



# Effect of Pre-harvest and Post-harvest Hexanal Treatments on Fruits and Vegetables: A Review

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## ABSTRACT

The membrane degradation process associated with ripening and senescence of fruit is accelerated by the enzyme phospholipase D (PLD). Hexanal is a compound with high potential to inhibit phospholipase-D enzyme, which is naturally secreted from plants and also promotes the shelf-life extension of fruits during its storage. Pre-harvest hexanal application as enhanced freshness formulation helps to reduce fruit decay and other post-harvest disease by preventing the microbial growth especially mold growth. Post-harvest application of hexanal in the forms of vapour or liquid and nano emulsion for dip treatment, etc. results in improved fruit quality with better colour firmness along with other improved biochemical qualities. The cell wall degrading enzymes such as PLD, PME (Pectin methyl esterase) suppressed after hexanal treatment, whereas accelerated the antioxidant enzymes activities. The hexanal can be used as a potential compound for the preservation and post-harvest storage of perishables with better quality and safety.

**Key words:** Hexanal, Phospholipase-D (PLD), Pectin methyl esterases (PME).

Vegetables and fruits add important supplements to human diet as they provide essential minerals, nutrients including thiamine, vitamin C, vitamin K, foliate, carotene, antioxidant phyto-compounds and dietary fibre required for maintaining health. Fruits are very much vulnerable to quantitative and qualitative losses, encompassing microbial, sensorial and nutritional. Major losses occur due to chilling injury, rapid maturation and fungal decay that enhance the process of senescence (Chan and Tian, 2006). Hence, fruits and vegetables are highly perishable commodities. Globally, post-harvest losses in vegetables and fruits vary from 35% to 60% of production (Gustavsson *et al.*, 2011). This represents one of the most alarming wastage scenarios among all the agricultural product categories. In developing countries, the majority of the losses occur during the post-harvest and distribution phases because of the deterioration in the quality of the produce and also due to seasonality resulting in unsalable gluts. Therefore, to preserve the quality of fresh produce, several postharvest treatments have been developed, including modified and controlled atmospheres, heat treatments, edible coatings, preservation by chemical and natural preservatives (Zhang *et al.*, 2009).

Among different natural compounds used hexanal is being popular and found efficient in improving postharvest storage qualities of fruits and vegetables. Hexanal is a naturally occurring compound found in all vegetables and fruits. FDA has recommended hexanal as a GRAS compound hence it has no adverse health effects and is safe for human use. Hexanal can be used for both pre-harvest and postharvest applications in fruits and vegetables to reduce lossage. The pre harvest application of hexanal has reported a significant reduction in fruit decay along with the retention of quality characteristics. The treatment of hexanal provides enhanced storage life along with the suppressed microbial attack.

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## Properties of hexanal

Hexanal is an alkylaldehyde with molecular weight 100.158g mol<sup>-1</sup>. The melting point and boiling point of hexanal are 20°C and 130-131°C respectively. The constant pressure heat capacity of hexanal is 210.4 Jmol<sup>-1</sup> K<sup>-1</sup> at 28.5° K (Vasilev *et al.*, 1991).

Hexanal is a natural chemical compound of C6 aldehyde which is volatile in nature. It is secreted by plant through the lipoxygenase pathway due to the disruption of tissues (Vick and Zimmerman, 1987). These are the main volatile compounds in many of the vegetables and fruits. Plant volatiles have been widely used as food flavouring agents (Newberne *et al.*, 2000). Hexanal is processed by oxidative degradation of fatty acids and contributes to the "green" taste of many vegetables and fruit varieties (Croteau, 1978). Hexanal has been approved as a food additive by the US Food and Drug Administration (FDA) (Song *et al.*, 1996) and now commercial products containing hexanal as an active ingredient for improving shelf life is available.

Paliyath *et al.* (2008) reported that hexanal has been observed to be a strong hindrance to PLD action and various technologies for its application on fruits, vegetables and flowers is under developing stage for enhancing shelf life and quality. The process of degradation of membrane is commenced by the activity of phospholipase D (PLD) during ripening and reactive oxygen species (ROS) produced during enzymatic processes and stress conditions enhances the senescence. Hexanal can also act as an ethylene inhibitor such that it has found that hexanal treatment significantly down-regulated ACC-synthase and to a lesser extent, other components of ethylene signal transduction (Tiwari *et al.*, 2011).

