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Review Article

CHILLING INJURY IN TROPICAL AND SUBTROPICAL FRUITS: A COLD STORAGE PROBLEM AND ITS REMEDIES: A REVIEW

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Introduction

Chilling injury (CI) is a physiological disorder. A function of time by temperature it occurs at low temperature that is above the freezing point of the produce. Low temperature storage is the most effective way of slower down deteriorative metabolic and pathological processes in harvested commodities. However, chilling injury possesses a major limitation to cold storage in most tropical and subtropical fruits. These fruits are very sensitive to chilling stress and even temperatures, when fruits are exposed to temperatures lower than 10^{o}C but above their freezing points. At chilling temperatures, the tissues weaken because they are unable to carry on normal metabolic processes. Various physiological and biochemical alterations and cellular disfunctions occur in chilling-sensitive species in response to chilling stress. These alterations include stimulation of ethylene production, increase in respiratory rate, enzyme inactivation, membrane disfunction and alteration of cellular structure which leads to the development of a variety of chilling injury symptoms such as pitting, discoloration, water-soaked appearance, internal breakdown, browning, uneven ripening, off-flavour and decay (Saltveit and Morris, 1990).

Table 1: Ideal storage temperature for tropical and subtropical fruits

Commodity	Recommended Minimum Storage Temperature (°C)	Potential Chilling Injury Symptoms
Mango	>13	Greyish skin discolouration, pitting, uneven ripening, poor flavour, increased susceptibility to alternaria rot.
Banana	>13	Brown to black peel discoloration, off-flavors, abnormal ripening.

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Lemon, Lime, Orange	10-14 9-12 2-5	Brown pitting of rind, watery breakdown of internal and external tissues, fermented odour plus red blotch.
Papaya	7-13	Pitting, olive or brown discolouration, abnormal ripening
Guava	4.5	Pulp injury, decay

Sources: Produce Handler's Guide, Postharvest Technology of Horticultural Crops, University of California; Hardfenburg *et al.,* 1986, The commercial storage of fruits, vegetable and florist and nursery stocks, U.S.D.A.

Remedies of chilling injury

The fruits sensitivity to chilling injury defers the possibility of prolonging the postharvest shelf life through low temperature storage. There are various strategies which have been used to alleviate chilling injury in fruits *viz.,* high or low temperature conditioning, intermittent warming, CA storage, applications of growth regulators, natural products, packaging, wax coating and other chemicals (Wang, 1993). The first three approaches manipulate and modify the storage environment while the others involve direct treatment to the commodities.

Temperature management is a non-chemical alternative that has been shown to alleviate CI in some commodities. High temperature conditioning has been used in postharvest handling of fruits for insect disinfestations, decay control, ripening delay and modification of fruit responses to other stresses. Short term treatment with temperatures higher than 35 ^{o}C can reduce chilling injury of some commodities. Ben- Yehoshua *et al*., (1987) observed that heat treatment increased anti fungal materials such as scoparone, umbelliferone, reduced decay and CI in lemon and pumelo fruits. Exposure to high temperature is known to induce thermo tolerance and in harvested commodities it has been shown to induce tolerance to chilling stress in some tropical and subtropical fruits. Exposure of plant tissues to a moderate stress not only induce the resistance to this kind of severe stress, but can also improve tolerance to other stress. This cross following heat shock has been reported to result in tolerance to chilling injury in various fruits including grape fruits and avocado. High temperature preconditioning is also thought to induce reactive oxygen species (ROS), followed by production of ROS scavengers such as superoxide dismutases (SOD), peroxidases (POD) and catalases commodities response to heat treatments vary depending on the temperatures and time of exposure, species (cultivars) as well as the preharvest factors. Although heat treatments have been successfully to control post harvest pests and fungal infections in banana avocado, citrus and mango.

Exposure of chilling sensitive fruits to temperatures slightly above the critical chilling range increases the tolerance of these commodities to chilling during subsequent low temperature storage and delay the development of injury symptoms. These modifications include reducing the loss of membrane phospholipids, increasing sugar, starch and proline content, maintaining high levels of polyamines, and long-chain aldehydes, and increasing the ratio of unsaturated to saturated fatty acids. Temperature conditioning can be performed as a single step or in multiple steps. Usually, multistep conditioning is more effective. For example, in bananas gradually decreasing the temperature in 3 ^{o}C steps from 21 to 5 ^{o}C at 12h intervals resulted in the least CI compared to 5 ^{o}C decrease every 24 h, an 8 ^{o}C decrease every 36 h or a single changes from 21 to 5 ^{o}C. Low temperature conditioning has been shown to be effective in alleviating chilling injury in lemon, lime, mango and papaya (Hatton, 1990).

Polyamines are a group of polycationic organic compounds and are ubiquitous in cells. Postharvest treatments with exogenous polyamines increase internal polyamine levels and reduce CI (Wang, 1994). The reduction of CI by polyamines may be related to their antioxidant activity and stabilizing effect on membranes. The half-mature fruits without ethrel treatment stored at 6.5±0.5 ^{o}C had more firm fruits with better shelf-life but having poor quality due to higher physiological loss in weight and incidence of chilling injury. Besides, half-mature and mature fruits treated with 500 ppm ethrel stored at lower temperature (6.5±0.5 ^{o}C or 12.5±0.5 ^{o}C) showed no chilling injury symptoms while untreated fruits (without ethrel) affected with CI at 6.5±0.5^{o}C (Bhoomika *et al.*, 2015).

