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MINI REVIEW

A review on chilling injury and antioxidant metabolism of pineapple (*Ananas comosus*)

Tarmizi, N.H.A. and *Dolhaji, N.H.

Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA Cawangan Melaka Kampus Jasin, 77300 Merlimau, Malaysia

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Abstract

Pineapple (*Ananas comosus*) is an economically significant crop as Malaysia is one of the countries that produce and export pineapples. Improper postharvest management is one of the factors that will adversely affect crop yields. Low-temperature storage is a commonly used postharvest technology to prolong fruit life and maintain its condition. This review is conducted to understand the chilling injury (CI) and antioxidant metabolism in pineapple fruits. CI can be divided into: i) causes and symptoms that appeared on chilled-injured crops, and ii) the mechanism associated with plants injured by chilling temperature while antioxidant metabolism can be divided into; i) mechanism of action and ii) classification of antioxidants. There are two leading theories associated with the source of CI which is membrane variability that relates to fatty acid and reactive oxygen species (ROS) induction. Antioxidants have many benefits, especially to human health and different antioxidants can have different beneficial effects. Understanding the cause, symptoms and action mechanism of CI will contribute to early prevention and proper crop handling practices. CI was also understood to have a correlation with antioxidant metabolism that relates to ROS. This review provides a collection of information and an in-depth understanding of CI and antioxidants in pineapple thus, it is extremely helpful for researchers to create new studies or make further research on existing studies because they can see the shortcomings entirely. Research and studies on CI and antioxidants in pineapple are believed to have prominent economic values.

1. Introduction

Pineapple (*Ananas comosus*) belongs to the *Bromeliaceae* family and the *Bromeliodeae* subfamily (Meagan, 2012a; ITIS, 2021). Pineapple is among the five most important tropical fruits (Maia *et al.*, 2020) and is the third-highest produced fruit in the world following bananas and citrus fruits (Wali, 2018). Hundreds of pineapple varieties exist all over the world but only six to eight varieties are pioneered by the world market (Ding and Syazwani, 2016) and four main classes are grouped for the numerous pineapple cultivars in international trade, that is 'Smooth Cayenne', 'Queen', 'Red Spanish', and 'Abacaxi' (ITFNET, 2016), despite many types of variations in each class of pineapple (Joy *et al.*, 2013). As of 2018, Malaysia has a total of more than 17,601 hectares of pineapple plantation (Ministry of Agriculture and Agro-Based Industry Malaysia, 2018). The state with the most pineapple crops is Johor which accounts for 57% (8,934.53 Ha) followed by Sabah with (988 hectares) and Sarawak (972.48 Hectares).

Malaysia is one of the world's pineapple suppliers and pineapple production is one of the essential agricultural areas in the country (Lasekan and Hussein, 2018; Nurul Hidayah and Fazleen, 2019). Pineapples are an extremely nutritious fruit and rich in antioxidants (WebMD, 2020) such as phenolic compounds, vitamin C, and β-carotene (Chiet *et al.*, 2014). Pineapple has an active metabolism and high moisture content that makes it perishable (Dolhaji *et al.*, 2020; Sarkar *et al.*, 2020). Final fruit quality is primarily determined by postharvest handling (Hussein *et al.*, 2020), as the fruits undergo deterioration after harvest (Joy and Rajuva, 2016; Liu *et al.*, 2019; Wahab and Khairuddin, 2020; Pott *et al.*, 2020). Improper postharvest treatment will adversely affect crop yields (Manzar and Rejaul, 2020). The most common postharvest technology used is low temperatures treatment during storage (Mercado *et al.*, 2018; Pérez-Gago and Palou, 2020) in order to lengthen the life of fruits and maintain their condition after harvesting, as the speed of cell metabolism will be decelerated along with extending the senescence and

*Corresponding author.
Email: *noer_hartini@uitm.edu.my*

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ripening of fruits (Aghdam, 2012; Hong *et al.*, 2013; Wang *et al.*, 2018; Sun *et al.*, 2020).