### Phospholipase D inhibition by Hexanal

A series of catabolic cascades is initiated by the key enzyme phospholipase D that lead to the gradual deterioration of the membrane, which is a part of the development of organoleptic quality of the fruits during ripening. However, uncontrolled progression of lipid degradation can reduce the life of fruits and vegetables.

In response to hormones and external stimuli Phospholipase D is believed to become bound to the membrane which initiates a group of catabolic reactions leading to the production of numerous neutral lipids, building up in to the destabilization of the membrane (Paliyath and Droillard, 1992). In general, enzymes such as phosphatidate phosphatase, lipolytic acyl hydrolase, lipoxigenase that act on intermediates generated during this catabolic cascade do not directly act as structural phospholipids. The activity of phospholipase D is also stimulated by calcium and low pH. Thus, if the action of phospholipase D is inhibited, then the rest of enzymes are unable to act on the intermediates. This would prevent the accumulation of neutral lipids and the destabilization of the membranes. Theoretically, this should preserve or enhance the stability and function of the membrane increasing the longevity of produce (Paliyath, 2008).

### Hexanal treatments for fruits and vegetables

#### Post-harvest disease control

Due to the controlled number of registered fungicides and fungicide resistance, the postharvest disease control has become more tedious. It has been reported that hexanal, is capable of reducing post-harvest diseases (Song *et al.*, 2010).

Hexanal vapour treatment reduced snow mold rot on Anjoru pears. Gardini *et al.* (1997) explained that with rise in temperature, there is an increase in vapour pressure, which account for its antifungal activity. Compared to the other decay-causing fungi, the snow-mold fungus appeared to be more sensitive to the vapour pressure of hexanal. *P. expansum* appeared to be stimulated by the application of hexanal.

Consumers demand for blemish-free, high-quality product free of fungicidal residues Alternatives to chemical

fungicides have been found to reduce the losses resulting from postharvest decay. (E)-2-hexenal is such an alternative having potential to hinder the growth of postharvest microbes and reduce postharvest diseases (Fallik, 1996 and Gardini *et al.*, 1997). It was reported that hexanal vapour inhibited the fungal growth and enhanced the aroma biosynthesis in apple slices and whole apple fruit (Song *et al.*, 1996; Lanciotti *et al.*, 1999 and Fan *et al.*, 2006).

Some fungi produce a range of cutin and cell-wall degrading enzymes that is capable of going deep into the cells and they may also use the degraded products as a nutrient source. These may include cellulases, poly galacturonases (PGs), pectin methyl esterases (PMEs) and cutinases. Thavong *et al.* (2010a) reported that hexanal is capable of altering expression, translation and/or secretion of these enzymes and may interact directly with the enzymes, to change their activities.

Utto *et al.* (2008) studied postharvest microbiological, physiological and quality attributes of control and hexanal vapour treated tomatoes during storage for 7 days at 20±1°C. They reported that continuous hexanal exposure of minimum inhibitory concentration (MIC) 40–70µLL<sup>-1</sup> effectively suppressed grey mould and there was no clarity in the trend observed in ethylene production, also the treated fruit and controls exhibited same firmness or mass loss.

Thavong *et al.* (2010b) studied the effect of hexanal vapour concentration and time of concentration on spore germination and mycelial growth of common decay causing fungi including *L. theobromae* in longan fruit. The *L. theobromae* was completely suppressed at 15µL hexanal for 1 h fumigation whereas spore germination was inhibited at 5µL hexanal per dish. Extracellular enzymes were not affected by hexanal treatment except cellulase, the activity of cellulase reduced to more than 80%.

Peaches were exposed to hexanal vapour for studying the *in vitro* development of *M. laxa* and *Monilinia fructicola* of brown rot. It was found that hexanal was effective in preventing the mycelial growth during the stage of pathogen transfer and completely inhibited the production of spores. It was also reported that hexanal did not inhibit the infection of the pathogen, but it could reduce the lesion diameter (Baggio *et al.*, 2014).

