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Recent advances in postharvest technologies for reducing chilling injury symptoms of fruits and vegetables: A review

Jiaxin Wu[a], Rui Tang[a], Kai Fan[a,b,*]

[a] College of Life Science, Yangtze University, Jingzhou, Hubei 434025, PR China
[b] Institute of Food Science and Technology, Yangtze University, Jingzhou, Hubei 434025, PR China

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ABSTRACT

Low temperature storage is widely used in the storage and transportation of postharvest fruits and vegetables. However, the negative effects of chilling injury (CI) on certain fruits and vegetables cannot be ignored. Therefore, efficient CI prevention technologies were used for reducing CI. This paper expounds the mechanisms of CI, common symptoms of CI and its impacts on the quality of fruits and vegetables, and summarizes the application of CI prevention technology. CI control methods are mainly classified into physical treatments (hot shock, near-freezing storage, high relative humidity storage, light-proof storage, and electromagnetic field), chemical treatments (melatonin, 1-methylcyclopropene, astragalus polysaccharides, γ-aminobutyric acid, 24-epibrassinolide, methyl jasmonate, trisodium phosphate, glycine betaine, and salicylic acid, etc.), coating treatments (sodium alginate, chitosan, carboxymethyl cellulose and *aloe vera* gel, etc.) and their combined treatments. These treatments have enhanced antioxidant activity, enzyme activity, membrane system integrity, and energy levels, thereby reducing the CI of fruits and vegetables.

1. Introduction

Low temperature storage can greatly increase the storage time and transportation distance of fruits and vegetables after harvest. However, many fruits and vegetables are not resistant to chilling injury (CI), such as peaches, bananas, mangoes and zucchini fruits. These fruits and vegetables in low temperature storage for a period will appear obvious symptoms of CI, such as pitting, browning, softening, and even decay. These negative effects will reduce consumers' desire to buy fruits and vegetables, resulting in a large amount of economic losses (Albornoz et al., 2022).

The ability to tolerate low temperature, maturity, and harvesting operation can influence the CI symptoms in fruits and vegetables. The degree of CI produced in cold areas with high maturity and less trauma is relatively low. Different fruits and vegetables have different temperatures of CI. Generally, subtropical fruits will suffer from CI at 5 ~ 8 °C, while tropical fruits will suffer from CI when the temperature is lower than 12 °C. The storage time also has a crucial impact on the CI of fruits and vegetables. CI symptoms often increase with the prolongation in storage time of fruits and vegetables. After CI of fruits and vegetables, changes in color, texture and taste can be observed macroscopically, while changes in cell membrane permeability, organelle damage and even cell lysis may be observed inside fruits and vegetables. Internal browning is one of the CI symptoms of many fruits and vegetables, which makes it more difficult to prevent and detect CI. Therefore, it is necessary to carry out preventive treatment of CI before fruits and vegetables are refrigerated (Zhang et al., 2021).

In recent years, certain physical, chemical and coating methods have been used to reduce the CI of fruits and vegetables. Common physical methods include hot shock treatment, cold shock treatment and controlled atmosphere storage. Chemicals commonly used to reduce CI include salicylic acid (SA), abscisic acid, and methyl jasmonate (MeJA), etc. Although certain methods have obvious effects on reducing CI of fruits and vegetables, these methods have not been accepted and applied by manufacturers and sellers. Therefore, more research results are needed. This paper aims to present an overview of the recent developments in controlling CI of fruits and vegetables and to prospect further research and applications.

2. Mechanism of CI

Fig. 1 shows the mechanism of CI caused by membrane lipid phase

* Corresponding author.
E-mail address: kaifan@yangtzeu.edu.cn (K. Fan).

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change. The theory of membrane lipid phase transition is one of the main theories of CI in fruits and vegetables. The theory of membrane lipid phase change is also the hypothesis of cell membrane damage, which believes that when fruits and vegetables are under low temperature stress for a long time, the phase of membrane system will change from flowing liquid crystal state to solid gel state (Song et al., 2022a). The phase change of membrane lipid will increase the permeability of cell membrane, and make the molecule of membrane binding enzyme likely to be compressed and its activity will be reduced, even the conformation will change, which will lead to its failure to perform normal physiological functions, and finally cause physiological metabolism disorder (Hou et al., 2022). Under low temperature, the normal function of mitochondria is damaged due to the phase change of membrane lipid, resulting in the shortage of ATP in cells, the inability to synthesize proteins, and the inability to actively absorb ions, which leads to the decomposition of certain proteins and the leakage of cell ions (Yan et al., 2022). After membrane lipid phase transition, aerobic respiration is inhibited and anaerobic respiration is enhanced. Toxic substances produced by anaerobic respiration and ion leakage caused by ion pump passivation on the membrane due to membrane lipid solidification will cause cell damage (Vichaiya et al., 2022).

Certain researchers believe that protein is the original site of CI (Aghdam et al., 2018, Li et al., 2021). Low temperature weakens the hydrophobic bonds in protein molecules and strengthens the interaction between hydrogen bonds and electrostatic attraction. Low temperature stress causes changes in the conformation of proteins, including antioxidant enzymes, which directly affects the activity of enzymes, leading to their continuous decline, thus affecting the regulation of many antioxidant enzymes on the accumulation of reactive oxygen free radicals in cells, leading to abnormal metabolic balance. In addition, certain low temperature sensitive poly protein structures in cells, such as microtubules and microfilaments, will disaggregate under low temperature stress, thus affecting the normal structure and function of cells under low temperature, causing metabolic imbalance.

Another theory is free radical injury theory. Biological free radicals have a strong destructive effect on biological macromolecules such as chloroplasts, protein nucleic acids in cells. When the tissues of fruits and vegetables are stressed by low temperature, the ability of scavenging active oxygen free radicals in fruits and vegetables is weakened, resulting in the accumulation of excessive free radicals, leading to the destruction of biological macromolecules. In particular, the double bond of unsaturated fatty acid in membrane lipid is very vulnerable to free radical attack to cause peroxidation, and lipid peroxidation will generate new free radicals. Free radicals are one of the culprits that accelerate cell death. Because it promotes lipid peroxidation of cell membranes, thereby destroying the integrity of membranes (Zuo et al., 2021a).

At present, there are several mechanisms to reduce the CI of fruits and vegetables. First, postharvest treatment maintains the fluidity and permeability of the cell membrane system of fruits and vegetables. Maintain the ATP level in fruits and vegetables so that cells can get sufficient energy supply. Enhance the antioxidant activity and certain enzymes activities of fruits and vegetables. CI can also be inhibited by regulating sugar metabolism of fruits and vegetables (Wang et al., 2019a). Finally, inhibiting the transcription and expression of CI related genes in fruits and vegetables is also an effective way to resist CI (Zhu et al., 2021).

3. Influence of CI on quality of fruits and vegetables

The macroscopic manifestations of fruits and vegetables CI are browning, softening, water soaking, off-flavor and even decay. Varieties of fruits and vegetables have different CI symptoms. Changes in the color of fruits and vegetables are the most easily detectable CI symptoms. The bamboo shoot, mangoes, and bananas (Khademi et al., 2019) will appear serious browning after cold storage. The untreated banana peel browned obviously during storage (Tian et al., 2022). The CI symptoms of zucchini fruits are whitening, sunken and brown spots on the peel (Bokhary et al., 2020). After being refrigerated for 120 days, the pear fruits exhibited severe browning (Sun et al., 2020). After being refrigerated for 20 days, the rib-edges of carambola fruits became noticeably darker. (Duan et al., 2022). The sensory properties of fruits and vegetables are mainly determined by firmness and nutrients.

