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1-MCP and Methyl jasmonateas an alternative to 6-BAP for enhance postharvest shelf life of commercial vegetables in ecofriendly and economical manner

Meenakshi Kumari, Manoj Kumar, SS Solankey, Deepak Baboo and Mayank Shekhar Singh

Meenakshi Kumari
Department of Vegetable Science, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur, Uttar Pradesh, India

Manoj Kumar
Division of Vegetable Science, Indian Institute of Horticultural research (An Outreach Campus of IARI-New Delhi), Banglore, Karnataka, India

SS Solankey
Department of Horticulture (Vegetable & Floriculture), Dr. Kalam Agricultural College, Kishanganj, Bihar Agricultural University, Sabour (Bhagalpur), Bihar, India.

Deepak Baboo
Department of Plant pathology, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur, Uttar Pradesh, India

Mayank Shekhar Singh
Genetics and Plant Breeding, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur, Uttar Pradesh, India

Correspondence
Meenakshi Kumari
Department of Vegetable Science, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur, Uttar Pradesh, India

Abstract

Vegetables are highly perishable in nature due to higher moisture content and faster respiration rate. In India, nearly 30-35% of its total production is deteriorate due to improper and poor postharvest handling. The physiological and biochemical processes, microbial decay, high perishability and sub-standard postharvest handling infrastructures are the major factors responsible for postharvest losses. For this reason, practices like proper handling, pre-cooling, washing and disinfection can be adopted before storage to check the postharvest losses. Few chemicals such as sodium hypochlorite, hydrogen peroxide, acetic acid are used for disinfection. However, hot water treatment can be an effective way of disinfection in organic vegetables for pathogen suppression. While, irradiation has been used as an effective means of maintaining colour, firmness, and other quality. Use of edible coating has been effective for maintaining quality and shelf life in pointed gourd. Other than these, reduction in physiological weight loss, delay senescence, maintains chloroplast activity, declines chlorophyll degradation can be possible by application of various plant growth regulators such as 1-MCP, 6-BAP MeJA, $CaCl_2$ and $KMnO_4$ as reported beneficial in many vegetables. Among these, 1-MCP and Methyl jasmonate can be suggested as alternative to 6-BAP for increasing the shelf life of most the vegetables in eco-friendly and economical way. By popularizing this among the farming community we can effectively reduce the postharvest losses in vegetable of about 35% every year which can play a significant role in enhancing farm income and also mitigate the hidden hunger of poor populations.

Keywords: Postharvest, shelf life, 1-MCP, MeJA, perishable vegetables.

Introduction

Vegetables are rich sources of vitamins and minerals in human diet. India is the second largest producer of vegetables in the world, next to China with an area of 9.57 million hectares and production 182.00 million metric tons with total productivity of 19.02 MT/ha (Anonymous, 2017) [4]. So far in India, more than 60 different types of vegetables are grown due to its diverse soil and climatic conditions like tropical, subtropical and temperate which places it at prime position among the countries with largest diversely grown vegetables. The employment generation, income and nutritional security of country depends on agricultural production like fruits and vegetables (Ali, 2004). The combined annual production of fruits and vegetables in India is likely to cross 377 million tonnes (MT) mark by 2021 from the current level of over 305 MT. Among states Bihar is the 3rd largest producer of vegetable. It produces 16.32 million metric tons in an area of 0.857 million hectares with productivity of 18.60 MT/ ha (Anonymous, 2015) [3]. Post-harvest loss of fruits and vegetables has been defined as "that weight of wholesome edible product (exclusive of moisture content) that is normally consumed by human and that has been separated from the medium and sites of its immediate growth and production by deliberate human action with the intention of using it for human feeding but which for any reasons fails to be consumed by human." The measurable qualitative and quantitative food loss along the supply chain, starting at the time of harvest till its consumption or other end uses also known as postharvest food loss (Hodges *et al*., 2011) [10].

