EFFECTS OF SALICYLIC ACID AND HOT WATER TREATMENTS ON POSTHARVEST QUALITY OF ‘NAM DOK MAI SI THONG’ MANGO

FATOU DARBOE

MASTER OF SCIENCE

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EXAMINATION COMMITTEE

Varit Srilaong ....CHAIRPERSON
(Assoc. Prof. Varit Srilaong, Ph. D.)

Sutthiwal Setha ....ADVISOR
(Asst. Prof. Sutthiwal Setha, Ph. D.)

Matchima Naradisorn ....EXAMINER
(Asst. Prof. Matchima Naradisorn, Ph. D.)

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Author	Fatou Darboe
Degree	Master of Science (Postharvest Technology and Innovation)
Advisor	Asst. Prof. Sutthiwal Setha, Ph. D.

ABSTRACT

The efficacy of different concentrations of salicylic acid (SA) and hot water treatment (HW) on postharvest quality of mango cv. Nam Dok Mai under cold storage at 13°C was evaluated. Mango (120 fruit) was divided into four different treatments including HW (49°C, 10 min), 1 mM SA + HW, 2 mM SA + HW and untreated fruits served as control treatment. After treatment, fruit was packed in paper boxes and stored at 13°C. Analyzes were performed at 5-day intervals for 20 days. Fruit firmness, weight loss, skin color (chroma and hue angle), total soluble solids (TSS), acidity (%) and percentage of disease incidence were measured. The results showed that fruits immersed in 2 mM SA + HW retained their firmness significantly. Weight loss was increased during storage in all treatments. The highest weight loss was observed in HW treatment with 10% weight loss, while 2 mM SA + HW and 1 mM SA + HW were 6%. The skin color of untreated fruits showed deep yellow color at the end of storage while treated mangoes showed lighter yellow color. In color indices, the results showed the highest value of hue angle in the treated fruits while the untreated control showed the highest chroma value. TSS was high in the control while TA showed high value in the sample with 2 mM SA + HW.

In addition, effect of SA and hot water treatment on physiological and biochemical attributes of mango fruit during storage was investigated. Postharvest quality (color, firmness, TSS and TA), bioactive compounds (total phenolic compound (TPC), vitamin C and carotenoid contents), percentage, disease incidence were observed under ambient (25°C) and cold storage (13°C). The treatments were separated as the following: (1) control (untreated) (2) HW (3) 2 mM SA (4) 2 mM SA+HW. At 13°C, the color indices, hue angle was high in the treated fruit while, chroma was the highest value on the untreated control. TSS was high in the control while TA increased in the sample treated with SA + HW. The result showed that the fruits treated with SA + HW retained their firmness significantly. Regardless of treatment, weight loss was increased throughout storage. Disease incidence was significantly lower in SA + HW treated fruits during storage. The content of bioactive compounds such as TPC and vitamin C remained higher in the treated fruits, while the content of carotenoids was higher in the control fruits, but not significantly. At 25°C, the color indices hue angle was high in the treated fruits and chroma was increased in the untreated control fruits. TSS decreased in treated fruits, while TA decreased in untreated control fruits. Firmness decreased throughout the storage period irrespective of treatment. However, weight loss was less in fruit treated with SA + HW compared to control. The incidence of diseases was also lower in the fruits treated with SA + HW than in the control. The treatment, especially SA 2 mM + HW application subsequent by storage at 13°C, could be used commercially as postharvest treatments for Nam Dok Mai mango.

