et al., 2017 in cucumber; Koundinya et al., 2019 in brinjal; Krishna et al., 2022 in mango; Locatelli et al., 2025 in apple; Palmieri et al., 2017 in strawberry). Cultivar is one of the key determinants of variance in horticultural crops (Crisosto, 1997). Selection of appropriate cultivars is major consideration prior to planting, though sometimes availability of planting materials could be constrained. Further, consideration eating habits and consumer preference helps in selecting cultivar. Plant breeding has come up with a broad range of commercial fruit and vegetable crops with varied quality traits, presenting growers with a variety of choices to grow. Post-harvest quality is significantly influenced by the variety of vegetable chosen and the marketing channel (Prussia, 1993). Cultivars that are highly tolerance to the stresses tend to have lower post-harvest losses. In other cases, though, these cultivars may show poor sensory quality. Although cultivars with low ethylene production and low respiration rates tend to have longer storage lifetimes, those with short shelf lives are more susceptible to post-harvest losses. Horticulture breeding and modern biotechnology are imperative for improvement of the post-harvest quality and safety of the fresh produce (Bekele, 2018). There is vast opportunity to enhance the quality and production of horticulture crops. Market acceptance of a cultivar resulting increased area and production is benefited to producers, entrepreneurs and consumers (Hall, 2004). Therefore, high nutritional quality, flavor with low wastage, resistance or tolerance to biotic and abiotic stresses should be the ultimate priorities to be achieved and maintained. Farmers thus need to select cultivars that have desirable edible quality traits, pest-and disease-resistant, having good storage keeping ability and highly productive.

2.3 *Harvestable maturity*

Maturity of horticultural crops signifies attainment of certain degree of growth where the quality meets the consumer preference and harvesting is occurred. It is the stage of full development of tissue of fruits and vegetables after which it ripe normally. The maturity stage is critical and different in horticultural crops as compared to field crops (Table 1). It is most important pre-harvest factor affecting the post-harvest life and final quality of horticulture crops. Grower face problem to decide time of harvest because it is directly related to consumer preferences. Harvesting must therefore take place at the right time, taking into account both horticultural and physiological maturity (Bekele, 2018). Attainment of maturity often leads to many biochemical reactions occurs in edible parts. For instance, the fruit and vegetables in which anthocyanins or chlorophylls is dominate where anthocyanin increases with decline in phenolic acids and carotenoids during development (Xu *et al.*, 2020).

Table 1: Maturity indices of tomato

Stages of harvesting	Types Maturity
Green stage, Breaker, Turning, Pink, Red, Fully Red	Horticultural maturity
Fully Red	Physiological maturity

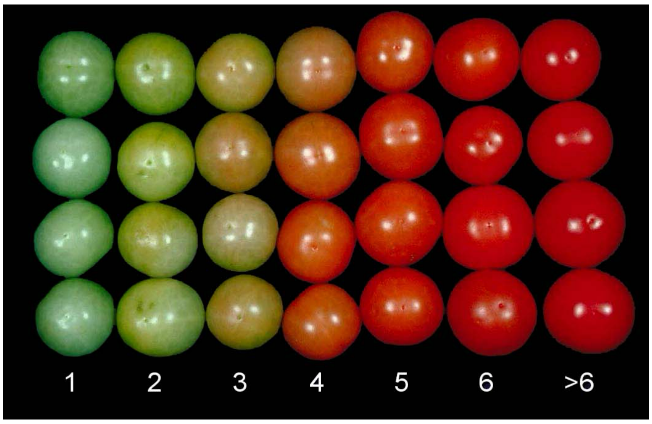

Figure 2. Maturity indices of tomato (1. Green mature, 2. Breaker stage, 3. Turning stage, 4. Pink stage, 5. Red ripe stage, 6. Fully ripe stage and over ripe stage)

The developmental stage at which a plant has reached its maximum growth and maturation, allowing for appropriate ripening even after harvest, is known as physiological maturity. Similarly, horticultural maturity is the developmental stage at which a plant or its components are prepared for consumer use for a particular purpose (Kader, 1984). While overripe fruits and vegetables have poor texture, flavor and a limited shelf life, immature fruits and vegetables are more likely to shrivel and sustain mechanical damage. When compared to fruits and vegetables picked at ideal maturity, early or late harvests might lower their storage life and make them more susceptible to physiological disorder and pests attack. Hence, crop maturity one of the most important factors influencing longer storage life and higher-quality products. The maturation stage at harvest has a major impact on a number of quality attributes, including form, size, color, texture, dry matter content, productivity levels and taste characteristics. Maturity is assessed using a variety of techniques, such as physiological techniques viz., respiration and ethylene production, chemical techniques viz., total soluble solids (TSS) and physical techniques viz., size, shape and color. It is improbable that the soluble solid content in fruit at the time of consumption may more than 12.5% and dry matter content less than 14.5% which may not meet consumer acceptance (Palou, 2001).