Table 1 summarizes the quality degradation (firmness, nutrients) of certain fruits and vegetables caused by CI. CI leads to a significant decrease in the firmness of certain fruits and vegetables tissues. Tomatoes (Aghdam et al., 2019b), strawberries (Wang et al., 2020), and pears (Sinha et al., 2022) soften during refrigeration. Peaches (Wang et al., 2019a), apricots (Li et al., 2022), guava fruits (Vichaiya et al., 2022), aonla fruits (Ali et al., 2022), pineapples (Nukuntornprakit et al., 2020), and green bell peppers (Wang et al., 2022b) showed water soaking after low temperature storage. Kiwifruits appeared lignified due to CI (Liu et al., 2021). The quality of fruits and vegetables has been altered by the loss of nutrients. The ascorbic acid (AsA) contents of Anthurium flower (Aghdam et al., 2019a) and mandarin (Ali et al., 2021) decreased by 40 % and 63 % respectively after refrigeration. The contents of flavonoids, AsA, and glutathione (GSH) in the Aonla fruit decreased by 63 %, 60 %, and 70 % respectively after refrigeration,

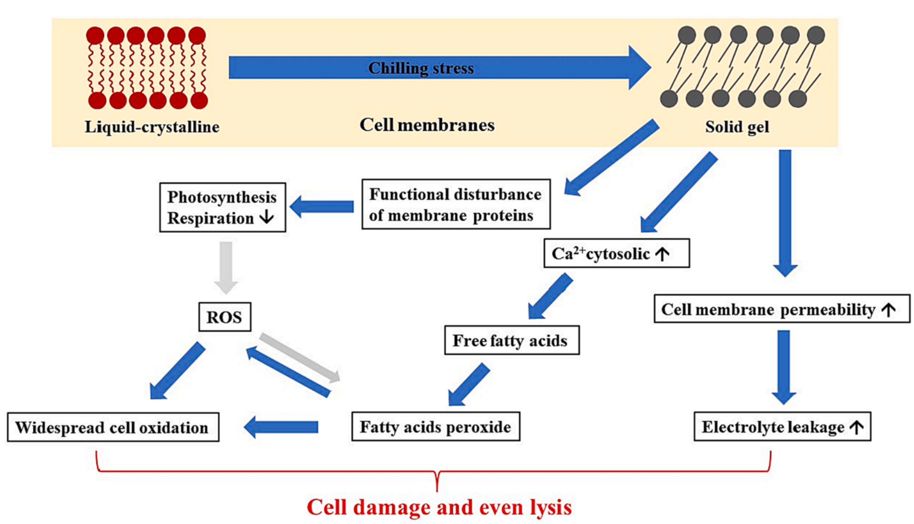

Fig. 1. CI of untreated fruits and vegetables.

Table 1
Quality deterioration of fruits and vegetables caused by CI.

Fruits and vegetables	Changes of firmness	Changes of nutrients	Changes of overall quality	References
Anthurium flower	–	AsA decreased by 40 %	–	Aghdam et al. (2019a)
Mandarin	–	AsA decreased by 63 %	Quality index decreased by 67 %	Ali et al. (2021)
Aonla fruit	–	Flavonoids, AsA and glutathione decreased by 63 %, 60 % and 70 %, respectively	CI index increased 3-folds	Ali et al. (2022)
Guava	Firmness decreased by 38 %	AsA and soluble solids decreased by 35 % and 17 %, respectively	Commercial acceptable decreased by 80 %	Chen et al. (2022b)
Banana	–	The contents of chlorophyll, total phenols, GSH and AsA decreased by 42 %, 22 %, 25 % and 53 %, respectively	–	Chen et al. (2021)
Apricot	Firmness decreased by 80 %	AsA content decreased by 53 %	–	Cui et al. (2019)
Sweet pepper	Firmness decreased by 70 %	AsA and GSH contents decreased by 12.5 % and 15 %, respectively	–	Endo et al. (2019a)
Chinese olive fruit	–	Chlorophyll, TSS and tannin contents decreased by 33 %, 3 % and 80 %, respectively	–	Fan et al. (2022)

Note: "-" represent no corresponding index in the reference list.

while the CI index increased 3-folds (Ali et al., 2022). AsA, soluble solids and overall quality of guava fruits decreased by 35 %, 17 % and 80 % respectively after refrigeration (Chen et al., 2022b). Chlorophyll, total phenols, GSH and AsA contents of banana decreased by 42 %, 22 %, 25 % and 53 %, respectively (Chen et al., 2021). Chlorophyll, total soluble solids (TSS) and tannin contents of olive fruits decreased by 33 %, 3 % and 80 %, respectively (Fan et al., 2022).

4. Methods of CI control

4.1. Physical methods for controlling CI

Table 2 summarizes certain common physical methods for CI control, including cold shock treatment (CST), hot shock treatment, near freezing temperature (NFT) storage, controlled atmosphere storage, electromagnetic treatment and relative humidity control. After the fruits and vegetables were treated with hot water, the integrity of the membrane was preserved and CI symptoms were alleviated. NFT delayed the degradation of pectin and cellulose. Because it inhibited the activity of cell wall modifying enzymes. Storage under controlled atmosphere can reduce CI of certain fruits and vegetables by controlling lipid metabolism in microsomal membranes.

NFT is very close to the biological freezing point of fruits and vegetables, but it will not cause fruits and vegetables cells to freeze. This temperature can effectively reduce the respiratory rate and biochemical reaction of fruits and vegetables, thus extending the shelf life (Cui et al., 2019). The symptoms of CI appeared 20 days later in the apricots stored at NFT. The CI index and malondialdehyde (MDA) content of treated apricots were 62.50 % and 26.19 % lower than the control, respectively.

Table 2
Physical methods of CI control.

Fruits and vegetables	CI control methods	Changes of quality after treatment	References
Apricot	NFT storage	Both MDA content and cell membrane permeability decreased by 30 %, CI index decreased by 0.5, and firmness increased by 8 N	Li et al. (2022)
Guava	NFT storage	MDA content and EL decreased by 1 μmol/kg and 30 %, respectively	Xiao et al. (2022)
Papaya	CST	CI index and cell membrane permeability decreased by 20 % and 10 %, respectively AsA increased 5 mg/100 g	Nian et al. (2022)
Eggplant	HWT	CI index and weight loss decreased by 2.5 and 1 %, respectively Total phenolic content increased by 0.3 g/kg	Kantakhoo et al. (2022)
Satsuma orange	Treated with hot electrolyzed functional water (EFW)	CI index, weight loss and cell membrane permeability decreased by 15 %, 45 % and 10 %, respectively The SOD, CAT and POD enzyme activities were significantly higher	Shi et al. (2020)
Zucchini	High relative humidity storage	CI index, weight loss and cell membrane permeability decreased by 0.5, 12 % and 10 %, respectively The firmness increased by 15 N	Zuo et al. (2021b)
Zucchini	NSH storage	CI index and weight loss decreased by 1 and 8 %, respectively Improved the antioxidant activity, enzyme (SOD, CAT, APX, POD) activities	Zuo et al. (2021a)
Sweet potato	Stored at 10 °C for 5 days and then refrigerated at 4 °C	CI index decreased by 1.2 Sucrose content increased by 60 mg/g	Li et al. (2018)
Guava	Controlled atmospheres	Protein content increased by 4.6 μg/g	Alba-Jiménez et al. (2018)
Star Ruby grapefruit	Light-proof refrigeration	CI index decreased by 1.1 Inhibited the expression of *GGDR, VTE1, VTE4, VTE3a* and *VTE2* genes	Rey et al. (2021)

The firmness, TSS, Na_2CO_3-soluble pectin and cellulose contents of apricots stored at NFT were much higher. The respiratory peak of treated apricots was delayed by 7 d (Li et al., 2022). NFT storage effectively reduced the CI index of postharvest guava fruits. Because the NFT stored fruits maintained a higher level of cell integrity and higher antioxidant activity. Antioxidant related enzymes, *PguAPX2, PguMDHAR1, PguMDHAR3, PguGR1* and *PguGR2* were activated and induced by NFT storage (Xiao et al., 2022). NFT reduced the CI of peaches by increasing the energy level and sucrose content. The sucrose and ATP contents of NFT stored fruits were 22 and 8 g/kg higher than the control, respectively (Zhao et al., 2019).

Soaking fruits and vegetables in ice water before refrigeration is CST. The respiratory peak and CI of CST Papaya fruits (4 °C, 1 h) were 6 and 12 days later than those of control, respectively. CST significantly reduced the ethylene production rate of Papaya. On the 6th day, the ascorbate peroxidase (APX) activity of CST fruits was 148.8 % higher than that of the control. After that, the activity of superoxide dismutase (SOD) in CST fruits was significantly higher, and the activity of catalase (CAT) increased sharply in the first 9 days (Nian et al., 2022).