However, an undesirable condition has occurred against plants stored at low temperatures known as chilling stress which leads to chilling injury (CI). CI causes a negative influence on the consumer acceptability (Giné-Bordonaba *et al.*, 2016), and is one of the very overwhelming postharvest disorders that can befall after low-temperature storage which can result in substantial rejection or downgrade of fruit in the market (Golding, 2019; Lo'ay and Dawood, 2019; Sangprayoon *et al.*, 2020; Liang *et al.*, 2020). One hypothesis of this review is, that chilling injury and antioxidant metabolism might be related to each other and to date there are no existing reviews on the relationship between chilling injury (CI) and antioxidant metabolism. A thorough understanding of the chilling injury would aid in preserving the value characteristics of fruits by enhancing the procedure and methods of fruit handling. In addition, before it gets worse, any action that will harm the crop can be prevented and avoided from the outset. Research on antioxidants has economic importance and commercialization value since antioxidants can provide far-reaching benefits, not only to human health, but also for fruits, and many more aspects to be explored.

2. Low-temperature storage and chilling injury

Much research has indicated that temperature is potentially the most important element in the production of pineapple (Marrero and Kader, 2006; Meagan, 2012b; Das and Bhattacharyya, 2017). They continue to suggest that production and growth are favourably associated with temperature, with 15-20°C minimum temperatures (Meagan, 2012b; Jonathan, 2019). After the pineapple is harvested, the recommended storage temperatures are around 7 to 12°C (Paull *et al.*, 2014), but it may vary among cultivars. For instance, cv. *Phulae* is found to be more high quality when stored at 20°C compared to 10°C (Sukporn *et al.*, 2019). Low-temperature storage is a post-harvest technology commonly used to store harvested crops as it is believed to be able to prolong the life of fruits after harvest (Pott *et al.*, 2020; Sun Lin *et al.*, 2020), owing to the fact that cold temperature storage makes pineapple competent to keep more water in the fruit.

Subsequently, the rate of respiration will be repressed or inhibited hence, the glucose and oxygen decomposition forming carbon dioxide and water will drop off (Rahmadhanni *et al.*, 2020). Chilling injury (CI) is a complex physiological condition caused by exposure to low temperatures (0–20°C) and is not caused by a disease (Luengwilai *et al.*, 2016; Golding, 2019). CI involves many physiological events identifiable (Nukuntornprakit *et al.*, 2020). Harvested fruit remains receptive to environmental stimuli as a living organ even though separated from the supportive tissues (Valenzuela *et al.*, 2017). To overcome stresses generated by exposure to low non-freezing temperatures, plants can elicit a cascade of measures that instigate deviations in gene expression and thus enhance their tolerance by inducing modifications physiologically and also biochemically (Theocharis *et al.*, 2012).

3. Chilling injury in pineapple

Pineapples are under the subtropical category of fruits that make them warm or temperate seasonal fruit and vulnerable to chilling injury (CI) (Peng *et al.*, 2013; Sun *et al.*, 2015; Butu and Rodino, 2019; Agribook, 2020). For pineapple, not all the fruit regions experienced CI, it has a specific location. Referring to the cross-section of pineapple fruit (Figure 1), the "core" is the fruit's central area that attaches to the pineapple plant stem while the peduncle, perianth, and bracts produce an edible portion is the 'flesh'. The area where CI started is the "flesh adjacent to the core" (flesh/core). Internal browning (IB) is a typical pineapple's CI main symptom that has been discussed widely (Zhang *et al.*, 2016; Luengwilai *et al.*, 2018; Dolhaji *et al.*, 2019; Mendes *et al.*, 2019; Nukuntornprakit *et al.*, 2020; Sangprayoon *et al.*, 2020).

