Post-Harvest Management of Ethylene: Maintain Quality of Fresh Produce and Shelf Life Enhancement

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Introduction and Background

Fruits and vegetables (F & V) occupied a special place in the human diet due to their high nutrient values. However, they are highly perishable commodity which together with roots and tuber reported 40-50% of total food waste globally (Pathak, Caleb, Geyer, et al., 2017). The probable causes of such a bulk amount of wastage and lower export are unscientific post-harvest management practices, poor infrastructure, inadequate ethylene management, weak supply chain, and insufficient food policies as well as traders cartel magnify the problems. Further according to an estimate, 10–30% of fresh produce or F & V is wasted due to undesirable ethylene exposure (Pathak, Caleb, Rauh, et al., 2017).

Ethylene is a phytohormone or gaseous plant hormone (odorless) that regulates a variety of physiological functions from seed germination to organ senescence. Ethylene exhibits both beneficial and detrimental effects on postharvest quality and storage life of F & V. Beneficial effects include the development of characteristic color, taste, and flavor of F & V. Conversely, it may cause/induce negative effects even at its low concentration such as increased susceptibility to decay leading to discoloration and softening, and promotion of senescence, all of which reduce the storage life. Thus, to slow down the natural process of ripening and senescence, one inherent cause of 1/3rd fruits waste, ethylene management is essential (Blanke, 2014; Pathak, Caleb, Rauh, et al., 2017). The food supply chain, storage chambers, transportation, and residential freezers are endogenous sources of ethylene production while the external source of ethylene includes motor exhausts, pollution, plant, and fungus metabolism.

The fresh produce is categorized into two groups in terms of ethylene production, that is, climacteric and non-climacteric. Climacteric items, such as fruit, create a burst of ethylene as they ripen, as well as an increase in respiration while non-climacteric products do not release ethylene as they ripen. The more obvious technique to determine which class a product belongs to is to observe whether it ripens after harvest. Climacteric products ripen after harvest and often soften, change colour, and become sweeter. Tomatoes, bananas, and mangoes are some examples of climacteric products that ripen after harvest. Some climacteric fruits, such as muskmelon, will soften rather than increase sugar content during ripening. After harvest, non-climacteric fruits do not alter appreciably. As they age, they soften slightly, lose their green colour, and develop rots, but they do not modify their eating features. Leafy vegetables, melons, strawberries, and grapes are examples of non-climacteric crops. Non-climacteric fruits will not respond to ripen with ethylene gas. Nevertheless, F & V should be stored separately since fruits release relatively more ethylene than vegetables that can spoil ethylene sensitive vegetables such as cabbage, cauliflower, cucumber lettuce and others. Even with a minimal change in ethylene concentration in the supply chain of F & V the shelf life and quality affect significantly.

In view of the present global challenge of minimizing post-harvest losses and waste of fresh produce, the significance of ethylene management in the supply chain is paramount. Nevertheless, the quality needs to be maintained for a longer period/higher postharvest storage life such that it stabilizes the market price along with better economic returns to farmers, processors, consumers and exporters.

Ethylene Management Methods

The traditional ethylene management methods such as controlled atmospheric storage, hypobaric storage, ventilated polybags, high-temperature catalytic oxidation, ethylene absorbers, ethylene adsorbers, ethylene inhibitors, venting by air, and application of biofilters were reported to be effective in maintaining post-harvest quality and enhancing the shelf life of fresh produce. Ethylene adsorbers such as clays, zeolite, activated carbon, etc. and ethylene oxidizers either chemical (potassium permanganate and ozone) or biological (biofilters) are used to remove the excess ethylene from the environment. Inhibition of ethylene by blocking the ethylene receptors using 1-methyl cyclopropene (1-MCP) was proclaimed most effective in maintaining the post-harvest quality of fresh produce. However, such traditional ethylene management methods pose some limitations/drawbacks such as high energy requirement, high initial capital and operational cost, challenge of waste disposal, require long exposure time and lower effectiveness in ethylene removal (Hussain et al., 2010; Jozwiak, 2003; Pathak, Caleb, Rauh, et al., 2017). Adsorption-desorbing devices and (or) gas processing units may be used to recover excess ethylene; however, the cost involved may be higher than the commercial production of ethylene. Conversely, advanced techniques based on photocatalytic and photochemical oxidation of ethylene offer an alternative approach that could aid in reducing some of these critical drawbacks.

The photocatalytic and photochemical oxidation techniques comprise the use of ultraviolet (UV) radiation with or without a catalyst. In photocatalytic oxidation, a catalyst primarily a semiconductor such as TiO2, ZnO, ZnS, CdS, Fe2O3, and SnO2 is essential which acts as a photocatalyst on irradiation with UV light (generally 200–380 nm catalyst dependent) and thus facilitates the oxidation of ethylene at its surface (Pathak, Caleb, Rauh, et al., 2017). TiO2 is the most popular among the catalyst due to its high stability, biological and chemical inertness, high ultraviolet absorption, and low cost (Hussain et al., 2010; Yang et al., 2007). However, in photochemical oxidation, extreme short wave (< 200 nm) vacuum ultraviolet radiation (VUV) consisting of high-energy photons eliminates ethylene in the gaseous state (Jozwiak, 2003). These methods have been extensively researched for air and water purification (Chang et al., 2013; Pathak, Caleb, Rauh, et al., 2017; Yang et al., 2007). Nevertheless, limited attention has been given to these potential techniques in postharvest storage of F&V (Hussain et al., 2010; Jozwiak, 2003; Pathak, Caleb, Rauh, et al., 2017).

Both photocatalytic and photochemical oxidation possess certain limitations individually such as photocatalytic oxidation suffer from catalyst deactivation and lower efficiency, especially under high humidity conditions. High humidity is essential in the storage of fresh produce to minimize mass loss (Rais & Sheoran, 2015). Although VUV photochemical oxidation is more effective at high RH, O3 is produced in the process, which could be toxic to plant tissues. Moreover, in the VUV process, only a small part (5–8 %) of the irradiation corresponding to 185 nm is utilized, and the rest is wasted (Pathak, Caleb, Rauh, et al., 2017). In the commercial market, ozone-producing UV lamps (UV254 + 185) with major emissions at 254 nm and minor emissions (~5 %) at 185 nm are available. The hybrid technique via coupling of VUV photochemical oxidation with UV/TiO2 photocatalytic oxidation can help in addressing these shortcomings.

The general focus of clubbed photocatalytic and photochemical oxidation studies has been on the removal of air pollutants such as toluene, formaldehyde, and benzene (Cassano et al., 1995; Hussain et al., 2010; Yang et al., 2007). Chang et al., 2013 has reported ethylene and selected organic aerosol removal by this method under atmospheric conditions. However, practical application of clubbed photocatalytic and photochemical oxidation of ethylene considering real-life storage conditions of F&V (temperature and humidity dependent) has not been reported. Nevertheless, limited studies are available on positive results on ethylene removal by both these techniques individually (Cassano et al., 1995; Hussain et al., 2010; Jozwiak, 2003; Pathak, Caleb, Rauh, et al., 2017).

Future Prospects

A combination of traditional and novel ethylene management methods may aid in the development of residual free and environmentally friendly management of ethylene in the fresh produce supply chain. In the future, mathematical and numerical models may be developed as a function of ethylene concentration and ethylene sensitivity of F & V to predict their shelf life and quality in components of the supply chain.

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