2.4 *Perishability and shelf life*

Fruits and vegetables report the highest magnitude of postharvest losses due to their perishable nature which subsequently impact the shelf or storage life. Fruits and vegetables are perishable in nature because these have high moisture content resulting in high respiration and transpiration rate. According to perishability fruits and vegetables are classified as perishable (very high rate of respiration and transpiration), semi perishable (moderate rate of respiration and transpiration) and non-perishable (low rate of respiration and transpiration) illustrated below.

Table 2: List of fruits and vegetables according to perishability

Perishable	Semi perishable	Non perishable
Cabbage, cauliflower, lettuce, pea, spinach, tomato, broccoli, asparagus	Celery, leek, marrow	Beetroot, carrot, onion, parsnip, pumpkin, potato, sweet potato, swede turnip
Banana, mango, strawberry, grape, Pineapple, passion fruit	Coconut, oranges	Apple, grape fruit, lemon, pear

3. CLIMATIC FACTORS

A number of environmental factors, such as relative humidity, light, temperature, rainfall, wind and carbon dioxide (CO_2) influences the growth and development of plants directly or indirectly. Abiotic factors such as low temperature and heavy rainfall coupled with biotic stress during fruit development stage resulted in pre- harvest losses of fruits and vegetables. Abiotic stresses is detrimental to fruits and vegetables at particular growth stages. For instances, high temperature accompanied with drought impaired the overall growth and development leads to reduction in fruit quality in capsicum even grown under protected structure (Pramanik et al., 2020). However, medicinal and aromatic plants produce more secondary metabolites such as alkaloids and essential oils in defence action against abiotic stresses (Pradhan et al., 2024). Additionally, the quality and shelf life of horticultural crops are mostly dependent on storage temperature, proper ventilation and relative humidity inside the storehouse. Following environmental factors are discussed.

3.1 Temperature

All physiological and biochemical processes related to plant growth and yield are strongly influenced by temperature. Storability of fresh fruits and vegetables is depending on the prevailing temperature at the time of post-harvest activities. High temperature during fruit maturity stage resulted in decreasing quality by increased respiration rate, which reduces the carbohydrate content of harvested produce, whereas produce with more stored carbohydrates have longer shelf lives (Irtwange, 2006). Fruit quality has significantly influenced due to variation in temperature at the time of fruit maturity, which also alter the harvesting time of fruits. For example, high temperature at fruit development stages hastens the ripening of fruits in tomato. Rising temperature have a direct impact on photosynthesis organic acid, sugar and flavonoid content as well as firmness and antioxidant activity of fruits. Extreme temperature conditions also reduce plant growth and development by causing stress leads to stunted growth, fruit drop, pest and disease infestations and physiological disorders that reduces post-harvest life of harvested produce. Therefore, for obtaining good yield and quality optimum temperature ranges plays an important role.

3.2 Light intensity

Light is essential for maintaining the growth and development of plants. It is essential for controlling a number of physiological functions, such as respiration, stomatal opening, phototropism, photosynthesis and other metabolic processes. Light quality, duration and intensity all have a big impact on plant growth. Photosynthesis is triggered by photosynthetically active radiation, which is characterized by wavelengths ranging from 400 to 700 nanometers Most horticultural crops need high light intensities, often ranging from 3000 to 8000 foot-candles Wolf (1999). In a study on avocados grown under sun and shade condition, Woolf (1999) found that fruits grown in the sun had higher dry matter content, higher calcium and magnesium levels, and more oil than fruits grown in shade. Both light intensity and quality have a major effect on the post-harvest eating quality of horticultural crops (Kays, 1999). Light intensity has a major effect on blooming, stem length, leaf color, and plant food production. Similarly, light duration is critical to plant development. Horticultural crops are either long-duration, short-duration, or day-neutral. Adequate amount, type, and duration of light are thus equally important for maximal plant productivity and harvest index. Following Hewett (2006), effective use of light is critical in regulation of productivity and quality in perennials because the amount of leaf area on a sunny day that is exposed to sunlight must be sufficient to supply the carbon needed for growth of fruits and vegetables.