Developed countries have significant losses at consumption stage, whereas in developing countries it occurs at early and middle stages of the supply chain (FAO, 2011) [8]. Statistical data are meager to indicate the magnitude of postharvest losses of vegetables in India. The major cause of vegetable spoilage is poor post-harvest practices which contributes nearly 30-35 per cent of the total vegetables, and shares about 908 million dollars of the total post-harvest economic losses (6,830 million dollar) (CIPHET, 2010) [7]. A study was conducted to examined the nature and extent of post-harvest losses in vegetable supply chain in Uttarakhand and reported the post-harvest losses of about 6-23 per cent of production for all vegetable at producer and retails level. The study has suggested that one possible solution to tackle these problems could be the establishment of producer co-operatives to handle various activities relating to production and marketing of vegetables (Sharma and Singh, 2011) [22]. A report on processed product given by Rahul *et al*. (2015) [19] shows that India contributes only less than 2% of the total vegetable production in processing industry as compare to 70% in Brazil and 65% in the USA. The presence of high moisture (60-95%) leads to more perishability which ultimately hasten the microbial population and physiological and biochemical activity.

The post-harvest life of a produce mainly depends on reserved food in plant organ and its rate of consumption. Anything that increases the rate of consumption of reserved material and moisture loss may make the produce inedible before it can be used. Numerous biochemical processes continuously change the original composition of the crop until it becomes unmarketable. The most important goals of postharvest handling are slow down the metabolic activity of produce by adopting different techniques such as cooling of produce, reduce moisture loss, slow down undesirable chemical changes, and avoiding physical damage such as bruising, to delay spoilage. These are affected by a number of factors leading to the postharvest spoilage. Besides, packaging, grading and transportation many factors contribute to these losses. Prevention of such losses is most important to make available quality vegetable. Harvested products are metabolically active, undergoing ripening and senescence processes that must be controlled to prolong postharvest quality. Inadequate management of these processes can result in major losses in nutritional and quality attributes, outbreaks of food borne pathogens and financial loss for all players along the supply chain, from growers to consumers. Optimal postharvest treatments for fresh produce seek to slow down physiological processes of senescence and maturation, reduce/ inhibit development of physiological disorders and minimize the risk of microbial growth and contamination can be used to maintain quality, reduce losses and waste of fresh produce.

The parameters like respiration, transpiration, ethylene production, ripening and senescence regulates the metabolic activity of any produce. Hence, to reduce the post-harvest losses we should adopt the suitable and reasonable practices *i.e.* physical, chemical and gaseous treatments to hold back these parameters. Respiration, involving enzymatic oxidation of organic substrates with energy production resulting in O_2 consumption and CO_2 and water production. Higher respiration rate related with reduced storage life because the produce is detached from its source of photosynthates (Wu, 2010) [30]. Transpirationis a term related to weight loss by reduction in total water content of cell. The rate of water loss via transpiration usually differs among intact plants and harvested products.

Ethylene production is taken place is minute quantity when produce is attached with plant. It is a small hydrocarbon gas occur naturally as well as a result of combustion and other processes. Ethylene will cause a wide range of effects in plants, depending on the age of the plant and how sensitive the plant is to ethylene. It can be produced when plants are injured, either mechanically or by disease and also detached plant parts in higher quantity. Hence, it has both beneficial and harmful effect on plant depends on stage of production (Blankenship, 2001). The enzymatic reactions like conversion of methionine to S- adenosyl- L-methionine (S-AdoMet) by S-AdoMet synthetase; the conversion of S-AdoMet to 1-aminocyclopropane- 1- carboxylic acid (ACC), is the rate limiting step catalysed by ACC synthase (ACS) in this pathway ACC oxidase (ACO) degrades ACC to release ethylene (Wu, 2010) [30].

Ripening is a developmental phase spanning from the last stage of maturation through the earliest stage of senescence in fleshy fruit and is commonly observed in many fruit products after harvest. It is widely accepted that ripening is a senescence process, due to breaking down of the cellular integrity of the tissue. Several biochemical and physiological events involving in change of colour, firmness, flavor and aroma take place in this transitional period, which results in the transformation of unripe fruits into ripe product. Senescenceis related to aging and ultimately death of plant tissue. It is a biochemical process in which anabolic process gives way to catabolic process. Development and maturation of fruit are completely only when it is attached to the plant, but ripening and senescence may produce on or off the plant. Once harvested, vegetables are subject to the active process of senescence.