Keywords: Hot Water Treatment, Mango Fruit, Postharvest Quality, Salicylic Acid

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CHAPTER 1

INTRODUCTION

1.1 Background and Significance of the Research Problem

Mango (*Mangifera Indica* L) is one of the oldest and most vital fruits and is the most important crop in the world after banana, with some of the world's largest producers such as India, China, Thailand, Mexico, Pakistan, Brazil, the Philippines and Egypt (FAO, 2017). In Thailand, the main mango growing areas are in the middle of the country, although they are now grown throughout the country (Matulaprungsan et al., 2019). Among mango cultivars, Nam Dok Mai Si Thong is a high commercial value in both domestic and international markets. Mango fruit is a good source of polyphenols, ascorbic acid, carotenoids, vitamins and carbohydrates (Singh, Singh, Sane & Nath, 2013). The nutritional properties of mango, particularly antioxidants, are important for human health as they have been reported to boost the immune system and also prevent cardiovascular diseases, cataracts and various cancers (Muhammad, Ashiru, Kanoma, Sani & Garba, 2014; Sivakumar, Jiang & Yahia, 2011). Especially in developed regions, mango consumption has been increasing dramatically for decades (Brecht & Yahia, 2009; Yahia, 2005, 2006). Mango is a climacteric fruit and susceptible to several postharvest diseases such as anthracnose and physiological disorders like chilling injury, spongy tissue, and lenticel spots. Unfortunately, these individual problems or their combination can lead to postharvest losses and economic losses for growers and all those involved in the management of the postharvest supply chain. A significant proportion of mango losses occur during storage and transportation due to poor handling and inadequate facilities (Sivakumar et al., 2011).

As a postharvest treatment is known to extend shelf-life by reducing the disease incidence triggered by pathogens and chilling damage during postharvest storage (Barman, Asrey, Pal, Jha & Bhatia, 2014). However, there are growing concerns about the use of such postharvest chemical treatments to induce harmful impact on the environment and human health. As a result, there is a strict need to focus on the less harmful chemical additives or other minimal processing additive free techniques for mangoes that could be ecofriendly and will not leave chemical residues to risk the life of consumers.

Thermal treatment is another additive free technique, has been reported to be effective in reducing postharvest diseases, fruit softening, and color preservation of mango (Dautt-Castro et al., 2018; Le, Shiesh & Lin, 2010; Luria et al., 2014; Wang et al., 2016). Hot water treatment (HWT), also called hydrothermal treatment is the widely used process at minimum cost and easy to operate (Zakariya & Alhassan, 2014). Heat treatments have become popular in the fruit industry in the last decade and are used in many countries to control postharvest diseases and pests because they are fungicidal and insecticidal. However, it has been reported to affect the quality of fruits (Anwar & Malik, 2007; Sivakumar et al., 2011) depending on the treatment temperature, duration, commodity, variety, size or weight and maturity stage of the fruit (Jacobi, MacRae & Hetherington, 2001). Heat treatment is reported to affect fruit quality, promote ripening, stimulate ethylene synthesis, increase respiration rate, soften mesocarp by breaking cells and cell wall metabolism, damage outer skin, affect pigment metabolism, volatile production, carbohydrate metabolism, increase β-galactosidase activity and disease development (Jha et al., 2010; Ngamchuachit, Barrett & Mitcham, 2014; Talcott, Moore, Lounds-Singleton & Percival, 2005). Kim, Brecht and Talcott (2007) reported that mangoes treated with HWT decreased major polyphenols (gallic acid and gallotannins) and total phenolics while retaining antioxidant capacity. Therefore, HWT needs to be further investigated for its effects on the nutritional quality of mangoes.

Exogenous application of salicylic acid (SA) at permissible levels could improve tolerance to pathogens and reduce postharvest decay (Asghari & Babalar, 2010; Asghari, Hajitagilo & Jalilimarandi, 2009; Babalar, Asghari, Talaei & Khosroshahi, 2007). SA at a concentration of 1 to 2 mM has been shown to retard fungal decay in Selva strawberry fruit (Babalar et al., 2007). Postharvest treatment of fruits with 1 and 2 mM potentially prolonged the shelf life of strawberry plants at vegetative and fruit development stages (Babalar et al., 2007). Immersion of pear fruits in 1 mM

SA solution-controlled fruit deterioration during 5 months cold storage (Asghari et al, 2009). SA enriched with chitosan coating significantly reduced fungal growth and biochemical quality changes of table grapes during postharvest storage (Asghari et al, 2009). As reported by Barman et al. (2014), treatment with SA was able to reduce chilling injury and disease incidence in mango fruit during cold storage. SA plays an important role in regulating a variety of physiological processes in plants (Reddy & Sharma, 2016).