3.2 Rainfall

Rainfall is another major influence on post-harvest loss for horticultural crops. The likelihood of mechanical damage and degradation during the subsequent harvest and handling operations impacted by extended rains during the harvest period. Apart from lowering the quality of crops, heavy rains raise the chances of physiological disorders like apple and cherry skin splitting (Sekse, 1995). The plant structure typically uptakes less than 5% of water, which is used for growth and development of different parts of the plant. Horticultural produce and perishables with metabolically active tissues lose much of their value at the time of harvesting due to senescence, physical damage, and microbial spoilage. High moisture stress restricts cell growth, resulting in low crop yield and poor quality. In addition, the rate of respiration is higher than the rate of absorption by these stresses. Nevertheless, too much water makes plants more turgid, thus more prone to physical damage, softer and with lower contents of soluble solids, and slower in maturation. Post-harvest horticultural crop changes can be retarded but not stop completely. Growers have been using water management techniques for years to reduce water stress and maximize growth, photosynthesis, and harvestable production. In some cases, water preservation through improved crop quality and the stimulation of growth over the long term can be done through judicious use of the water supply.

4. MINERAL NUTRITION

Mineral nutrients must be supplied in a timely and balanced manner for soil to have an impact on plant performance and quality (Calouro et al., 2008). Although inorganic mineral nutrients affect horticulture product quality in a number of ways, their primary function is to avoid physiological problems (Ferguson, 2002). Horticultural crops' quality and post-harvest life are significantly impacted by plant nutrition. For plants to grow and flourish, a balanced supply of critical nutrients is necessary. On the other hand, nutritional surpluses or deficiencies can have a major effect on post-harvest life and quality. According to Cuquel et al. (2011), nitrogen and potassium are regarded as vital nutrients for plants. Onion is provided with major micronutrients viz., Fe, B, Zn, Cu and Mo improved the growth, bulb yield and quality (Pramanik and Tripathy et al., 2017; Pramanik et al., 201). Early research reported that phosphorus fertilization in cow pea influence the overall performance and quality of pods (Sudharani et al., 2018). Mineral shortages are associated with a number of physiological problems, which in turn cause postharvest losses. To increase agricultural output and quality, a variety of management techniques have been developed for the proper application of fertilizers and minerals. Fertilizers may be sprayed on the soil, administered topically, or even irrigated in the field. Nutritional imbalances of particular mineral minerals cause certain post-harvest problems in agricultural products (Kays, 1999). Increased post-harvest rot and decreased firmness can result from overapplying nitrogen. A lack of calcium, a particularly crucial mineral nutrient, can cause a variety of post-harvest problems in horticultural crops (Shear, 1975). These conditions include blossom end rot in tomatoes and capsicums and bitter pit in apples. However, post-harvest dipping or drench treatments, as well as the use of calcium salts during fruit growth, can help alleviate calcium insufficiency (Hewett et al., 1991). Calcium applied foliarly is thought to be advantageous because it increases fruit firmness and prolongs post-harvest life. On the other hand, plants may also suffer from too high calcium uptake since it lowers respiration rate and ethylene synthesis (Singh et al., 2013). Chemical fertilizers and organic ingredients are equally significant. Vermicompost is regarded as a crucial component for raising crop yields. It is well known that using organic management techniques can enhance the quality of fruit consumed.

5. CULTURAL BEHAVIORS

Every cultural activity has a direct impact on the crops' ultimate quality. Numerous cultural practices, including the use of appropriate cultivars, irrigation, mulching, training/pruning, fertilization, soil management, growth regulator application and phytosanitary control, impact the plant's supply of nutrients and water, which in turn impacts the nutritional value of crops that are harvested.

5.1. Density of Plants

The quantity and quality of horticultural products are greatly influenced by planting density. The amount and quality of produce are eventually reduced by high planting densities because they increase plant competition and decrease light penetration. On the other hand, low planting density may produce better-looking and larger fruits. However, because they are more vulnerable to physiological diseases, larger fruits might have a shorter shelf life. According to Mendlinger (1994), the total soluble solids content of muskmelons decreased as planting density increased.