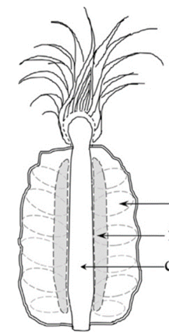

Figure 1. Schematic representation of a longitudinal section of a pineapple fruit that involves in Chilling injury. Source: Luengwilai *et al.* (2016)

Internal browning (IB) occurs at the flesh/core region is a familiar symptom of CI in pineapple fruit as vascular bundles are localized to this area. Waterlogging (water soaking) of the pulp, beginning near to the heart, was the original CI symptom. This was accompanied by the spread of the water to the pulp, soaking both within the heart and outside. The water-soaked areas consequently shifted to a slightly brownish hue (Nukuntornprakit *et al.*, 2020). The metabolic malfunction from chilling-induced membrane damage is the product of IB in pineapple. Endogenous brown patch, physiological breakdown, blackheart, and internal browning (Figure 2) are signs of chilling damage and develop after the fruit is restored to physiological temperatures of 15 to 30°C (Paull *et al.*, 2014).

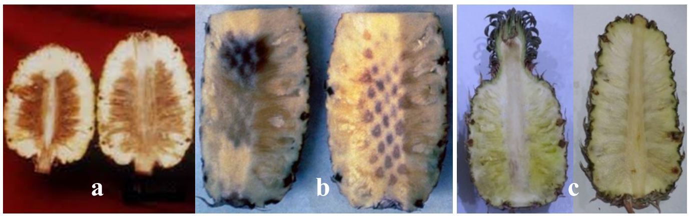

Figure 2. CI symptoms: a) Blackheart (Hassan *et al.*, 2010), b) Brown spot (Kader, 1996), c) Slight internal browning. Source: Dolhaji *et al.* (2019)

4. Mechanism of chilling injury

According to Nukuntornprakit (2020), there are two leading hypotheses associated with the source of chilling injury. The first one is the change in membrane variability that relates to fatty acid and the second one is stimulation of reactive oxygen species (ROS) production (Nukuntornprakit *et al.*, 2020). Membranes of cells are the primary site of chilling injury. Cell membrane damage is an early chilling injury reaction, and chilling fruit injury stored at low temperatures can result in loss of membrane-associated protein function, including ethylene receptors (Jiang *et al.*, 2004). Phospholipids, a complex family of compounds consisting of a hydrophilic head group covalently bound to a pair of hydrophobic fatty acids, are mainly composed of biological membranes and form bilayers (Libretexts, 2019). While the bilayers manage to exist under physiological conditions in the fluid phase, under some environmental conditions, their component phospholipids can undergo phase transitions (Alberts *et al.*, 2002; Liang *et al.*, 2020).

4.1 Membrane variability

The first theory is where the membrane becomes rigid because of the phase transition of the lipid component beginning with liquid or fluid-crystalline phase to gel-solid condition (Figure 3) that will lead to various maladaptive consequences (Nievola *et al.*, 2017). Steponkus *et al.* (1984) suggested that the disruption of the plasma membrane was the primary cause of chilling injury thus it can be assumed that structure and function alteration of the plasma membrane is the primary occurrence for CI (Liang *et al.*, 2020). In addition, membrane lipids unsaturation level is associated with crop's chilling sensitivity (Einset *et al.*, 2007) where it is believed that more susceptible plants or crops have greater saturated fatty acid residues in the lipids while a less susceptible one is high in desaturation of fatty acid contents (Pareek *et al.*, 2014; Liang *et al.*, 2020).

Numerous earlier studies that support the hypothesis of membrane variability came from analyses on the mitochondria of crops (Uritani and Yamaki, 1969; Lyons, 1973; Kane *et al.*, 1978). A study from Lyons *et al.* (1964) discovered a larger intensity of lipid unsaturation in the membranes of mitochondria that relates the relationship between the sensitivity of plants to chilling temperature and the physical complexion of cellular membranes (Parkin *et al.*, 1989). For instance, findings from Nievola *et al.* (2017) that uses two hybrid varieties of sweet sorghum; M81-E and Roma, proposes that during the initial stress exposure, the greater unsaturation intensity would shield the photosynthetic system that ensures a better tolerance to chilling.