Before cold storage, hot water treatment (HWT) at about 40 °C can effectively reduce the CI of fruits and vegetables. The CI index, electrolyte leakage (EL), MDA content and weight loss of Zucchini fruits soaked in hot water (40 °C) were significantly reduced, while the firmness, AsA and soluble solids contents were significantly increased (Zhang et al., 2019). During the 4-week storage period, the CI index, MDA and H_2O_2 contents of untreated *Prunus mume* fruits were significantly higher than those of HWT fruits, especially the CI index was about twice that of the treated fruits. The content of AsA in fruits decreased gradually during storage, but the decline rate of treated fruits was slower. Moreover, the total antioxidant capacity of HWT fruits was higher than that of control (Endo et al., 2019b). The CI index and weight loss of HWT eggplants (45 °C, 10 min) were the lowest, and the antioxidant activity and total phenol content of HWT eggplants were twice those of control (Kantakhoo et al., 2022). The CI index of the HWT sweet pepper was significantly lower than that of the control. After storage for 5 days, the contents of MDA and H_2O_2 gradually decreased in the HWT group, while the opposite was true in the control group. After 13 days of storage, the AsA content, GSH content, and APX activity of the HWT group were 100 mg/100 g, 3 mg/100 g, and 29 % higher than those of the control group, respectively. Moreover, the monodehydroascorbate reductase (MDHAR), dehydroascorbate reductase (DHAR), and glutathione reductase (GR) activities of the HWT group were much higher than those of the control. However, there was little difference in EL and weight loss between the two groups of bell peppers (Endo et al., 2019a). After 20 days storage at 5 °C, the CI index of the control mangoes was 4 times that of the HWT mangoes. HWT significantly reduced the respiration rate of fruits during room temperature storage. However, the total phenol content and antioxidant activity of treated fruits were significantly higher (Vega-Alvarez et al., 2020). Similarly, the decay index of another variety mango treated with hot water was 80 % lower than that of the control (Salazar-Salas et al., 2022). After 60 days of storage, the CI index and weight loss of HWT Satsuma oranges were the lowest, only about 60 % of that of the control. The trends of TSS and TA contents in the treated fruits were the same as that of the control but slightly higher. The cell membrane permeability and MDA content of treated fruits were significantly lower than those of control. On the 40th to 60th day of storage, the SOD, CAT and peroxidase (POD) enzyme activities of treated fruits were much higher (Shi et al., 2020).

High relative humidity storage can reduce the CI of fruits and vegetables. During the 15-day storage period, the CI index and weight loss of the Zucchini fruits stored at high relative humidity (98 ± 2 %) were much lower than those of the control. Moreover, fruits stored at high relative humidity had lower cell membrane permeability, trypan blue accumulation, and PDH activity. However, fruit firmness, brightness, proline content, ornithine-δ-aminotransferase (OAT), ornithine decarboxylase (ODC) and Δ1-pyrroline-5-carboxylate synthetase (P5CS) activities were enhanced by high relative humidity. In addition, the contents of abscisic acid and spermidine in fruits stored at high relative humidity were much higher (Zuo et al., 2021b). During the 15-day storage period, the weight loss and CI index of Near-saturated relative humidity (NSH) stored Zucchini fruits were greatly lower. The weight loss of treated fruits is only 50 % of that of the control. In addition, the EL, MDA, $O_2^{\bullet-}$ and H_2O_2 contents of NSH stored fruits were much lower than those of the control. The antioxidant activity, enzyme (SOD, CAT, APX, POD) activities of NSH stored fruits were significantly higher than the control. However, the PLD activity and lipase activity of NSH storage fruits were lower than those of the control before the 12th day, and then higher than those of the control (Zuo et al., 2021a). Relative humidity may affect the quality of strawberries by affecting the transpiration rate. The appearance quality of strawberries deteriorated faster under low relative humidity (Ktenioudaki et al., 2019). High relative humidity may improve the quality of pears by maintaining wax content on the surface (Wang et al., 2021b).

Storage at suitable temperature before refrigeration enhanced the tolerance of fruits and vegetables to low temperature. Sweet potato roots were stored at 10 °C for 5 days and refrigerated at 4 °C for 28 days. CI index, EL, $O_2^{\bullet-}$ production rate, MDA and H_2O_2 contents of sweet potato roots treated at 10 °C were significantly lower than those of directly refrigerated sweet potato roots. The activities of β-amylase, sucrose phosphate synthetase, CAT and SOD in the pretreatment group were the highest (Li et al., 2018).

There are also certain other physical methods to reduce the CI. During dark storage, the expression of *GGDR, VTE1, VTE4, VTE3a* and *VTE2* genes of Star Ruby grapefruit were inhibited. These genes may affect the synthesis of tocopherol and thus affect the cold resistance of fruits. The CI index of non-covered fruits was almost twice that of covered fruits (Rey et al., 2021).

Guava fruits were treated with controlled atmospheres (10 kPa O_2; 5 kPa CO_2; 10 + 5 kPa of O_2 and CO_2). The CI of fruits stored under 5 kPa CO_2 condition was significantly reduced, and the shelf life was also prolonged (Alba-Jiménez et al., 2018).

4.2. Chemical methods for controlling CI

Table 3 summarizes certain chemical methods for reducing CI symptoms in fruits and vegetables, including trehalose, Astragalus polysaccharides (APS), 1-methylcyclopropene (1-MCP), γ-aminobutyric acid (GABA), 24-epibrassinolide (24-EBL), MeJA, trisodium phosphate (TSP), Melatonin, glycine betaine (GB), and SA.

Trehalose is an atypical disaccharide composed of α-D-glucopyranosyl-α-D-glucopyranoside, which can enhance the tolerance of plants in harsh environments (Villanueva et al., 2019). The browning index of the control peaches was 0.3 higher than that of the trehalose treated peaches. Trehalose increased the activities of enzymes involved in sucrose synthesis and decreased the activities of enzymes related to sucrose degradation (Wang et al., 2022d). The CI symptoms of guavas after trehalose treatment were also significantly inhibited (Vichaiya et al., 2022).

APS is widely used because of its superior biological activity. The CI index of 0.5 g/L APS-treated bananas was the lowest, and it were still green on the eighth day. The MDA contents in 0.5 g/L APS-treated fruits, 0.1 g/L APS-treated fruits and control fruits were 0.378, 0.418 and 0.451 mmol/kg, respectively. The H_2O_2 content in the control fruits was approximately 1.2 times that of the treated fruits. APS enhanced the DPPH scavenging activity of fruits (Tian et al., 2022).

1-MCP can inhibit ethylene production and is widely used in agriculture and plant protection. Ethylene has been widely used in fruits. It suppressed the CI symptoms of bananas and pears (Wei et al., 2019), but increased the CI symptoms of kiwifruits. However, the CI, EL, and MDA content of 1-MCP and ethylene-treated kiwifruits were much lower than those of the control. The CAT activity of treated kiwifruits was much higher than the control (Liu et al., 2021). The CI index, H_2O_2 and MDA contents of nectarines treated with 1 μl/L 1-MCP for five times were significantly lower than those of the control and other treatment groups. The firmness of treated fruits was 79.19 % higher than the control. The enzymes activities of CAT, SOD, APX and POD in treated fruits were higher than those in other treatment nectarines (Zhang et al., 2020).

GABA is a kind of plant metabolite beneficial to humans and widely used in foods. Compared with other concentration treatment groups, 1.0 mmol/L GABA effectively reduced the CI index and cell membrane permeability of olive fruits. The chlorophyll, TSS, titratable acid, and tannin contents of treated fruits were significantly higher than those of other treatments. The treatment kept the lowest weight loss percentage during the whole storage period (Fan et al., 2022). The CI index, decay incidence, EL, and MDA contents of GABA treatment aonla fruits were 50 %, 60 %, 20 %, and 30 nmol/kg lower than the control, respectively. The GAD, P5CS, OAT, APX, CAT, POD, SOD, and PAL activities in treatment group were significantly higher than those in control group. The proline, total phenolics, AsA and glutathione contents in treated group were much higher than the control, too (Ali et al., 2022). The color and firmness of hydrogen sulfide and GABA treated persimmons

Table 3
Chemical methods for CI control.