Although HWT has been used as a commercial treatment for mango, this treatment may result in weight loss and decreased firmness, which facilitates mango fruit ripening. To overcome this problem, this research aims to evaluate the effects of SA and HWT and their combination on postharvest quality of mango. The effects of SA and HWT on the physiological and biochemical quality changes of mango fruit were also studied during storage periods at 13°C and 25°C, respectively.

1.2 The Objective of the Study

1.2.1 To evaluate the effectiveness of different salicylic acid (SA) concentration and hot water treatment (HWT) on postharvest quality of mango cv. Nam Dok Mai Si Thong under cold storage at 13°C.

1.2.2 To investigate the influence of SA and HWT on physiological and biochemical changes of mango cv. Nam Dok Mai Si Thong under ambient temperature (25°C) and cold storage (13°C).

1.3 Scope of Research

1.3.1 Screening of effective concentration of SA (1 mM and 2 mM) and HWT (49°C, 10 min) to delay ripening of Nam Dok Mai Si Thong mango during stored at 13°C .

1.3.2 Evaluation of the combined effects of SA and HWT on the physical and biochemical changes of Nam Dok Mai Si Thong mango stored at 25°C and 13°C for 12 days and 20 days, respectively.

1.4 Expected Benefits

1.4.1 Research Outcome

The result of this study can summarize a simple method of SA and HWT immersion technique for other mango cultivars, which is environmentally friendly and delays ripening during the harvest season. This formulation treatment together with cold storage conditions could prevent postharvest losses of mangoes and thus counteract economic losses in domestic and export markets.

1.4.2 Research Output

This study provides information on the combined treatment of SA and HWT as a dip solution for Nam Dok Mai Si Thong mango with promising results on the overall quality attributes during storage at 13°C for 20 days and 25°C for 12 days respectively.

CHAPTER 2

LITERATURE REVIEWS

2.1 Mango (*Mangifera Indica* L.)

Mango is popular fruit as seen its appearance in Figure 2.1 it remains the best essential tropical fruit international in relations of consumption (attractive odor and taste) nutritive significance. The fruit belongs to the Anacardiacea family (Tharanathan, Yashoda & Prabha, 2006). Mango cultivation and global occupation remain regularly increasing (Singh et al., 2013). Presently, Asia remains the leading producer as shown in Table 2.1 by production of which Thailand is the third exporting country of mango about 3,803 tons of mango traded worldwide (FAO, 2017). Nam Dok Mai is the major mango variety in Thailand for domestic consumption and export (Chomchalow, Somsri & Songkhla, 2008). Mango is a climacteric fruit exhibiting a climacteric pattern of respiration and an increase in ethylene production during ripening (Brecht & Yahia, 2009; Lalel, Singh & Tan, 2003; Reddy & Srivastava, 1999). The flesh of the ripe mango ranges between various colors such as greenish yellow, yellow orange in most cultivars (Yahia, 2011). Mango fruit contain various numbers of bioactive compounds such as vitamin C, beta carotene and polyphenolics that contribute towards antioxidant and nutritional properties (Sivakumar et al., 2011)

Figure 2.1 Appearance of 'Nam Dok Mai Si Thong' Mango Fruit

2.2 Mango Characteristics

Mango fruit is a fleshy drupe containing of peel (epicarp) and ripe skin (mesocarp) close to a fibrous, hard stone (endocarp) comprising a single seed. There are huge changes in size, shape, color and physical appearances among unlike varieties ranging from below 80 to above 800 g (Yahia, 2011). The fruit can be segregated into three parts, i.e., exocarp, the portion that protects the fruit that is firstly green and advanced modifications to yellow or reddish or orangish dependent on the variety and phase of maturing, and waxy. With progressive phase of ripeness and maturing, chlorophyll content drops and carotenoids and/or anthocyanins tend to rise (Tharanathan et al., 2006). The mesocarp is the pulp consumable share or the flesh, which is continuously yellow due to the presence of carotenoids (de Jesús Ornelas-Paz, Yahia & Gardea, 2008).