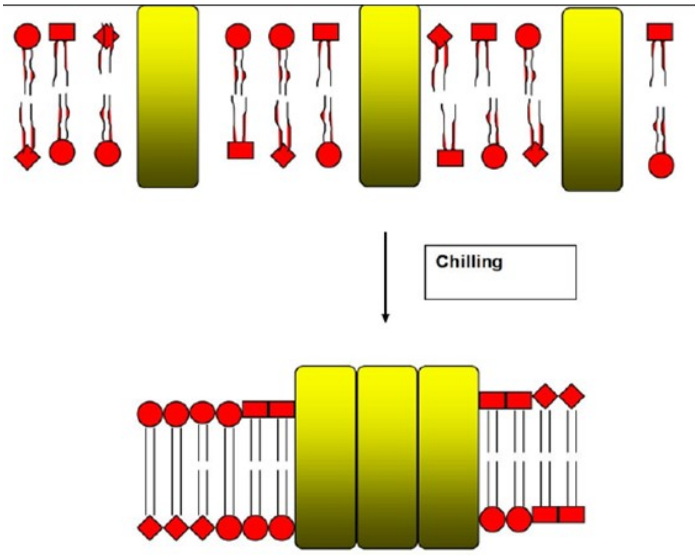

Figure 3. Illustration of phase separation-driven protein aggregation Source: LibreTexts (2020)

4.2 Induction of ROS

Loss of membrane fluidity is the primary signal for cold response pathways that then lead to an increase in reactive oxygen species (ROS) development (Nievola *et al.*, 2017). The second theory states that the indication of chilling injury (CI) is caused by the damaging action of ROS where chilling action will elevate the level of ROS (Nukuntornprakit *et al.*, 2020). The antioxidant mechanism is used by many species to regulate the escalation of ROS and thereby leads to cooling resistance. ROS, under cold conditions, for instance, hydrogen peroxide (H_2O_2) is produced (Meitha *et al.*, 2020). Peroxidation of membrane lipids by H_2O_2 will result in degraded outcomes such as malondialdehyde (MDA) (Nukuntornprakit *et al.*, 2015).

All living organisms utilize oxygen to metabolize and use the dietary nutrients to produce energy for survival. Oxygen thus is a vital component for living. Oxygen meditates chemical reactions that metabolize fats, proteins, and carbohydrates to produce energy. However, these processes may produce excess reactive species or free radicals that will result in unfavourable oxidative deviations (Bunaciu *et al.*, 2016). Generally,

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Reactive Oxygen Species (ROS) generation starts with express oxygen uptake, followed by NADPH oxidase activation, hence the superoxide anion radical construction (Nimse and Pal, 2015) thus it is also termed oxygen radical (Wang *et al*., 2019). Free radicals are unstable atoms. To become more stable, they take electrons from other atoms. This may cause diseases or signs of ageing (Villines, 2017).

5. Antioxidants

Pineapple is a wonderful source of antioxidants Lawler, 2019). Antioxidants are compounds competent in slowing or suppressing oxidation processes developing under the influence of ROS (Naji *et al*., 2020). It also helps alleviate oxidative stress in the human body (Raman and MS, 2018). Without having themselves unstable, antioxidants will donate an electron to a free radical. This stabilizes the free radicals and reduces their reactivity of the free radicals (Megan Dix, 2018). For self-protection purposes in opposition to oxidative stress, plants will up-regulate the metabolism of antioxidant enzymes (Hu *et al*., 2018). Antioxidants are substances that when present at very low concentration inhibit the oxidation of a substrate molecule (Francenia Santos-Sánchez *et al*., 2019).