Fruits and vegetables	Treated with	Changes of quality after treatment	References
Banana	APS	CI index decreased by 1.5 Strach content increased by 6 g/kg	Tian et al. (2022)
Banana	GB	CI index, EL and MDA content decreased by 0.1, 25 % and 1.4 nmol/g, respectively The contents of chlorophyll, soluble sugar, total phenol and GSH increased by 0.5 mg/g, 1 mg/g, 0.4 mg/g and 0.04 μg/g, respectively	Chen et al. (2021)
Banana	Phytosulfokine α (PSKα)	CI index, EL, and MDA content decreased by 0.5, 5 %, and 0.75 μmol/kg, respectively	Wang et al. (2022a)
Kiwifruit	1-MCP and ethylene	CI index decreased by 0.15 Firmness increased by 20 N	Liu et al. (2021)
Olive fruit	GABA	CI index, weight loss and cell membrane permeability decreased by 3, 2.5 % and 40 %, respectively The chlorophyll and TSS increased by 0.1 g/kg and 2 %, respectively	Fan et al. (2022)
Pomegranate	24-EBL	CI index and weight loss decreased by 3, and 10 % Proline content increased by 50 %	Islam et al. (2022)
Pomegranate	MeJA	CI index decreased by 2.5 Total phenolic content increased by 0.4 g/kg	García-Pastor et al. (2020)
Eggplant	Eugenol	CI index, weight loss and MDA content decreased by 30 %, 2 % and 1.1 nmol/g, respectively	Huang et al. (2019)
Nectarine	1-MCP	CI index, H_2O_2 and MDA contents decreased by 50 %, 5 mmol/kg and 3 μmol/kg, respectively	Zhang et al. (2020)
Mango	Sorbitol	CI index decreased by 0.5	Sanches et al. (2021)
Peach	H_2S	Browning index and MDA content decreased by 20 % and 2 nmol/g, respectively	Wang et al. (2022c)
Peach	Jasmonic acid	Browning index decreased by 2 Firmness increased by 5 N	Zhao et al. (2021b)
Peach	SA	Browning index decreased by 25 % Sugar content increased by 0.3 %	Zhao et al. (2021a)
Peach	Trehalose	Browning index decreased by 0.3	Wang et al. (2022d)
Bell pepper	SA and TSP	CI index decreased by 30 % The contents of GSH and AsA increased by 25 μmol/g and 2 μg/mg, respectively	Ge et al. (2020a)
Bell pepper	Glutathione	CI index, H_2O_2 and MDA content decreased by 30 %, 4 mmol/g and 1.8 mmol/g, respectively AsA and GSH content increased by 1 μg/mg and 10 μmol/g, respectively	Yao et al. (2021)
Pomegranate	Melatonin	CI and decay index decreased by 25 % and 10 %, respectively	Molla et al. (2022)
Carambola	Brassinolide	MDA content decreased by 1 μmol/kg Total flavonoid and AsA contents increased by 0.8 g/kg and 30 mmol/kg, respectively	Duan et al. (2022)
Okra pod	Putrescine	H_2O_2 content, CI and browning index decreased by 1.5 mg/kg, 50 % and 3 %, respectively	Phornvillay et al. (2019)
Persimmon	Hydrogen sulfide and γ-aminobutyric acid	Peel browning, EL and MDA content decreased by 6 %, 20 % and 0.8 μmol/kg, respectively	Niazi et al. (2021)
Potato tuberous root	Progesterone	CI index and EL decreased by 5 % and 2 %, respectively	Chen et al. (2022c)

were better maintained. The CI, EL and MDA contents in persimmons were significantly decreased after treatment. This treatment increased the CAT, SOD, PAL and APX enzyme activities and AsA content of persimmons (Niazi et al., 2021). The CI symptoms of blood oranges (Habibi et al., 2019) and zucchinis (Palma et al., 2019) treated with GABA also decreased.

Brassinolide is a steroid plant hormone, which can enhance the response ability of plants to abiotic stress. The CI index, decay incidence and weight loss rate of the control pomegranate fruits were much higher than those of the groups treated with 24-EBL. The LOX, PPO, PDH enzyme activities, EL and MDA contents of control fruits were significantly higher than those of the treated fruits. However, the P5CS, OAT, APX, CAT, POD, SOD, and PAL enzyme activities, proline and total phenols contents of control fruits were much lower (Islam et al., 2022). Moreover, 24-EBL can increase the expression of genes related to energy metabolism in peaches, thus promoting the accumulation of sugar and reducing the symptoms of CI in fruits (Hu et al., 2023). 15 μmol/L 24-EBL decreased the lignin content of loquats, increased the contents of cell wall polysaccharides and unsaturated fatty acids, and thus reduced the symptoms of CI (Chen et al., 2022a).

MeJA, a widely used plant hormone, can affect plant growth and stress tolerance (Wang et al., 2021a). When cucumbers were treated with only one chemical substance, the CI index and EL of SNP treatment group were the lowest. The H_2O_2 contents of MeJA and SNP treatment group were 20 % lower than that of the control group. However, the CAT activity of SNP treated group was significantly higher than that of other groups. The change trends of external CI index and ion leakage of the pomegranates treated with MeJA in the two groups were similar and significantly lower than those of the control. The firmness and TSS content of treated fruits were higher than the control (García-Pastor et al., 2020).

TSP, a safe additive, is widely used in foods. The appearance of CI symptoms of TSP + SA treated bell pepper was five days later than that of the control. Moreover, the EL, MDA content and LOX enzyme activity of treated bell pepper were greatly lower. However, the contents of GSH, AsA and proline and the activities of LOX and FAD in the treated fruits were much higher than those in the control (Ge et al., 2020a). Similarly, TSP also maintained the quality of postharvest apples (Ge et al., 2019) and jujube (Ge et al., 2020b).

Melatonin (*N*-acetyl-5-methoxytryptamine), one of many plant hormones, is an indole derivative of tryptophan. Many reports have confirmed that melatonin plays an important role in resisting abiotic stress, controlling the growth of fruits and vegetables, and reducing CI. Melatonin enhances cold tolerance of fruits and vegetables by up regulating cold response genes, transcription factors and antioxidant genes (Kong et al., 2020). CI symptoms of pomegranates (Molla et al., 2022), eggplants (Song et al., 2022b), bananas (Wang et al., 2022e), guavas (Chen et al., 2022b), kiwifruits (Jiao et al., 2022), plums (Du et al., 2021) and cut anthurium flowers (Aghdam et al., 2019a) were significantly reduced after melatonin treatment.

GB (N,N,*N*-trimethylglycine) can maintain the integrity of plant cell membrane, thus enhancing the tolerance to environmental stress (Golestan Hashemi et al., 2018). The CI index of the control bananas was higher than that of the GB treatment group. The chlorophyll, soluble sugar, total phenolics, GSH and AsA contents of GB treatment bananas were significantly higher than those of the control. The changes of APX, CAT, SOD, POD enzyme activities in the control group and GB treatment group were similar. However, the enzyme activities of APX and CAT in GB treatment group were significantly higher (Chen et al., 2021). GB enhanced the cold tolerance of peaches by maintaining high levels of individual phenols and sucrose content (Wang et al., 2019a). GB treatment reduced the CI index of pears by regulating the antioxidant capacity and increasing proline content of fruits. The activities of APX, CAT and SOD in the pears treated with GB were higher than the control fruits (Sun et al., 2020).

Abscisic acid is also a plant hormone, which has obvious inhibitory effect on CI of peaches. The browning index of peaches treated with abscisic acid was 25 % lower than the control. After 21 days of storage, the sucrose content in the processed peaches was 2.5 mg/g higher than the control (Zhao et al., 2022).

4.3. Coating methods for controlling CI

Edible coatings can extend the shelf life of food to a certain extent. Because the coatings can form a semipermeable barrier on the surface of fruits and vegetables, regulate the transpiration and respiration, and have a certain inhibitory effect on microorganisms. Table 4 summarizes certain coating methods for reducing CI of fruits and vegetables, including sodium alginate, chitosan, CMC, shellac and *aloe vera* gel.