These are some process occurred during senescence like oxidative stress, reactive oxygen species (ROS) production, lipid peroxidation, firmness loss, membrane permeability and microbial infections etc. Oxidative stress is the disruption of critical balance due to excess of ROS, reduction in antioxidants, or both. The environmental perturbations (extreme temperature, drought and flooding, salinity, ozone exposure, UV irradiation, heavy metal toxicity, herbicides, and environmental pollutants) enhance the ROS production in the plant or plant organs. If ROS production exceeds the antioxidant capacity of the tissue, it causes oxidative damage to the cell, which ultimately leads to cell death (Apel and Hirt, 2004) [5].

ROS production occur due to excitation of O_2 to form singlet oxygen or transfer of one, two, or three electrons to O_2 to form, respectively, superoxide (O_2^-), hydrogen peroxide (H_2O_2) or hydroxyl radical (OH). Both O_2^- and OH are extremely reactive and can cause oxidative injury leading to cell death. The average life span of these ROS varies from nanoseconds (e.g., OH) to milliseconds (e.g., O_2^-, H_2O_2). The OH can also be generated by the interaction of O_2^- and H_2O_2 in the presence of transition metal ions, i.e. called as "Haber-Weiss reaction" (Singh, 2015) [25]. The concentration of ROS in the cell is an important factor in determining their role as beneficial molecules in various signal transduction processes or in causing oxidative damage (Suzuki and Mittler, 2006) [27]. ROS has the ability to initiate cascade reactions and their products and intermediates result in damage to the lipids, proteins, and DNA. Therefore, the level of ROS is regulated by scavenging them to avoid accumulation to toxic levels in the cell. The scavenging mechanism of these ROS is also as complex and diverse as their generation sites. It involves both enzymatic and non-enzymatic antioxidant systems to act cooperatively to mitigate the ROS levels (Hodges *et al*., 2011) [10].

Lipid peroxidation is class of fatty acids or their derivatives that are insoluble in water and include many natural oils, waxes etc. Peroxidative products increase during plant senescence (Wismer *et al*., 1998) [29] and in hypersensitive response to microbial attack (Beckman and Ingram, 1994). Whether the accumulation of these products is a cause or an effect of deterioration is not clear (Shewfelt and Purvis, 1995) [23]. Both nonenzymic and enzymic defense compounds exist to prevent peroxidation or limit adverse effects. Antioxidants such as β-carotene, lycopene, and α-tocopherol, as well as reducing agents such as ascorbic acid and glutathione, help limit peroxidative damage. Enzymes important in protecting membranes from lipid peroxidation include catalase, peroxidase, and superoxide dismutase. Failure of a critical enzyme within a specific membrane would lead to metabolic imbalances within the cell manifested at the tissue level as visible symptoms of a disorder (Shewfelt and Rosario, 2000) [24]. Firmness loss it is a visual representation of texture in fruits and vegetables. The metabolic processes such as respiration and transpiration play a major role in the loss of firmness during storage which influences the quality and susceptibility of the produce. Membrane permeability includes cell membrane which plays a vital role in plants in response to chilling and freezing injury. It is determined by ion or electrolytic leakage from cells. Microbial infection is mainly influenced by increase in membrane permeability and lipid peroxidation which ultimately decrease shelf life and quality of the produce.

1. Ethylene inhibiting treatments

a. 1-Methylcyclopropene (1-MCP)