Antioxidants can be classified in several ways such as based on solubility or their activity. The antioxidants can be categorized as hydrophilic (water-soluble) and lipophilic (lipid-soluble) antioxidants based on their solubility in the water or lipids (Nimse and Pal, 2015). To put it simply, hydrophilic is the opposite of hydrophobic in that it does not repel water (BD, 2017) while lipophilic (PhysiologyWeb, 2012) means the compounds are readily passed across a lipid bilayer. Based on their activity, antioxidants can be classified as enzymatic and nonenzymatic antioxidants (Azat Aziz *et al*., 2019). Generally, water-soluble antioxidants will react with ROS whereas the fat-soluble antioxidants commonly shield the cell membranes from lipid peroxidation caused by ROS (Lazzarino *et al*., 2019).

Enzymatic and non-enzymatic antioxidants subsisted inside cells to eradicate reactive oxygen species. Enzymatic antioxidants will break down and eliminate free radicals while non-enzymatic antioxidants operate by intersecting with the chain reactions of free radicals (Nimse and Pal, 2015). Many non-enzymatic antioxidants are not naturally synthesized by the human body but are obtained from organic nutritional sources consumption (Bunaciu *et al*., 2012). In these pathways, superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx) and glutathione reductase predominantly partake significant functions. Plants change the levels of manifestation of these enzymes to react with oxidative stresses. According to much research, cells that are exposed to oxidative stresses will increase their SOD, CAT and GPx regulation so that they can resist stress (Blokhina *et al*., 2003; Behrouzi *et al*., 2015; González-Olmedo *et al*., 2018; Hu *et al*., 2018; Cai *et al*., 2019; Jiang *et al*., 2021).

5.1 Antioxidants in pineapple

5.1.1 Ascorbic acid

In extracellular fluids, ascorbic acid (AsA) or vitamin C, is a water-soluble vitamin or enzyme (Szalay, 2019) that primarily exists as the ascorbate anion beneath physiological pH conditions, ascending from the entirely disassociated 3-hydroxyl group (Macan *et al*., 2019). AsA responsible in scavenging ROS and its ascorbate form is efficient against the singlet oxygen, hydroxyl radical, H_2O_2, water-soluble peroxyl radicals and superoxide radical anion (Stahl and Sies, 2001) since it exists as a reduced agent (Murray and Rodriguez, 2004). In the cells' aqueous condition or phases, by removing peroxyl radicals before initiation of peroxidation, AsA is a great and effective antioxidant that can safeguard biomembranes against the damage caused by peroxidation of lipid (Martinello and Luiz da Silva, 2006). AsA will lose electrons in order to achieve stability of ROS molecules while also having purposes as a cofactor of enzymes (Azat Aziz *et al*., 2019).

5.1.2 Phenolic acids (PAs)

Phenolic acids (PAs), are members of a broad group of phenolic compounds, in the category of secondary metabolites which are commonly dispersed in the kingdom of plants (Bento-Silva *et al*., 2020). In general, phenolic acids (PAs) classify phenolic compounds that contain one carboxylic acid group (Kumar and Goel, 2019). The essential constituents of food are known to contribute to flavour, colour and nutritional properties (Bento-Silva *et al*., 2020). Conditional on agricultural and technical conditions, phenolic compounds diverge among species and their profile is highly variable (Arola-Arnal *et al*., 2019). Hydroxycinnamic acid hydroxybenzoic acid are two principal classes of phenolic acids, which are the derivation from cinnamic acid or benzoic acid skeletons respectively (Menon *et al*., 2016; Jiang *et al*., 2021). PAs are formed by the phenylpropanoid pathway via shikimic acid, through the rundown of cell wall polymers involving lignin during the monolignol pathway as by-products, and some are also produced by microbes (Kumar and Goel, 2019). In plants, hydroxycinnamic acid is typically distributed, and involves conjugate reaction with quinic, shikimic and tartaric acids or with amino acids or amines that makes it normally appear as esters or amides respectively (Bento-Silva *et al*., 2020).