The use of the composite coating significantly reduced the CI index of the rose apples. The LOX activity, EL, MDA and H_2O_2 contents of the coated fruits were significantly lower than those of the control. The SOD, CAT, APX activities, AsA and total phenolic contents of the coated fruits were much higher than those of the control (Duong et al., 2022). The addition of carvacrol or thymol to shellac significantly reduced the CI index of the grapefruits (Yan et al., 2020). The firmness, antioxidant activity, AsA, total phenol, and TA contents of the guava fruits treated with composite coating (gum Arabic, oleic acid and cinnamon essential oil) were greatly higher than those of the fruits treated with single coating and the control. The browning index, EL, MDA content and TSS content of the fruits treated with composite coating were significantly lower than those of other groups (Etemadipoor et al., 2020). "*Paluma*" guava fruits were coated with galactomannan (0.75 %) and carnauba wax (0.9 %). Shelf life of the coated fruit was one week longer than that of the control. The coating treatment alleviated the CI of the fruits and kept the firmness, color, CAT and SOD activities of the fruits (Germano et al., 2019). Plums were treated with glycine betaine coated chitosan nanoparticles (CTS-GB NPs). The CI index, electrolyte leakage, MDA and H_2O_2 contents of fruits treated with CTS-GB NPs (0.5 %, w/v) were significantly lower than those of other treatments. However, the PAL, CAT, POD, SOD and APX enzyme activities, phenol content and antioxidant activity of fruits treated with CTS-GB NPs were significantly higher than those of other fruits (Mahmoudi et al., 2022). The weight loss, crack and decay incidences of the *Akebia trifoliate* fruits treated with coating (0.15 % montmorillonite, 0.15 % peel extracts, and 1.50 % chitosan) combined with heat shock were significantly lower than those of the control fruits. On the 25th day of storage, the starch content of uncoated fruits reached 425.94 g/kg DW, while that of coated and heat shock treated fruits was 540 g/kg DW. However, heat shock treatment reduced the soluble sugar content of fruits. The changes of MDA content, ion leakage, SOD and APX activities in all fruits were similar. However, after 25 days, the MDA content of 45 °C heat shock treatment fruits began to rise sharply, while that of 40 °C heat shock treatment fruits decreased slowly (Jiang et al., 2022). The weight loss, MDA content and cell membrane permeability of the coating treatment (chitosan 2 % + salicylic acid 2 mM) pears were much lower than the control. Especially, the MDA content of coated fruits was 85.88 μmol/kg FW, while that of control fruits was 117.43 μmol/kg FW (Sinha et al., 2022). The control pomegranates showed CI symptoms after 30 days of storage, while the coating treatment (chitosan + CMC + oxalic acid or malic) fruits showed symptoms after 60 days. Compared with the control, the EL of fruit treated with CMC + 5 mmol/L oxalic acid, CMC + 50 mmol/L malic and chitosan decreased by 33.37 %, 31.20 % and 31.07 % respectively. The MDA content of fruits treated with CMC + 5 mmol/L oxalic acid was 34.92 % lower than that of the control. Furthermore, the H_2O_2 content of fruits treated with chitosan + 5 mmol/L oxalic acid was 33.16 % lower than that of the control. The total phenol contents of fruits treated with chitosan + 5 mmol/L oxalic acid and chitosan + 50 mmol/L malic were 12.74 % and 14.65 % higher than the control fruits, respectively. In addition, after storage, the antioxidant activities of fruits treated with CMC + 5 mmol/L oxalic acid and chitosan + 5 mmol/L oxalic acid were 23.31 % and 26.36 % higher than those of the control, respectively

Table 4
Coating methods for CI control.

Fruits and vegetables	Coating materials	Changes of quality after treatment	References
Apple	Sodium alginate and $CaCl_2$	CI index, EL and MDA decreased by 75 %, 10 % and 1 μmol/kg, respectively	Duong et al. (2022)
Grapefruit	Shellac containing carvacrol or thymol	CI index decreased by 0.5	Yan et al. (2020)
Guava	Gum Arabic, oleic acid and cinnamon essential oil	Firmness, total phenol and AsA contents increased by 20 N, 20 mg/100 g and 15 mg/100 g respectively	Etemadipoor et al. (2020)
Guava	Galactomannan and carnauba wax	H_2O_2 content decreased by 25 mmol/kg Firmness increased by 30 N	Germano et al. (2019)
Plum	CTS-GB NPs	Browning index and weight loss decreased by 30 % and 5 %, respectively	Mahmoudi et al. (2022)
Pear	Chitosan and salicylic acid	Firmness increased by 10 N	Sinha et al. (2022)
Pomegranate	Chitosan, CMC, oxalic acid or malic	MDA content decreased by 2 nmol/g	Ehteshami et al. (2019)
Strawberry	Chitosan	Firmness increased by 0.2 kg/cm^{-2}	Wang et al. (2020)
Orange	SA and *Aloe vera* gel	Decay index decreased by 4 %, Firmness increased by 3 N	Rasouli et al. (2019)
Mandarin	CMC	Weight loss and CI index decreased by 4.5 % and 1, respectively AsA and total phenolic contents increased by 15 mg/100 g and 100 mg/kg, respectively	Ali et al. (2021)
Banana	Fibroin	CI index and EL decreased by 1 and 3 % respectively	Liu et al. (2019)

(Ehteshami et al., 2019). The firmness of control strawberries decreased significantly on day 4, while there was no significant change in the chitosan coated fruits. The activity of pectin methylesterase (PME) in coated fruits was 13.2 % lower than that in control. On day 12 of storage, the poly-galacturonase (PG) activity of chitosan coated fruits was 21.0 % lower than that of control. The soluble solid content, decay rate and water loss rate of coated fruits were greatly lower than those of control fruits (Wang et al., 2020). After 80 days of storage, decay occurred in most oranges but the SA + *Aloe vera* gel treatment had the lowest decay index. During the first 20 days of storage, total yeast and mold counts continued to decrease in treated fruits, in contrast to the control fruits. At the end of storage, the firmness, titratable acid (TA), soluble solids, AsA, and total phenolic contents of treated fruits were significantly higher than the control (Rasouli et al., 2019). After 30 days of storage, the weight loss of the control mandarin fruits was three times that of the CMC coated mandarin fruits. The coating delayed CI symptoms in the fruits by 12 days. The EL, H_2O_2 and MDA contents of the coated fruits were significantly lower than those of the control. Moreover, the APX, CAT, POD and SOD activities of the coated fruits were higher than those of the control. The AsA, TA, total phenolic contents and DPPH scavenging activity of coated fruits were also increased (Ali et al., 2021). When fibroin was wrapped on the bananas surface, it formed a film to regulate the diffusion and exchange of water vapor, O_2 and CO_2, and reduced the respiration rate. The decline of soluble sugar and ATP level in the coated bananas was slowed. Coating treatment up-regulated the transcriptional level of *MaATPase1* and *MaAAC1* genes and down-regulated the transcriptional level of *MaAOX1* and *MaUCP1* genes (Liu et al., 2019).

4.4. Combination of physical and chemical methods for controlling CI

Table 5 summarizes certain combination of physical and chemical methods for controlling CI, including cold shock (CS) combined with oxalic acid (OA) treatment, low temperature conditioning combined with MeJA, atmosphere packaging (MAP) combined with 1-methylcyclopropene (1-MCP) and hot water (45 °C, 15 min) combined with methyl salicylate (MS, 0.05 mmol/L).

Green bell peppers were treated with CS and OA. The CI index and weight loss of the treatment group were 46.2 % and 39.6 % lower than those of the control, respectively. The chlorophyll content was about 8.5 % higher than the control. Moreover, the AsA content, proline content and enzyme activities of treated fruits were much higher than those of other treatments (Wang et al., 2022b). The CI index of bell pepper fruits treated with low temperature and MeJA was greatly lower. The MDA content in the treated fruits was 0.0065 mol/kg, which was 15 % lower than that in the control. The AsA content, chlorophyll content, POD, CAT and APX enzyme activities in the fruits treated with low temperature combined with MeJA were much higher than the control (Wang et al., 2019b). Sweet persimmons were treated with MAP and 1-methylcyclopropene (1-MCP). The respiratory activity of treatment group was significantly lower. The firmness of control group, 1-MCP treatment group and MAP + 1-MCP treatment group were 42.6 N, 100.7 N and 106.6 N at the 70th day, respectively. Moreover, ethylene production in the control group reached the peak on the 28th day, while MAP + 1-MCP treatment group reached the peak on the 49th day (Zhao et al., 2020). The EL, CI index, weight loss, MDA content, H_2O_2 content and $O_2^{\bullet -}$ content of sweet peppers treated by hot water combined with methyl salicylate were significantly lower than those of other treatments. Moreover, the AsA content, total phenolic content, DPPH scavenging activity, APX, CAT, POD, and SOD enzymes activities of treated fruits were significantly higher (Rehman et al., 2021).