Zhang *et al.* (2018) reported that the application of hexanal at sub MIC (minimum inhibition concentration) levels significantly inhibited soft rot on Chinese cabbage and leaf scorch on lettuce leaves without any phyto toxic effect. The best inhibitory concentration was recognized as 1/2 MIC and hexanal could also decrease the activity of extracellular enzymes produced by *Erwinia carotovora* and *Pseudomonas fluorescens*. This inhibitory action hexanal in extracellular enzyme activity was due to the inhibition of related gene expression.

#### Post-harvest shelf life extension

External application of hexanal volatile aldehyde, hexanal in the form of formulation is reported to extend the shelf life

**Table 1:** Effect of hexanal treatment on post-harvest disease control.

Fruit / Vegetable	Post-harvest disease	Hexanal treatment	Result	Author
Apple slices	<i>Penicillium expansum</i> and <i>Botrytis cinerea</i>	4.1 mmol·L <sup>-1</sup> (100 ppm) hexanal for 48 hours	50% reduction in growth of both fungi hyphae compared to untreated controls	Song <i>et al.</i> (1996)
Fresh-Sliced Apples	<i>Escherichia coli</i> , <i>Salmonella enteritidis</i> and <i>Listeria monocytogenes</i>	150,150 and 20 ppm for hexanal, hexyl acetate and (E)-2-hexenal, respectively	<ul style="list-style-type: none"> <li>➤ Inhibitory effect against pathogen microorganisms</li> <li>➤ Bactericide effect on <i>L. monocytogenes</i> significantly extended lag phase of <i>E. coli</i> and <i>S. enteritidis</i></li> </ul>	Lanciotti <i>et al.</i> (2003)
Fruits	Fungal species	0, 200, 450, or 900 µL/L hexanal for 6, 12, or 24 h at 7 or 20°C.	Hindered fungal spore germination and mycelial growth	Song <i>et al.</i> (2007)
Anjou' Pears and Apples	blue and gray mold decay incited by <i>Penicillium expansum</i> and <i>Botrytis cinerea</i>	2 mgL <sup>-1</sup> for 24 hours or 4 mgL <sup>-1</sup> for 18 hours	<ul style="list-style-type: none"> <li>➤ Inactivated conidia of <i>B. cinerea</i> in the pear surface</li> <li>➤ Reduced blue mold decay to low levels at 15. 8°C.</li> </ul>	Sholberg and Randall, (2007)
Longan Fruit	Fruit decay	hexanal vapor for 2 h at 900 µL·L <sup>-1</sup> at 5, 30, or 40°C 8 d and at 5°C for 30 d	<ul style="list-style-type: none"> <li>➤ Treatment at 5 and 30°C reduced fruit decay</li> <li>➤ Treatment at 40°C was not effective</li> </ul>	Thavong, <i>et al.</i> (2010a)
Longan	Four common longan fruit decay fungi, <i>Lasiodiplodia theobromae</i> ;	1 h with 15 µL hexanal per Petri dish	Suppressed <i>L. theobromae</i> Spore germination was inhibited	Thavong <i>et al.</i> (2010b)
Blueberry fruit	Fruit decay	5 µL per dish for only 1 h, 900 mL L <sup>-1</sup> for 24 h (10-12 kPa O <sub>2</sub> and 12-15 kPa CO <sub>2</sub> ) at 0.58°C	50-70% reduction in fruit decay	Song <i>et al.</i> , (2010)
Peach	Brown rot, caused by <i>Monilinia</i> spp.,	215 µL of liquid hexanal	Inhibited mycelial growth during pathogen transfer	Baggio, <i>et al.</i> (2013)
Chinese Cabbage and Lettuce	<i>Erwinia carotovora</i> and <i>Pseudomonas fluorescens</i> .	0, 1/10MIC, 1/5MIC, and 1/2 MIC	<ul style="list-style-type: none"> <li>➤ Chinese cabbage soft rot and lettuce leaf scorch were significantly inhibited</li> <li>➤ Inhibited the activities of extracellular enzymes</li> </ul>	Zhang <i>et al.</i> (2018)

of fruits and vegetables (Sharma *et al.*, 2010). They are also important precursors for the formation of 6 carbon alcohols and 6 carbon esters which are among the most abundant volatile compounds in apple, pears and bananas and contribute to typical fruity odours (Paillard, 1986).