5.1.3 Flavonoids

Out of all plant phenolics, flavonoids comprise one of the most abundant groups, comprising more than part of the 8000 compounds of natural polyphenols (Hui *et al.*, 2013). According to Watson (2019), in plants, the existence of flavonoids is primarily as colouring pigments. Likewise, at various levels, it acts as a very powerful antioxidant (Watson, 2019). Variations in substitution patterns to ring C result in the major flavonoid classes, i.e., flavones, flavanones, flavanols (or catechins), isoflavones, flavanonols, and anthocyanidins (Villines, 2017). Some chemical structures and action mechanisms of flavonoid subclasses as shown in (Table 1) (Zuiter, 2014).

6. Relationship between chilling injury and antioxidant metabolism

It is hypothesized that chilling injury (CI) is correlated with antioxidant metabolism. To deduce the hypothesis, several existing studies can be referred to. Firstly, Dolhaji *et al.* (2019) use 3 Malaysian cv.; *Josapine*, *Morris* and *MD-2*. They observed a non-enzymatic antioxidant that is ascorbic acid (AsA) content in cv. *MD-2* was significantly higher compared to cv. *Josapine* and cv. *Morris*. The chilling injury that is reflected with IB symptoms can be seen in (Figure 4) where the IB occurrence in cv. *MD-2* is almost non-existent while cv. *Josapine* and cv. *Morris* experienced IB at the flesh/core region.

Besides, research by Nukuntornprakit *et al.* (2015) used two pineapple cultivars that are cv. *Trad-See-Thong* and cv. *Pattavia*. Total antioxidant capacity in both cultivars was analyzed to testify that the development of CI was related to ROS metabolism by antioxidants. They found that cv. *Trad-See-Thong* has lower ascorbate peroxide (APX) activity compared to cv. *Pattavia*. As shown in (Figure 5), the percentage of CI of cv. *Trad-See -Thong* increases when stored at a low temperature (10°C) while cv. *Pattavia* remains constant. As a result, it can be concluded that CI symptoms are interrelated with total antioxidant capacity.

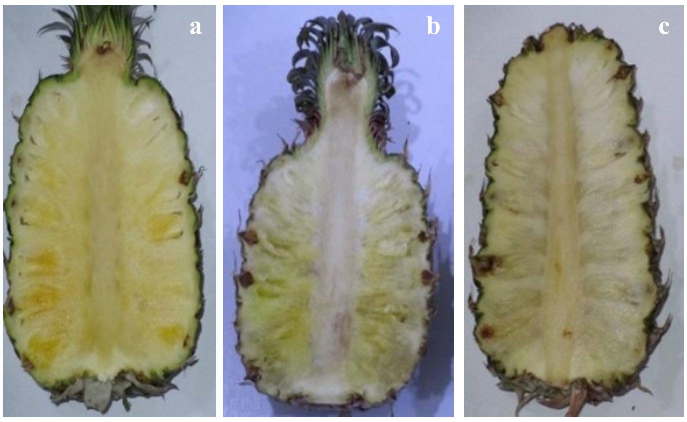
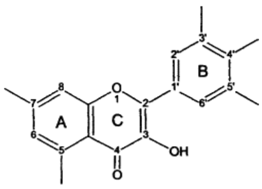
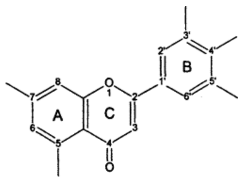
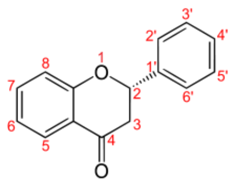
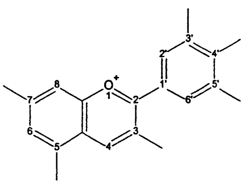


Figure 4. Development of IB in a) cv. *MD-2*, b) cv. *Josapine* and c) cv. *Morris* after 28 days of storage in low temperature Source: Dolhaji *et al.* (2019)

In addition, research on postharvest treatment named anoxic treatment was used by Phonyiam *et al.* (2016) to increase antioxidant metabolism and reduce IB symptoms for harvested pineapple. They use the DPPH