Intermittent warming is the interruption of low-temperature storage with one or more periods of warm temperature. This treatment must be applied before CI becomes irreversible. Warming of chilled tissues for short periods helps to repair damage to membranes, organelles, or metabolic pathways. The raising temperature in the middle of chilling exposure usually induces higher metabolic activities and allows the tissue of metabolizes excess intermediates or toxic materials accumulated during chilling. Intermittent warming that shifting the temperature from low to high and then from high to low probably induces a rapid metabolic readjustment that increases polyunsaturated fatty acid synthesis. Fatty acid elongation and desaturation can occur when the temperature is changed from high to low. This change likely affects membrane fluidity and increases tolerance to low temperature. CI in lemons can be reduced by warming the fruit for 7 days at 13 °C after every 21 days in cold storage at 2°C. Intermittent warming has been found to alleviate chilling injury in maxican lime (Harhash and Al-Obeed, 2006), grapefruit and Lisbon lemon fruit (Safizadeh *et al.*, 2007).

The effectiveness of controlled atmosphere in reducing chilling injury varies with commodities. Most commodities respond favorably to a decrease in oxygen level and an increase in carbon dioxide concentration. In some crops, such as avocados, grapefruit, Japanese apricots, nectarines, peaches, pineapples, lemons and limes, controlled atmosphere storage does not seem to have any effect on their susceptibility to CI.

Growth regulators influence a wide range of biochemical and physiological processes in plant tissues. The modifications of these processes may in turn alter the chilling tolerance. The level and balance of certain growth regulators can also affect the susceptibility of plant tissues to chilling injury. Abscisic acid (ABA) has been studied extensively in relation to CI. ABA induces stomatal closure, reduces water loss and prevents chilling-induced wilting of seedlings (Rikin and Richmond, 1976). ABA applications reduce chilling injury in grapefruit and zucchini squash. Ethylene treatment reduces CI in 'Honey Dew' melons. Since ethylene is a ripening hormone, the effect of ethylene on CI may be mediated through its effect on maturity and ripening.

Natural products like, methyl jasmonate occurs naturally in a wide range of higher plants and has been shown to affect a number of biological processes. Treatment of chilling-sensititve crops with methyl jasmonate induces the synthesis of some stress proteins, such as heat shock proteins, pathogenesis-related proteins and alternative oxidase (Ding *et al.*, 2001, 2002; Fung *et al.*, 2004). Postharvest application of methyl jasmonate was found to reduce chilling injury of avocados and grapefruit.

The packaging of fruits with plastic films helps to maintain high relative humidity and modify the concentrations of oxygen and carbon dioxide in the atmospheres surrounding the commodity. The reduction of water loss from the tissue apparently inhibits the collapse of epidermal and underlying cells and prevents pitting formation. Packaging with low density polyethylene film and fruit were wrapped in heat-shrinkable film also reduced pitting and scald in chilled grapefruit (Wang and Qi, 1997; Miller *et al.*, 1990). Packaging has also been shown to delay chilling injury in bananas, pineapples, Japanese apricots and lemons.

Waxing not only improves the appearance of fruits but also restricts gas exchange and retards transpiration of fresh produce. Waxing has been proven to reduce chilling injury in grapefruit, oranges, pineapples, and cucumbers. Some chemicals that possess the properties of antioxidants or free radical scavengers have been reported to reduce chilling injury.

Coating with vegetable oil, safflower oil, mineral oil, or dimethylpolysiloxane also has been shown to prevent the development of under peel discoloration in bananas stored at chilling temperatures. These compounds may act as antioxidants and reduce oxidative damage induced by chilling temperature. Calcium apparently strengthens cell walls and cell membranes and help tissues withstand chilling stress. There have been some good correlations between calcium content in tissues and the susceptibility of fruits chilling injury. Lime fruit with the lowest calcium content in their juice develop the highest percentage of chilling injury. Application of calcium significantly reduced the severity of chilling injury in avocados and peaches. For example, ethoxyquin and sodium benzoate applied to cucumbers and sweet peppers were found to maintain a high degree of unsaturation of fatty acids in polar lipids and reduce chilling injury (Wang and Baker, 1979).

Conclusions

CI is responsible for substantial postharvest losses in tropical horticultural commodities. Although no method can completely eliminate CI, several approaches do show promise in alleviating this problem. These techniques reduce CI either by retarding the development of injury symptoms or by increasing the tolerance of commodities to chilling. In addition, environmental conditions under which the crops are grown have great influence on the susceptibility to chilling injury. Chilling injury is responsible for substantial postharvest losses in tropical and subtropical horticultural commodities. The effectiveness of these methods in reducing chilling injury often varies with the commodity and is affected by the maturity and physiological state of the commodity as well as a number of environmental factors. Some techniques described in this paper are applicable for several commodities. In summary, above technological interventions can be used to extend shelf life and maintain quality in supply chain management of fruits during cold storage and ambient storage at retail.

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