A new exciting strategy for controlling ethylene production which responsible for ripening and senescence of fruit and vegetable especially climacteric ones, as well as senescence of vegetative tissues, has emerged with the discovery of the inhibitor of ethylene perception, 1-methylcyclopropene (1-MCP). 1- MCP is thought to interact with ethylene receptors and thereby prevent ethylene dependent response (Rajapae and Beneragama, 2016) [20]. The use of cyclopropenes to inhibit ethylene action was patented by Sisler and Blankenship (1996). A commercial break through in 1- MCP application technology resulted from the formulation of 1-MCP as a stable power in which it is complexed with γ-cyclodextrin, so that 1- MCP is easily released as a gas when powder is dissolved in water. 1-MCP is ethylene action inhibitor and proved to be extremely active, but unstable in the liquid phase. However, 1MCP can be complexed with *α*- cyclodextrin to maintain its stability (Mahajan *et al*., 2015) [17]. Huang *et al.* (2012) [12] investigate the effects of 1-MCP on chilling injury disorders and quality maintenance of harvested okra fruits during storage at low temperature. Okra fruits were treated with 1 or 5 µl L/1, 1-MCP for 16 hrs before storage for 18 days at 7°C. Application of 1-MCP significantly alleviated the development of chilling injury disorders such as browning and pitting in okra pods in a concentration dependent pattern, which was associated with lower membrane permeability and lipid peroxidation. The findings revealed that okra fruits treated with 5µl/L significantly reduces chilling injury, inhibit loss of membrane integrity and also inhibit lipid peroxidation. Another study conducted by Anbarasan and Tamilmani (2013) [2], kept bitter gourd fruits in the laboratory naturally while the experimental fruits were treated with 1-MCP in different time intervals (6-hrs, 12 hrs and 24 hrs). The control fruit and the fruit treated with 1-MCP in 6 hrs and 24 hrs ripened on 7th day and the fruit treated in 12 hrs ripened on 9th day. The colour of the fruit changed from green to yellow, finally orange and the detached fruit became over ripened and the pericarp got split into many valves after 9th day of storage. Hu *et al*., (2017) [11] mentioned in their review paper that preservation function of fruit and vegetable can be imparted by introducing 1-MCP into paper products as 1-MCP acts as ethylene inhibitor.

Table 1: Effect of 1-MCP treatment on important commercial vegetables

S.No.	Vegetable	Storage period (Days) and Temperature (ºC)	Doses	Best result	References
1.	Tomato	21 d at 10º C 28d at 12°C	1 µL/L for 24 h at 20°C 1 µL/L at 12°C	1 µL/l reduces weight loss Increases TA Maintain surface colour Delay Senescence Retard chlorophyll degradation and lycopene formation in the pericarp tissue	Sabir *et al*., 2012 [21] Lee *et al*., 2010 [16]
2.	Egg Plant	21 d at 10º C	1 µL/L for12 h at 20°C	Delay Senescence Prevent browning Decease weight loss	Massolo *et al*., 2011 [18]
3.	Okra	18 d at 7º C	1 or 5 µl /L for 16 h	5 µl /L reduces chilling injury Inhibit loss of membrane integrity Inhibit lipid peroxidation	Huang *et al*., 2012 [12]
4.	Bitter gourd	30 d at 28º C ± 2 90 d at 28º C ± 2	0.5 µl/ L for 24 h at 20º C 1000 ppb	Increase shelf life Increase TSS	Anbarasan and Tamilmani (2013) [2]
5.	Broccoli	7 d at 10, 20 and 30 ºC 5d at 20º C	1 ppm for 24 h at 20ºC	Reduced respiration rate Reduced yellowing	Yasunaga and Uchino (2012) [31]
6.	Tomato	31-42 d at room temperature	0.6 µL/ L- for 12 h	Reduced incidence of Alternaria rot Reduced post-harvest decay within a certain storage period	Su and Gubler (2012) [26]
7.	Squash	21d at 8-10º C	0.5 µl/ L for 12 h at 20º C	Reduced the production of CO_2 and softening of squash for 3 weeks	Lee *et al*., 2006 [15]
8.	*Cucumis melo* L. cv. Hetao	6d at 20º C	100 and 300 nl/litre for 18 h	Inhibited ethylene production and respiration rate Reduced the activities of polygalacturonase	Yu Mei *et al*., 2008

				and galactosidase	[32]
9.	Chinese kale	7d at 20º C	0 & 10 µl l/1 for 24 h	extended shelf life, delayed weight loss,decreased the rate of softening, Chlorophyll degradation and changes in hue angle , reduced the loss of health promoting compound.	Bo *et al.*, 2012 [6]
10.	Sessile joyweed (leafy vegetable)	1 d at room temperature	1-MCP at 5 ppm for 8 hr	Extended shelf life for one day. Avoid yellowing of leaf	Rajapae and Beneragama, 2016 [20]