Table 1. Structures and action mechanism of flavonoid subclasses

No.	Structures	Description	Action Mechanism
1		Flavonols: Presence of a hydroxyl group at position 3 (Pietta *et al.*, 2003)	Can chelate metal cations rapidly because of neighboring hydroxyl-keto functional groups' existence.
2		Flavones (Pietta *et al.*, 2003): No C-ring at position 3	Interfere in events related to oxidative stress by decreasing the free radicals' intracellular levels (Marcelo *et al.*, 2015)
3		Flavanones: Lack double bond on C2 (Nazzaro *et al.*, 2020)	The double bond between positions 2 and 3 is saturated thus making the radical scavenging process possible (Panche *et al.*, 2016)
4		Anthocyanidins: Heterocyclic C-3 ring (Celli *et al.*, 2018).	Anthocyanidins are said to control a weak antioxidant action (Kähkönen and Heinonen, 2003)

assay to determine the antioxidant activity where an increase in DPPH activity will match up with the increase in IB appearance. They found that antioxidants such as glutathione and AsA content increase when treated with an anoxic treatment. Hence, the fruit becomes resistant to CI that is IB even when stored at 10°C for 28 days after treatment where it can be seen (Figure 6) that no IB symptoms are appearing on the fruit that is treated with anoxic treatment (Phonyiam *et al.*, 2016).

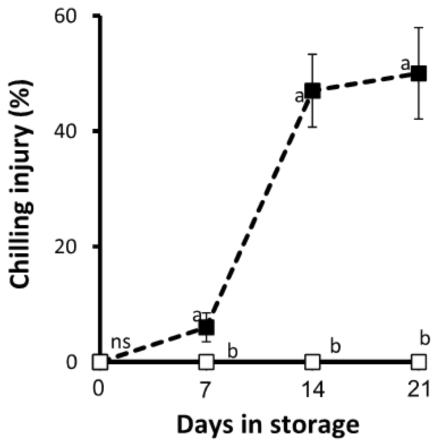


Figure 5. IB symptom of both cv. *Trad-See-Thong* (black) and cv. *Pattavia* (white) when stored at 10°C. Data are means ± SD of 3 replications, each containing 5 fruits. Different notations above data labels are statistically significant different (P<0.05). ns, not significant. Source: Nukuntornprakit *et al.* (2015)

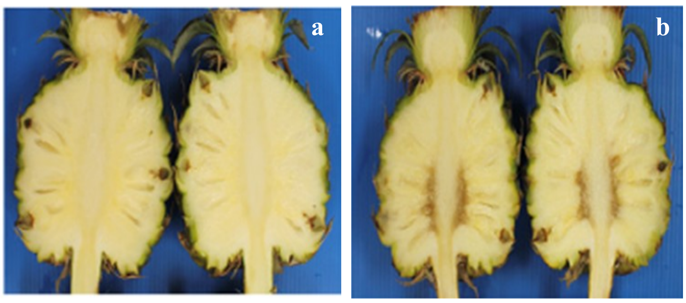


Figure 6. IB in *Phulae* pineapple was; a) treated with anoxic treatment, b) untreated. Source: Phonyiam *et al.* (2016)

Moreover, Dolhaji *et al.* (2020) used 2 Malaysian cv.; *Josapine* and *Morris* also proved that chilling injury is closely related to antioxidant metabolism. As shown in modified (Table 2) from Dolhaji *et al.* (2020), *Morris* IB score is higher than *Josapine* as antioxidant activity in *Josapine* is higher than *Morris* making it more resistant to CI. Therefore, it is believed that crops with higher antioxidant metabolism are less susceptible to CI (Dolhaji *et al.*, 2020).