Geetha *et al.*, (2015) reported that the shelf life of the mangoes exposed to hexanal vapour was found to be more than 21 days under both (atmospheric and cold) storage conditions for cultivars, both *Bangalora* and *Banganapalli*, whereas control mango had a shelf life of 14 days under cold storage conditions and only 10 days under atmospheric storage.

Hexanal application in many fruits and vegetables showed improvement in quality and shelf life of the product. It has been observed to be a strong hindrance to PLD action

and currently, different technologies for enhancing the shelf life of fruits and vegetables are under development (Paliyath *et al.*, 1999, 2003; Paliyath and Murr, 2007; Paliyath and Subramanian, 2008).

Hexanal can be applied as pre harvest spray in fruits while they are in tree, whereas hexanal dip treatment and vapour treatment can be applied as post-harvest treatments. Among this hexanal vapour treatment is found to be more popular compared to other methods of application. The pre-harvest sprays of hexanal EFF (0.015% hexanal) on guava before 2-4 weeks of harvest showed retention in fruit quality attributes up to 28 days during cold storage at 6-8°C and 90-95% relative humidity (Gill *et al.*, 2015). Pre-harvest spray with 1 mM hexanal twice a week on greenhouse tomatoes showed

higher levels of ascorbic acid and soluble solids in fruit than those subjected to EFF treatment (Cheema *et al.*, 2014).

A colour contrast from purple red in control fruits to a bright red colour was seen in fruits from the EFF (2% EFF) sprayed sweat cherry trees at the time of harvest. However, during storage the EFF sprayed fruits also developed the purple red colour characteristic of 'Bing' cherries. The post-harvest exposure of cherries to hexanal did not result in any significant enhancement in colour suggesting that hexanal is only effective as a pre-harvest spray in sweet cherries (Sharma *et al.*, 2010).

Mango cultivars Banganapalli and Bangalora dipped in hexanal formulation containing 2% hexanal exposed for three minutes and shade dried showed that some fruits lost their shelf life within two weeks of storage due to phytotoxic effect and oozing of fluids from fruits (Geeta *et al.*, 2015). Cheema *et al.* (2014) reported that tomatoes resulted in enhanced brightness and hue angle values, increased fruit firmness, reduced red colour and ascorbic acid content due

to postharvest dip application of 2 mm hexanal as EFF after storage period of 21 days, indicative of better quality. In case of strawberries of *Mira* and *Jewel* varieties sprayed with hexanal formulation altered the profiles of phenolics and volatiles (Misran *et al.*, 2015).

### Effect of hexanal on fruit quality

Several studies showed improved fruit quality and shelf life by hexanal application. Fruits treated with hexanal showed difference in colour, firmness other parameters when compared with control fruits.

### Effect of hexanal on firmness of fruits

Firmness is an important quality parameter of fruits in which pre-harvest spray of hexanal 0.01% EFF (Enhanced Freshness Formulation, twice a week) and harvested after 3 weeks of spraying, indicated a 100% increase in firmness with respect to that of untreated tomatoes. Postharvest treatments of tomatoes with hexanal formulation and EFF