Table 5
Combination of physical and chemical methods for CI control.

Fruits and vegetables	CI control methods	Changes of quality after treatment	References
Green bell pepper	Treated with CS and OA	CI index and weight loss decreased by 22 % and 2 %, respectively The AsA content, proline content and enzyme (SOD, CAT, APX, GR, P5CS, OAT) activities of treated group were significantly higher	Wang et al. (2022b)
Bell pepper	Low temperature conditioning combined with MeJA	Reduced the CI index and MDA content The AsA content, chlorophyll content, POD, CAT and APX enzyme activities were significantly higher	Wang et al. (2019b)
Persimmon	Treated with MAP and 1-MCP	Kept the firmness and cell integrity Reduced the respiratory rate, ethylene production, EL, MDA content, LOX, PPO, POD enzyme activities	Zhao et al. (2020)
Sweet pepper	Hot water combined MS treatment	Overall visual quality index increased by 3 CI index and weight loss decreased by 35 % and 4 %, respectively	Rehman et al. (2021)
Bamboo shoot	Melatonin combined with UV-C	Reduced the lignification Increased the contents of fatty acids and flavonoids Regulated the metabolic pathways of phenylalanine, tyrosine and shikimic acid	Liu et al. (2023)
Akebia trifoliate fruit	Chitosan combined with hot shock	Reduced the cracking incidence Maintained the strength and structure of the cell wall	Jiang et al. (2022)

5. Conclusions and prospects

CI causes the quality of fruits and vegetables that are not cold-tolerant to decrease during low temperature storage. Therefore, it is of great significance to explore the mechanism of CI and the control methods. This paper reviewed the CI control methods, CI symptoms and physicochemical properties of certain common fruits and vegetables in recent years. These methods are classified as physical methods, chemical methods, physical combined with chemical methods and coating methods. These methods mainly reduce CI in fruits and vegetables by protecting the normal function of membrane system, enhancing antioxidant and enzyme activities, and inhibiting the expression of CI genes. Traditional heat shock treatment, near-freezing temperature storage and chemical compounds (APS, 1-MCP, GABA, MeJA) treatments are widely used because of their low cost and ease of operation. However, certain research results show that these single traditional techniques are not as effective as certain new techniques, such as coating technology and physicochemical combination, in controlling CI in fruits and vegetables.

After harvesting, fruits and vegetables may be stored and sold multiple times. Therefore, this poses higher requirements for CI control technology when stored alternately at low temperature and room temperature. The correlation between physical treatment intensity and CI response of fruits and vegetables needs to be further determined. Researches on the mechanisms of using chemical compounds to control CI are relatively mature. However, high concentration chemical compounds may exacerbate CI symptoms. Therefore, the mechanisms of high concentration chemical compounds disrupting the metabolic pathways in fruits and vegetables are also worth exploring. Additionally, the effects of new technologies such as intermittent electromagnetic field treatment, pulsed light treatment, ultrasonic treatment and physical treatment combined with coating or chemical materials on cold response genes of fruits and vegetables need to be explored.

CRediT authorship contribution statement

Jiaxin Wu: Writing – original draft. **Rui Tang:** Writing – review & editing. **Kai Fan:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

Aghdam, M. S., Jannatizadeh, A., Luo, Z. S., & Paliyath, G. (2018). Ensuring sufficient intracellular ATP supplying and friendly extracellular ATP signaling attenuates stresses, delays senescence and maintains quality in horticultural crops during postharvest life. *Trends in Food Science & Technology, 76*, 67–81.

Alba-Jiménez, J. E., Benito-Bautista, P., Nava, G. M., Rivera-Pastrana, D. M., Vázquez-Barrios, M. E., & Mercado-Silva, E. M. (2018). Chilling injury is associated with changes in microsomal membrane lipids in guava fruit (Psidium guajava L.) and the use of controlled atmospheres reduce these effects. *Scientia Horticulturae, 240*, 94–101.

Albornoz, K., Zhou, J., Yu, J., & Beckles, D. M. (2022). Dissecting postharvest chilling injury through biotechnology. *Current Opinion in Biotechnology, 78*, Article 102790.

Ali, S., Anjum, M. A., Ejaz, S., Hussain, S., Ercisli, S., Saleem, M. S., & Sardar, H. (2021). Carboxymethyl cellulose coating delays chilling injury development and maintains eating quality of 'Kinnow' mandarin fruits during low temperature storage. *International Journal of Biological Macromolecules, 168*, 77–85.

Ali, S., Anjum, M. A., Nawaz, A., Ejaz, S., Anwar, R., Khaliq, G., Hussain, S., Ullah, S., Hussain, R., Saleem, M. S., & Hasan, M. U. (2022). Postharvest γ-aminobutyric acid application mitigates chilling injury of aonla (Emblica officinalis Gaertn.) fruit during low temperature storage. *Postharvest Biology and Technology, 185*, Article 111803.

Bokhary, S. U. F., Wang, L., Zheng, Y. H., & Jin, P. (2020). Pre-storage hot water treatment enhances chilling tolerance of zucchini (Cucurbita pepo L.) squash by regulating arginine metabolism. *Postharvest Biology and Technology, 166*, Article 111229.

Chen, L. L., Shan, W., Cai, D. L., Chen, J. Y., Lu, W. J., Su, X. G., & Kuang, J. F. (2021). Postharvest application of glycine betaine ameliorates chilling injury in cold-stored banana fruit by enhancing antioxidant system. *Scientia Horticulturae, 287*, Article 110264.

Cui, K., Zhao, H., Sun, L., Yang, L., Cao, J., & Jiang, W. (2019). Impact of near freezing temperature storage on postharvest quality and antioxidant capacity of two apricot (Prunus armeniaca L.) cultivars. *Journal of Food Biochemistry, 43*, e12857.

Du, H., Liu, G., Hua, C., Liu, D., He, Y., Liu, H., Kurtenbach, R., & Ren, D. (2021). Exogenous melatonin alleviated chilling injury in harvested plum fruit via affecting the levels of polyamines conjugated to plasma membrane. *Postharvest Biology and Technology, 179*, Article 111585.

Duan, W., Ngaffo Mekontso, F., Li, W., Tian, J., Li, J., Wang, Q., & Xu, X. (2022). Alleviation of postharvest rib-edge darkening and chilling injury of carambola fruit by brassinolide under low temperature storage. *Scientia Horticulturae, 299*, Article 111015.

Duong, N. T. C., Uthairatanakij, A., Laohakunjit, N., Jitareerat, P., & Kaisangsri, N. (2022). An innovative single step of cross-linked alginate-based edible coating for maintaining postharvest quality and reducing chilling injury in rose apple cv. 'Tabtimchan' (Syzygium samarangenese). *Scientia Horticulturae, 292*, Article 110648.

Ehteshami, S., Abdollahi, F., Ramezanian, A., Dastjerdi, A. M., & Rahimzadeh, M. (2019). Enhanced chilling tolerance of pomegranate fruit by edible coatings combined with malic and oxalic acid treatments. *Scientia Horticulturae, 250*, 388–398.

Etemadipoor, R., Mirzaalian Dastjerdi, A., Ramezanian, A., & Ehteshami, S. (2020). Ameliorative effect of gum arabic, oleic acid and/or cinnamon essential oil on chilling injury and quality loss of guava fruit. *Scientia Horticulturae, 266*, Article 109255.

Fan, Z., Lin, B., Lin, H., Lin, M., Chen, J., & Lin, Y. (2022). γ-Aminobutyric acid treatment reduces chilling injury and improves quality maintenance of cold-stored Chinese olive fruit. *Food Chemistry: X, 13*, Article 100208.

García-Pastor, M. E., Serrano, M., Guillén, F., Zapata, P. J., & Valero, D. (2020). Preharvest or a combination of preharvest and postharvest treatments with methyl jasmonate reduced chilling injury, by maintaining higher unsaturated fatty acids, and increased aril colour and phenolics content in pomegranate. *Postharvest Biology and Technology, 167*, Article 111226.