Methyl jasmonate- Methyl jasmonate (abbreviated MeJA) is a volatile organic compound used in plant defense and many diverse developmental pathways such as seed germination, root growth, flowering, fruit ripening, and senescence. Methyl jasmonate is derived from jasmonic acid and the reaction is catalyzed by S-adenosyl L-methionine: jasmonic acid carboxyl methyl transferase. Plants produce jasmonic acid and methyl jasmonate in response to many biotic and abiotic stresses (in particular, herbivory and wounding), which build up in the damaged parts of the plant. The methyl jasmonate can be used to signal the original plant's defense systems or it can be spread by physical contact or through the air to produce a defensive reaction in unharmed plants. In a study conducted by Ku *et al*. (2013) [14] on cauliflower curds and he reported that cauliflower curds treated with methyl jasmonate showed significantly higher quinone reductase activity, a biomarker for anticancer bioactivity, without reducing visual colour and postharvest quality for 10 days at 4°C storage. In this study cauliflower curds were treated with 500 µM MeJA solutions four days prior to harvest, then stored at 4°C. Tissue sub samples were collected after 0, 10, 20, and 30 days of postharvest storage and assayed for visual colour change, ethylene production, glucosinates (GS) concentrations, and extract quinone reductase inductive activity. MeJA treatment increased curd GS concentrations of glucoraphanin, glucobrassicin, and neoglucobrassicin by 1.5, 2.4, and 4.6-fold over controls, respectivelyafter 10 days storage at 4°C.

Another study conducted by Tzortzakis *et al.* (2007) [28] reported that fruit treated with Methyl jasmonate vapours reduced fungal spore germination/ production and 44.8 µl/l methyl jasmonate also suppressed incidence of anthracnose rot in tomato in comparison to the tomato fruits treated with chlorine (48 ml l^{-1}) and stored at 12°C and 95% relative humidity.

Table 2: Effect of Methyl Jasmonate treatment on important commercial vegetables

S. No.	**Vegetable**	**Storage period (Days) and Temperature (º C)**	**Doses**	**Best result**	**References**
1.	Cauliflower	0, 10, 20 & 30 d at 4º C	500 ppm	10 days, increases GS concentration Higher quinone reductase activity	Ku *et al*., 2013 [14]
2.	Broccoli	10 d at 4º C	1- MCP@ 500 ppb for 24 h, MeJA @ 500ppb, MeJA and 500 ppb 1MCP for 24 h	500 ppb MeJA, Increases GS concentration	Ku *et al*., 2015 [13]
3.	Tomato	7 d at 12º C	44.8 µl/l Meja and 48 ml/L	44.8 µl/l, Suppress incidence of anthracnose rot	Tzortzakis, 2007 [28]
4.	Fresh-Cut Celery and Peppers	2 Weeks at 10º C	10_{-4} or 10_{-5} mol/L Meja	10_{-4} or 10_{-5} mol/L retarded deterioration of celery sticks Decreased microbial growth. Prolonged storage life number of bacterial colonies was reduced to 1/1000 of control also after 1 week of storage	Buta and Moline,1998 [9]

Conclusion

It is evident that vegetables being highly perishable in nature, which needs proper pre and post-harvest handling and management to increase their shelf life. The postharvest life depends on the rate at which they utilize their stored food reserves and their rate of water loss. There are various postharvest treatment like physical treatments (hot water treatment, radiation), ethylene inhibiting treatments ($KMNO_4$, 1-MCP), anti-senescence treatments PGRs (like 6-BAP), transpiration inhibiting treatment (waxing), $CaCl_2$ and Methyl jasmonate can effectively increase shelf life of vegetables. There is ample scope to work on the postharvest treatments of vegetables. In broccoli quality was affected with increase in the senescence process which includes various processes. The undesirable changes were delayed by treating broccoli with 1-MCP which showed similar response using 6-BAP in case of cauliflower.

Last but not the least the maintenance of quality characteristics such as physical appearance, flavor and taste profile is very much important to get the required market value. This will in turn to helpful for enhancing the per capita availability of vegetables which also includes application of intensive and modern technologies. The reduction in losses will ultimately increase the availability of commodities without applying extra resources for enhancing the production and productivity to feed the millions of hungry people.

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