**Table 2:** Effect of hexanal treatment on shelf-life extension and quality attributes.

Fruit and vegetables	Hexanal application	The quality changes	Authors
Mango Banganapalli	Post-harvest hexanal concentration (600, 900, 1200 ppm)	Treatment (600ppm for 4h) showed better colour and textural qualities	Geetha and Thirupathi, (2015)
Guava	Pre-harvest hexanal formulation (EFF-0.01%, 0.015% and 0.02% v/v)	Treated fruits (0.015% v/v) showed minimum decay incidence, reduced PME activity, increased firmness, total soluble solids, acidity, pectin and phenol contents and also maintained quality up to 4 weeks	Gill <i>et al.</i> , (2016)
Mango (var. Alphonso and Banganapalli)	Pre-harvest sprays of EFF (1.6 mM) on 30 and 15 days before harvest (25 ± 2°C; 70–75% RH) and cold (14 ± 2°C; 85–90% RH)	The firmness, total sugars, acidity of treated fruits were higher than controls regardless of storage conditions	Anusuya <i>et al.</i> (2016)
Mango	0.02% hexanal solution	Reduced ethylene evolution rate, oxidants content and PLD enzyme activity, antioxidant enzymes activities increased.	Jincy <i>et al.</i> (2017)
Fantasia' nectarines	Enhanced Freshness Formulation (EFF)	Maintained higher firmness until 38d. No differences in TSS, TA and color values between treated and untreated.	Kumar <i>et al.</i> (2018)
Green house Tomato	Hexanal formulation enhanced freshness formulation (EFF) at 2 mM	Enhanced brightness and hue angle values, reduced red colour, increased fruit firmness and ascorbic acid content after 21 days of storage,	Cheema <i>et al.</i> (2018)
Bell pepper	Post harvest hexanal vapour treatments (0.005, 0.01 and 0.02%, w/w)	Ripening process delayed Preserved postharvest qualities for 21 days	Cheema <i>et al.</i> (2018)
Banana	hexanal vapour ( 600, 900 and 1200 ppm for 2 and 4 h at 7±2°C).	Treated fruits (1200 ppm for 2 h and 4 h) reported a maximum shelf life of 18 days.	Ashwini <i>et al.</i> (2018)
Grapes	pre-harvest hexanal formulation EEF(US Patent # 6514914: # 7198811 B2) (EFF @ 1.0%, 1.5% & 2.0% v/v)	Delayed the rachis browning Retention of quality under prolonged cold storage. Suppressed activity of PPO and PME	Kaur <i>et al.</i> (2019)



significantly reduced the decline in firmness observed after 14 and 21 days of storage (Tiwari and Paliyath, 2011).

Hexanal application of high bush blueberry fruit during controlled atmosphere storage showed higher firmness values than control fruit, which were greater even after 9, 12 and 15 weeks of controlled atmosphere storage when fruit was evaluated at every 7 days at 10°C (Song *et al.*, 2010). Pre harvest hexanal efficient enhanced formulation (EEF) treatment on guava, maintained significantly higher average fruit firmness during storage, of which EFF (0.015% v/v hexanal) found to be the best treatment, recorded a highest mean fruit firmness (79.19 N) over the storage period (Gill *et al.*, 2015).

Banganapalli mangoes on hexanal vapour treatment with 600 ppm for 4h showed increased texture values than control, similar effect was reported with another mango variety Bangalora on treatment with 600 ppm for 2 h duration (Geeta *et al.*, 2015). Only the study of hexanal treatment on Anjoru pear reported that hexanal did not affect the firmness of fruits during storage (Spotts *et al.*, 2007).

#### Effect of hexanal treatment on colour of fruits

Colour is one of the important quality parameter considering the fruits. The change in colour from green to yellow denotes the ripening; also it is a good indicator of maturity and most important consideration for consumer acceptance. Pre harvest spray of 2% EFF on sweet cherries resulted in consistently high red colour, on the other hand the post-harvest exposure of cherries to hexanal did not result in any significant enhancement in colour (Sharma *et al.*, 2010).

Geeta *et al.* (2015) reported that mango varieties treated with hexanal vapour of 600 ppm showed better colour values than the control. Tomatoes dipped in EFF (enhanced freshness formulation) and hexanal showed higher L values, hue angle and reduced red colour intensity than control fruit during storage, suggesting a delay in ripening (Cheema *et al.*, 2014).

#### Effect of hexanal treatment on respiration rate

The respiration rate studies on hexanal treated fruits are limited. The respiration studies conducted on hexanal treated tomatoes followed a similar trend in respiration rate and ethylene production as control fruits (Tiwari and Paliyath, 2010). It was also observed 50% increases in the fruit respiration rate in tomatoes during continuous exposure to hexanal vapour (Utto *et al.*, 2008).

Ashwini *et al.* (2018), reported that significant difference was found in respiration rate of fruits treated with hexanal vapour compared to fruits without treatment, throughout the storage periods. Rapid change in colour from green to yellow accompanied the climacteric rise in respiration rate. In bananas treated with hexanal vapour the climacteric peak of respiration rate was reached at the stage 5 whereas untreated fruit observed higher rate of respiration throughout the storage period. The rate of respiration was lower in hexanal treated banana than in

untreated banana (Pelayo *et al.*, 2003; Lohani *et al.*, 2004).