Ge, Y., Chen, Y., Li, C., Wei, M., Li, X., Li, S., Lu, S., & Li, J. (2019). Effect of trisodium phosphate dipping treatment on the quality and energy metabolism of apples. *Food Chemistry, 274*, 324–329.

Germano, T. A., Aguiar, R. P., Bastos, M. S. R., Moreira, R. A., Ayala-Zavala, J. F., & de Miranda, M. R. A. (2019). Galactomannan-carnauba wax coating improves the antioxidant status and reduces chilling injury of 'Paluma' guava. *Postharvest Biology and Technology, 149*, 9–17.

Golestan Hashemi, F. S., Ismail, M. R., Rafii, M. Y., Aslani, F., Miah, G., & Muharam, F. M. (2018). Critical multifunctional role of the betaine aldehyde dehydrogenase gene in plants. *Biotechnology & Biotechnological Equipment, 32*, 815–829.

Habibi, F., Ramezanian, A., Rahemi, M., Eshghi, S., Guillen, F., Serrano, M., & Valero, D. (2019). Postharvest treatments with gamma-aminobutyric acid, methyl jasmonate, or methyl salicylate enhance chilling tolerance of blood orange fruit at prolonged cold storage. *Journal of the Science of Food and Agriculture, 99*, 6408–6417.

Hou, Y. Y., Wang, L., Zhao, L. Y., Xie, B., Hu, S. Q., Chen, G. F., Zheng, Y. H., & Jin, P. (2022). $CaCl_2$ mitigates chilling injury in loquat fruit via the CAMTA5-mediated transcriptional repression of membrane lipid degradation genes. *Food Research International, 162*.

Hu, S., Hou, Y., Zhao, L., Zheng, Y., & Jin, P. (2023). Exogenous 24-epibrassinolide alleviates chilling injury in peach fruit through modulating PpGATA12-mediated sucrose and energy metabolisms. *Food Chemistry, 400*, Article 133996.

Huang, Q., Qian, X., Jiang, T., & Zheng, X. (2019). Effect of eugenol fumigation treatment on chilling injury and CBF gene expression in eggplant fruit during cold storage. *Food Chemistry, 292*, 143–150.

Islam, M., Ali, S., Nawaz, A., Naz, S., Ejaz, S., Shah, A. A., & Razzaq, K. (2022). Postharvest 24-epibrassinolide treatment alleviates pomegranate fruit chilling injury by regulating proline metabolism and antioxidant activities. *Postharvest Biology and Technology, 188*, Article 111906.

Jiang, Y., Yin, H., Wang, D., Zhong, Y., & Deng, Y. (2022). Combination of chitosan coating and heat shock treatments to maintain postharvest quality and alleviate cracking of Akebia trifoliate fruit during cold storage. *Food Chemistry, 394*, Article 133330.

Jiao, J., Jin, M., Liu, H., Suo, J., Yin, X., Zhu, Q., & Rao, J. (2022). Application of melatonin in kiwifruit (Actinidia chinensis) alleviated chilling injury during cold storage. *Scientia Horticulturae, 296*, Article 110876.

Kantakhoo, J., Ose, K., & Imahori, Y. (2022). Effects of hot water treatment to alleviate chilling injury and enhance phenolic metabolism in eggplant fruit during low temperature storage. *Scientia Horticulturae, 304*, Article 111325.

Khademi, O., Ashtari, M., & Razavi, F. (2019). Effects of salicylic acid and ultrasound treatments on chilling injury control and quality preservation in banana fruit during cold storage. *Scientia Horticulturae, 249*, 334–339.

Kong, X.-M., Ge, W.-Y., Wei, B.-D., Zhou, Q., Zhou, X., Zhao, Y.-B., & Ji, S.-J. (2020). Melatonin ameliorates chilling injury in green bell peppers during storage by regulating membrane lipid metabolism and antioxidant capacity. *Postharvest Biology and Technology, 170*, Article 111315.

Ktenioudaki, A., O'Donnell, C. P., & do Nascimento Nunes, M. C., (2019). Modelling the biochemical and sensory changes of strawberries during storage under diverse relative humidity conditions. *Postharvest Biology and Technology, 154*, 148-158.

Li, C. H., Wang, K. T., Xu, F., Lei, C. Y., Jiang, Y. B., & Zheng, Y. H. (2021). Sucrose metabolism and sensory evaluation in peach as influenced by β-aminobutyric acid (BABA)-induced disease resistance and the transcriptional mechanism involved. *Postharvest Biology and Technology, 174*.

Li, X., Yang, H., & Lu, G. (2018). Low-temperature conditioning combined with cold storage inducing rapid sweetening of sweetpotato tuberous roots (Ipomoea batatas (L.) Lam) while inhibiting chilling injury. *Postharvest Biology and Technology, 142*, 1–9.

Li, Y., Zhao, Y., Zhang, Z., He, H., Shi, L., Zhu, X., & Cui, K. (2022). Near-freezing temperature storage improves shelf-life and suppresses chilling injury in postharvest apricot fruit (Prunus armeniaca L.) by regulating cell wall metabolism. *Food Chemistry, 387*, Article 132921.

Liu, D., Wang, F., Brennan, C., Benjakul, S., Xiao, G., Ying, X., & Ma, L. (2023). Combined melatonin and UV-C treatment maintains the quality of fresh-cut bamboo shoots during storage by altering microbial diversity and metabolites. *Postharvest Biology and Technology, 200*.

Liu, H., Pei, H., Jiao, J., Jin, M., Li, H., Zhu, Q., Ma, Y., & Rao, J. (2021). 1-Methylcyclopropene treatment followed with ethylene treatment alleviates postharvest chilling injury of 'Xuxiang' kiwifruit during low-temperature storage. *Food Control, 130*, Article 108340.

Liu, J., Li, F., Li, T., Yun, Z., Duan, X., & Jiang, Y. (2019). Fibroin treatment inhibits chilling injury of banana fruit via energy regulation. *Scientia Horticulturae, 248*, 8–13.

Mahmoudi, R., Razavi, F., Rabiei, V., Gohari, G., & Palou, L. (2022). Application of Glycine betaine coated chitosan nanoparticles alleviate chilling injury and maintain quality of plum (Prunus domestica L.) fruit. *International Journal of Biological Macromolecules, 207*, 965–977.

Molla, S. M. H., Rastegar, S., Omran, V. G., & Khademi, O. (2022). Ameliorative effect of melatonin against storage chilling injury in pomegranate husk and arils through promoting the antioxidant system. *Scientia Horticulturae, 295*, Article 110889.

Nian, Y., Wang, N., Li, R., Shao, Y., & Li, W. (2022). Cold shock treatment alleviates chilling injury in papaya fruit during storage by improving antioxidant capacity and related gene expression. *Scientia Horticulturae, 294*, Article 110784.

Niazi, Z., Razavi, F., Khademi, O., & Aghdam, M. S. (2021). Exogenous application of hydrogen sulfide and γ-aminobutyric acid alleviates chilling injury and preserves