Furthermore, there is also research done to observe the effect of a substance named Methyl Jasmonate (MeJA) which is believed will enhance the antioxidant system metabolism in pineapple when applied to it (Nilpprapruck *et al.*, 2008; Boonyaritthongchai and Supapvanich, 2017). The membrane structure of pineapple fruit and its system will be maintained by triggering antioxidant metabolism. They found that the occurrence of antioxidants such as AsA and superoxide dismutase (SOD) will convert quinone to phenols, thus delaying or decreasing the symptom of IB. Boonyaritthongchai and Supapvanich (2017) applied MeJA to 'Queen' pineapple cv. *Trad-See-Thong* and stored for 20 days at 10°C. A big difference can be observed (Figure 7) between the control pineapple and the one applied with MeJA where IB can be observed clearly on the flesh of the control while it was almost non-existent on the other.

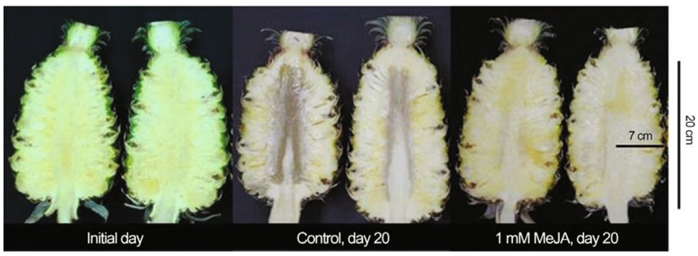


Figure 7. Observation of IB for cv. *Trad-See-Thong* when applied MeJA. Source: Boonyaritthongchai and Supapvanich (2017).

Meanwhile, besides pineapple, the relationship between CI and antioxidant metabolism has also been shown in other crops. Research by Wang and Zhu (2017) conducted on cucumber for cold storage and shipping has also demonstrated that chilling injury can be inhibited by enhancing four enzymatic and two non-enzymatic antioxidants that will scavenge ROS. The antioxidants will work by obstructing reactive oxygen species (ROS) that are MDA, O_2•– and H_2O_2 (Wang and Zhu, 2017). Similar outcomes were obtained for citrus (Shi *et al.*, 2020), longan (Lin *et al.*, 2015), mandarin fruits (Sala and Lafuente, 2000,) and many more.

To put it simply, plants or crops that are exposed to non-freezing, but the low temperature will experience chilling stress and induction of ROS will be triggered

Table 2. IB percentage for cv. *Morris* and cv. *Josapine*

Cultivars	CI, IB Score (%)				
	Day 0	Day 7	Day 14	Day 21	Day 28
Josapine	0.00±0.00^a	0.67±1.07^a	1.33±1.08^a	3.33±2.88^a	26.33±0.75^a
Morris	0.00±0.00^a	1.33±1.96^a	2.66±1.98^a	9.66±2.62^b	27.67±2.57^a

Values are expressed as mean±SD of 3 replications. Values with different superscripts within a row are significantly different ($p < 0.05$). Source: Dolhaji *et al.* (2020).

(Nukuntornprakit *et al.*, 2020) thus causing chilling injury to occur (Das and Bhattacharyya, 2017). Antioxidants that are present in the fruits will reduce or prevent the symptom and occurrence of CI. Antioxidants will metabolize and react with free radicals. In addition, every antioxidant has its own mechanism of action, and it is believed that each antioxidant varies among the others (Martinello and Luiz da Silva, 2006; Francenia Santos-Sánchez *et al.*, 2019; Jing *et al.*, 2020).

7. Conclusion

To sum up, the plant will experience chilling injury when exposed to a low temperature and will cause the plants to modify their gene expression to enhance tolerance, inducing physiological modification and biochemically. Visible symptoms of the chilling injured plant include black heart, brown spot, and internal browning (IB). Membrane fluidity and ROS induction are the main hypotheses explaining the chilling damage. Antioxidants will inhibit the harmful oxidation progression and their action mechanism varies according to certain classifications, some will remove and break down free radicals while some only interrupt free radical chain reactions. Antioxidant metabolisms partake a wide range of valuable and favourable effects, especially on human well-being and health. This review evidenced that chilling injury and antioxidant metabolism are related where plants with higher antioxidants will be more resistant to chilling temperatures and hence will be of assistance in inventing solutions to CI by utilizing antioxidants.

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