#### Quality changes after hexanal treatment

##### Changes in pH of fruits treated with hexanal during ripening

Hexanal treatment did not report any effects on pH of fruits and vegetables. Hexanal vapour treatment and wax coating on longan fruit showed no change in quality parameters like pH (Utto *et al.*, 2008). Another study on tomatoes subjected to spraying with the hexanal formulation and the EFF (Enhanced Freshness formulation) reported that no major differences in citric acid content and pH values were observed between treated as compared to untreated tomatoes. In general, pH was in the range of 4.0-4.5 and citric acid content was between 0.35 and 0.45% on a fresh weight basis and not statistically significant (Cheema *et al.*, 2014).

##### Effect of hexanal treatment on ascorbic acid content

Nowadays, consumers are very much concerned about the vitamin contents of fruits and vegetables; hence preservation methods should not result in reduction of vitamin contents. Hexanal treatment has shown improvement in ascorbic acid content of several fruits on storage. Tomato fruit subjected to spray treatment with hexanal formulation twice a week, showed a gradual and significant increase in ascorbic acid levels from 22 to 47 mg/100g fresh weight, during the third week of harvest. Control fruits showed a declining trend in ascorbic acid levels after the second week. Pre harvest spray of EFF 0.015% hexanal treated guava fruit registered the maximum mean ascorbic acid (2.19 g/kg) content, followed by EFF (0.01% v/v and 0.02% v/v hexanal) treatments. Untreated fruits showed a reduced ascorbic acid level (1.76 g/kg) on storage (Gill *et al.*, 2014).

##### Effect of hexanal treatment on TSS

Pre- and post-harvest treatments with hexanal did not result in any major changes in the levels of soluble solids in cherries. Similar results were obtained for postharvest hexanal dip treatment on tomato (Cheema *et al.*, 2014) and vapour treatment on mango (Geeta *et al.*, 2015). Whereas in EFF (0.015% hexanal) and EFF (0.02% hexanal) EFF treated guava fruits TSS content increased gradually up to 28 day and thereafter declined to 35 days of storage. Control fruit recorded an increase in TSS up to 14 days followed by a sharp decline during storage (Gill *et al.*, 2014). Similarly pre-harvest treatments with hexanal and EFF (enhanced freshness formulation) showed significantly higher soluble solid contents in tomato fruit (Cheema *et al.*, 2014).

##### Effect of hexanal on titrable acidity

Titrable acidity (TA) is total acid content in the fruit which include the citric acid, tartaric acid and malic acid etc. on the product. Acidity level is an important factor in consumer acceptance to determine the sweetness and acid blend (Winkler *et al.*, 1974). Acid content in the fruit followed a declining trend throughout the storage period. The pre-

harvest application of hexanal formulation in flame seedless grapes observed a reduction in TA during storage of 60 days. Higher two dosages of hexanal formulation (1.5 and 2.0%) effectively retarded the degradation rate in titratable acidity at each storage interval untreated control berries showed an abrupt decline up to 45 days thereafter increased due to higher metabolic activity. This might be attributed to reduced respiration and delayed carbohydrate utilization in various metabolic activities (Kaur *et al.*, 2019). Pre harvest application of hexanal formulation of guava resulted in a gradual decline in acidity, whereas a rapid decline was observed in untreated fruits (Gill *et al.*, 2015). Fruit treated with EFF and calcium maintained a higher acidity value during storage, possibly due to a reduction in the respiration rate and delayed ripening. (Sharma *et al.*, 2010; Gill *et al.*, 2014). But some other researchers have reported no major changes in titratable acidity between treated and untreated samples *viz.* tomato, fantasia nectarines (Cheema *et al.*, 2014, 2018; Kumar *et al.*, 2018).

#### Effect of hexanal on enzyme activity

The ripening process of fruits and vegetables, with typical changes in fruits include fruit softening due to enhanced activity of enzymes causing cell wall degradation. Loss of fruit quality begins with the loss of membrane integrity and it is initiated by PLD, a membrane lipid degrading enzyme (Paliyath and Subramanian, 2008). Post-harvest application of hexanal formulation in mango inhibited PLD activity and improved the shelf life (Jincy *et al.*, 2017). Hexanal is a strong inhibitor of PLD action (Paliyath *et al.*, 2003; Paliyath and Murr, 2008). The enzyme PLD splits phospholipids to generate phosphatidic acid (PA), which is proposed as an early step in membrane degradation process (Devaiah *et al.*, 2007).