quality of persimmon fruit (Diospyros kaki, cv. Karaj) during cold storage. *Scientia Horticulturae, 285*, Article 110198.
Nukuntornprakit, O.-A., Luengwilai, K., & Siriphanich, J. (2020). Chilling injury in pineapple fruit is related to mitochondrial antioxidative metabolism. *Postharvest Biology and Technology, 170*, Article 111330.
Palma, F., Carvajal, F., Jiménez-Muñoz, R., Pulido, A., Jamilena, M., & Garrido, D. (2019). Exogenous γ-aminobutyric acid treatment improves the cold tolerance of zucchini fruit during postharvest storage. *Plant Physiology and Biochemistry, 136*, 188–195.
Phornvillay, S., Pongprasert, N., Wongs-Aree, C., Uthairatanakij, A., & Srilaong, V. (2019). Exogenous putrescine treatment delays chilling injury in okra pod (Abelmoschus esculentus) stored at low storage temperature. *Scientia Horticulturae, 256*, Article 108550.
Rasouli, M., Koushesh Saba, M., & Ramezanian, A. (2019). Inhibitory effect of salicylic acid and Aloe vera gel edible coating on microbial load and chilling injury of orange fruit. *Scientia Horticulturae, 247*, 27–34.
Rehman, R. N. U., Malik, A. U., Khan, A. S., Hasan, M. U., Anwar, R., Ali, S., & Haider, M. W. (2021). Combined application of hot water treatment and methyl salicylate mitigates chilling injury in sweet pepper (Capsicum annuum L.) fruits. *Scientia Horticulturae, 283*, Article 110113.
Rey, F., Rodrigo, M. J., Diretto, G., & Zacarias, L. (2021). Effect of fruit shading and cold storage on tocopherol biosynthesis and its involvement in the susceptibility of Star Ruby grapefruit to chilling injury. *Food Chemistry: Molecular Sciences, 3*, Article 100037.
Salazar-Salas, N. Y., Chairez-Vega, D. A., Vega-Alvarez, M., González-Nuñez, D. G., Pineda-Hidalgo, K. V., Chávez-Ontiveros, J., Delgado-Vargas, F., & Lopez-Valenzuela, J. A. (2022). Proteomic changes in mango fruit peel associated with chilling injury tolerance induced by quarantine hot water treatment. *Postharvest Biology and Technology, 186*, Article 111838.
Sanches, A. G., Pedrosa, V. M. D., Checchio, M. V., Fernandes, T. F. S., Mayorquin Guevara, J. E., Gratão, P. L., & Teixeira, G. H. d. A., (2021). Polyols can alleviate chilling injury in 'Palmer' mangoes during cold storage. *Food Control, 129*, 108248.
Shi, F., Li, X., Meng, H., Wei, W., & Wang, Y. (2020). Reduction in chilling injury symptoms by hot electrolyzed functional water treatment may function by regulating ROS metabolism in Satsuma orange fruit. *LWT - Food Science and Technology, 125*, Article 109218.
Sinha, A., Gill, P. P. S., Jawandha, S. K., & Grewal, S. K. (2022). Composite coating of chitosan with salicylic acid retards pear fruit softening under cold and supermarket storage. *Food Research International, 160*, Article 111724.
Sun, H., Luo, M., Zhou, X., Zhou, Q., Sun, Y., Ge, W., Wei, B., Cheng, S., & Ji, S. (2020). Exogenous glycine betaine treatment alleviates low temperature-induced pericarp browning of 'Nanguo' pears by regulating antioxidant enzymes and proline metabolism. *Food Chemistry, 306*, Article 125626.
Tian, J., Xie, S., Zhang, P., Wang, Q., Li, J., & Xu, X. (2022). Attenuation of postharvest peel browning and chilling injury of banana fruit by Astragalus polysaccharides. *Postharvest Biology and Technology, 184*, Article 111783.
Vega-Alvarez, M., Salazar-Salas, N. Y., López-Angulo, G., Pineda-Hidalgo, K. V., López-López, M. E., Vega-García, M. O., Delgado-Vargas, F., & López-Valenzuela, J. A. (2020). Metabolomic Changes in Mango Fruit Peel Associated with Chilling Injury Tolerance Induced by Quarantine Hot Water Treatment. *Postharvest Biology and Technology, 169*, Article 111299.
Vichaiya, T., Faiyue, B., Rotarayanont, S., Uthaibutra, J., & Saengnil, K. (2022). Exogenous trehalose alleviates chilling injury of 'Kim Ju' guava by modulating soluble sugar and energy metabolisms. *Scientia Horticulturae, 301*, Article 111138.
Villanueva, E., Fujibayashi-Yoshii, N., Matsuzaki, S., Yamazaki, K., Burana, C., & Yamane, K. (2019). Effects of trehalose and sucrose on the vase life and physiology of cut astilbe (Astilbe × arendsii arends) flowers. *The Horticulture Journal, 88*, 276–283.
Wang, F., Yang, Q., Zhao, Q., & Li, X. (2022). Cold shock treatment with oxalic acid could alleviate chilling injury in green bell pepper by enhancing antioxidant enzyme activity and regulating proline metabolism. *Scientia Horticulturae, 295*, Article 110783.
Wang, K., Li, T., Chen, S., Li, Y., & Rashid, A. (2020). The biochemical and molecular mechanisms of softening inhibition by chitosan coating in strawberry fruit (Fragaria x ananassa) during cold storage. *Scientia Horticulturae, 271*, Article 109483.
Wang, L., Chen, S., Shao, J., Zhang, C., Mei, L., Wang, K., Jin, P., & Zheng, Y. (2022). Hydrogen sulfide alleviates chilling injury in peach fruit by maintaining cell structure integrity via regulating endogenous H_2S, antioxidant and cell wall metabolisms. *Food Chemistry, 391*, Article 133283.
Wei, C., Ma, L., Cheng, Y., Guan, Y., & Guan, J. (2019). Exogenous ethylene alleviates chilling injury of 'Huangguan' pear by enhancing the proline content and antioxidant activity. *Scientia Horticulturae, 257*, Article 108671.
Xiao, J., Gu, C., Zhu, D., Chao, H., Liang, Y., & Quan, S. (2022). Near-freezing temperature (NFT) storage alleviates chilling injury by enhancing antioxidant metabolism of postharvest guava (Psidium guajava L.). *Scientia Horticulturae, 305*, Article 111395.
Yan, F., Zhang, D., Wang, X., Liu, C., & Zhang, F. (2022). Reduction of postharvest diseases of loquat fruit by serine protease and possible mechanisms involved. *Scientia Horticulturae, 304*.
Yan, J., Zhang, J., Hu, C., Deng, L., & Ritenour, M. A. (2020). Use of carvacrol and thymol in shellac coating to control stem-end rot on 'Ruby Red' grapefruit and maintain fruit quality during simulated storage and marketing. *Scientia Horticulturae, 272*, Article 109606.
Yao, M., Ge, W., Zhou, Q., Zhou, X., Luo, M., Zhao, Y., Wei, B., & Ji, S. (2021). Exogenous glutathione alleviates chilling injury in postharvest bell pepper by modulating the ascorbate-glutathione (AsA-GSH) cycle. *Food Chemistry, 352*, Article 129458.
Zhang, M., Liu, W., Li, C., Shao, T., Jiang, X., Zhao, H., & Ai, W. (2019). Postharvest hot water dipping and hot water forced convection treatments alleviate chilling injury for zucchini fruit during cold storage. *Scientia Horticulturae, 249*, 219–227.
Zhang, W., Jiang, H., Cao, J., & Jiang, W. (2021). Advances in biochemical mechanisms and control technologies to treat chilling injury in postharvest fruits and vegetables. *Trends in Food Science & Technology, 113*, 355–365.
Zhang, W., Zhao, H., Jiang, H., Xu, Y., Cao, J., & Jiang, W. (2020). Multiple 1-MCP treatment more effectively alleviated postharvest nectarine chilling injury than conventional one-time 1-MCP treatment by regulating ROS and energy metabolism. *Food Chemistry, 330*, Article 127256.
Zhao, H., Jiao, W., Cui, K., Fan, X., Shu, C., Zhang, W., Cao, J., & Jiang, W. (2019). Near-freezing temperature storage enhances chilling tolerance in nectarine fruit through its regulation of soluble sugars and energy metabolism. *Food Chemistry, 289*, 426–435.
Zhao, Q., Jin, M., Guo, L., Pei, H., Nan, Y., & Rao, J. (2020). Modified atmosphere packaging and 1-methylcyclopropene alleviate chilling injury of 'Youhou' sweet persimmon during cold storage. *Food Packaging and Shelf Life, 24*, Article 100479.
Zhao, Y., Tang, J., Brummell, D. A., Song, C., Qi, S., Lin, Q., Bi, J., & Duan, Y. (2022). Abscisic acid alleviates chilling injury in cold-stored peach fruit by regulating the metabolism of sucrose. *Scientia Horticulturae, 298*, Article 111000.
Zhu, Y., Wang, K., Wu, C., Hao, Y., Zhang, B., Grierson, D., Chen, K., & Xu, C. (2021). DNA hypermethylation associated with the development of temperature-dependent postharvest chilling injury in peach fruit. *Postharvest Biology and Technology, 181*, Article 111645.
Zuo, X., Cao, S., Zhang, M., Cheng, Z., Cao, T., Jin, P., & Zheng, Y. (2021). High relative humidity (HRH) storage alleviates chilling injury of zucchini fruit by promoting the accumulation of proline and ABA. *Postharvest Biology and Technology, 171*, Article 111344.