5.2. Watering/ Irrigation

Maintaining crop quality after harvest depends on having enough soil moisture throughout the pre-harvest phase. Fruit size and quality are negatively impacted by moisture stress during the growth season, which results in softened or dehydrated fruits that are more likely to deteriorate in storage. On the other hand, vegetables that receive too much water during the growing season may experience a dilution of soluble solids and acids, which could affect their flavor and nutritional value (Prussia, 1993). In addition to reducing crop yield, water stress on plants speeds up fruit ripening (Henson, 2008).

5.3. Factors related to the soil

The main goal of organic production is to maintain high-quality, sustainable soil health. Reaching this goal has a direct positive impact on horticulture crops' post-harvest quality. Similarly, the quality of some crops after harvest can be greatly impacted by the texture of the soil. For instance, carrots grown on muck soils have higher levels of terpenoids chemicals that give carrots their bitter flavor than carrots produced on sandy soils. Simon (1985).

5.4. Thinning and Pruning

Important cultural methods like pruning and thinning have a big impact on crop load and fruit size, which in turn affects the nutritional makeup of fruits. By lowering the crop load, these practices help to improve the growth and development of individual fruits. Pruning and thinning provide a healthy balance between vegetative growth and fruit production, which improves product quality by decreasing rivalry between plants or fruits and enhancing light penetration. Because it makes it easier to remove undesirable, sick and damaged plant portions, proper pruning is crucial.

5.5. Regulator of Growth

By either delaying or speeding up maturity, the use of growth regulators has an indirect impact on fruit composition rather than a direct one. Reduced output and deterioration in quality might result from poorly managed plant protection systems. The quality and longevity of flower crops have been found to be improved by growth hormones like Indole-3-acetic acid (IAA), Gibberellic acid (GA_3) and cytokinins like Benzyladenine (BA), as well as growth retardants like B-9 (Daminozide) and Phosphon-D (Chlormequat chloride). By preventing diseases from directly affecting plants, effective chemical application can prolong postharvest life. Consequently, it seems more sensible to prevent pre-harvest infections in order to reduce postharvest losses in horticultural crops (Pathak, 1995). The quality of horticultural crops after harvest is greatly influenced by a number of additional postharvest factors in addition to these preharvest ones. Pre-cooling, sorting and grading, storage, packaging and shipping are a few of these important considerations.

6. BIOTIC STRESSES

Biotic stresses such as insect pests, fungal and bacterial pathogens, nematodes and herbivores can adversely affect fruit and vegetable quality before harvest. *Fusarium*-associated soil-borne disease causes not only yield losses in solanaceous crops, cucurbits but also affect the quality (Dash *et al*., 2021). Pest feeding and pathogen infection may cause physical injury, blemishes and tissue damage, while also modifying phenolic compounds, antioxidants, sugars, organic acids, flavour compounds and cell-wall metabolism**.** Such changes can influence appearance, flavour and texture and may increase susceptibility to post-harvest decay, thereby shortening shelf life. Hence, effective pre-harvest management of pests and diseases is important not only for protecting yield but also for maintaining quality and post-harvest life (Saha *et al.,* 2018; Kumar and Vishwakarma, 2018; Prusky and Romanazzi, 2023).

7. CONCLUSION

Horticultural crops' post-harvest quality and nutritional makeup are significantly impacted by pre-harvest influences. Produce quality degradation starts as soon as it is harvested and lasts until it is consumed. Effective management of the variables affecting product quality is the sole determinant of the success or failure of any business endeavor involving horticulture commodities. Although handling procedures and post-harvest treatment techniques cannot improve food quality, they can successfully preserve it. These pre-harvest variables need to be carefully controlled throughout the production stage in order to guarantee high-quality output. All parties involved, including farmers, laborers and merchants, must receive thorough education about fundamental scientific concepts and proper handling techniques at every stage of the post-harvest chain in order to successfully handle the difficulties presented by factors affecting the post-harvest quality of horticultural products. The post-harvest chain's losses can be considerably decreased by this knowledge sharing. Furthermore, for further development, the proper government laws and regulations must be put into place. There is a lot of promise for improving the post-harvest quality of horticultural crops through more research on human control elements, such as field management techniques, cultivar selection and development.

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