PME is a cell wall degrading enzymes present in vegetables and fruits. It eliminates the methyl group of galacturonic acid polymers of pectin. De-esterification of pectin chain by PME may make the chain more vulnerable to polygalacturonase mediated degradation (Carpita and Gibeau, 1993) fostering a rapid loss of cell wall structure. The PME activity of guava was significantly influenced by pre-harvest hexanal formulations. The fruits treated with EFF (0.015% v/v hexanal) observed a gradual rise in the activity of PME, which peaked at 28<sup>th</sup> day of storage and declined thereafter, whereas control fruits showed a peak in PME activity between 7<sup>th</sup> and 14<sup>th</sup> day of storage and an abrupt decline along with the loss of quality (Gill *et al.*, 2015).

Pre harvest application of hexanal formulation in table grapes showed a gradual increase in PME activity irrespective of applied treatments even though grapes treated with EFF at 2.0% significantly reduced PME activity during long-term storage in cold condition. Control fruits observed a sharp increase in PME activity up to 30 days and thereafter showed a steady rise and finally reached peak within 45<sup>th</sup> day (Kaur *et al.*, 2019). Similarly tomato fruit treated with hexanal formulations down regulate the PME transcript levels (Tiwari and Paliyath, 2011).

The flesh breakdown and softening grapes were observed during storage due to the increase in the activity of polyphenoloxidase (PPO) throughout the storage period. Pre-harvest hexanal formulation at a concentration of 2.0% reported least affinity for PPO at 60<sup>th</sup> day of cold storage. Reduced activity of PPO in treated fruits might be due to arrested phenolic compound oxidation via quinones for the production of brown pigments in rachis of cold stored table grapes (Kaur *et al.*, 2019).

#### Effect of hexanal on the activity of antioxidant enzymes

Before attacking the cellular components, the antioxidant enzymes stabilize, or deactivate free radicals. It is attained by the reduction of energy of the free radicals or by giving up some of their electrons, thereby making it stable. Along with this, they may also interfere with the oxidizing chain reaction to lessen the damage caused by free radicals (Krishnamurthy and Wadhwani, 2012).

Jincy *et al.* (2018) observed an increased superoxide dismutase (SOD) and catalase (CAT)/ glutathione peroxidase (GPX)/ ascorbate peroxidase (APX) activity of enzymes in mango fruits subjected to post harvest 0.02% hexanal dip treatments. The adverse effects of reactive oxygen species in fruits can be mitigated by combined action of antioxidant enzymes (Hariprasad and Niranjana, 2009). It was also reported that increased antioxidant activities could have resulted in the conversion of superoxide anion radical to water molecules (Foyer and Noctor, 2005). The reduction in oxidative damages in hexanal fruits compared to control was observed due to the efficient scavenging of ROS.

Sharma *et al.* (2010) studied about the pre harvest and post harvest application of hexanal formulations in sweet cherry. He found that pre harvest EFF with 1 and 2 % and control fruits showed decline in activity of SOD, whereas hexanal treatment after harvest observed a remarkably higher activity of SOD from control fruits by around 288% after storing it for 15 days. But enzyme ascorbate peroxidase did not show any effect on hexanal treatment. Post-harvest hexanal vapour treatment of 0.005, 0.01 and 0.02%, w/w concentrations in bell pepper observed significantly higher activity of antioxidant enzymes, such as superoxide dismutase (SOD), catalase (CAT), glutathione reductase (GR) and guaiacol peroxidase (POX) compared to control samples. Among the treatments 0.02% hexanal treatments resulted in an increased activity of 71% in SOD, 27% in GR and 43% in POX (Cheema, *et al.*, 2019).

#### CONCLUSION

The hexanal have a high potential to be widely applied in the field of post-harvest technology and preservation of fruits and vegetables. Application of hexanal prior to the harvest can be a better alternative for fungicides and pesticides to prevent the diseases. The post-harvest applications of hexanal proved to have improved the fruit quality and storage life, which can help farmers to manage the glut season and

reduce the post-harvest losses. The researches and studies regarding hexanal applications still in budding stages hence more studies in different dimensions are required in this field to promote wide applications of hexanal among the farmers all over the world.

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