Table 2.1 Total Production of The World's Top Fresh Mango Exporting Countries (Thousand Tons) (2008-2017)

Country	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
India	13997	12750	15026	15188	16196	18002	18431	18527	18643	19506
China	3976	4140	4268	4425	4501	4640	4625	4784	4795	4917
Thailand	2374	2469	2550	2793	3295	3421	3597	3331	3404	3803
Mexico	1716	1509	1632	1827	1760	1901	1754	2069	2197	2283
Pakistan	1753	1727	1845	1888	1700	1658	1716	1636	2159	2331
Brazil	1154	1197	1189	1592	1521	1512	1491	1400	1515	1547
Philippines	897	785	843	800	783	831	899	917	827	748
Egypt	466	534	505	598	786	712	927	1214	1305	1404
Peru	322	170	457	355	188	461	380	349	377	385
Ecuador	201	205	182	176	172	174	170	60	82	70
Guatemala	113	116	110	116	113	115	127	126	124	115

Source FAO (2017)

2.3 Worldwide Importance and Economic Value

Mango production and export are expected to grow further especially in Asia and the Pacific, supported by reasonably strong demand and strong forecast growth in China, Thailand, the Philippines and India. Mango consumption can offer important quantities of bioactive compounds with antioxidant activity (Yahia, 1998). As in Table 2.2 which shows the nutritional value of mango in nutrient per 100 g. Mango fruit comprises diverse classes of phytochemicals such as polyphenols, ascorbic acid and carotenoids, enlightening health supporting properties mostly due to their antioxidant properties (Talcott et al., 2005).

Import to the US takes place throughout the year, but there is a pronounced seasonality in the European market, with a large quantity imported during April to June and October to December quarters (Yahia, Ornelas-Paz & Gardea, 2006). In the Asian region (the Philippines, Malaysia, Indonesia, Singapore and Thailand) there are over 500 cultivars but only a few are cultivated commercially (Yahia, 2006). Mango has been cultivated in India for more than 4000 years, and today its culture is extended in more than 80 countries in tropical and sub-tropical regions. Mango trade is becoming increasingly important in the recent years, about a decade ago mango was an exotic rare fruit in many countries especially in Europe and North America (Yahia, 2005).

2.4 Nutritional Value and Health Benefits

Mango fruit is a source of vitamin C (Table 2.2), and the content decrease during ripening (Yahia, 2005) mango fruit is also a rich in carotenoids some of which are beta carotene and pro-vitamin A (Mercadante, Rodriguez-Amaya & Britton, 1997; Ornelas-Paz, Yahia, & Gardea-Bejar, 2007; Yahia et al., 2006; Yahia & Ornelas-Paz, 2010). Carotenoids are the pigment responsible for the yellow orange color of mango exocarp and mesocarp (Vásquez-Caicedo, Neidhart & Carle, 2002). Furthermore, mangoes are excellent source of dietary antioxidants (bioactive compounds) (Talcott et al., 2005). The mango cv. Nam Dok Mai No.4 comprises entire phenols ~3.42 mg (GAEg-1 DW) and discloses DPPH antioxidant capability extending from10.94 to 28.16 mg GAEg-1 DW (Gorinstein et al., 2011).

Table 2.2 Nutritional Value of Mango

Nutrient	**100g**
Water (g)	81.71
Energy (kcal)	65
Energy (kj)	272
Protein (g)	0.51
Total lipid (fat)(g)	0.27
Ash (g)	0.50
Carbohydrate, by difference (g)	17.00
Fiber, total dietary (g)	1-8
Minerals	
Calcium (mg)	10
Iron (mg)	0.13
Magnesium (mg)	9
Phosphorus (mg)	11
Potassium (mg)	156
Sodium (mg)	2
Zinc (mg)	0.04
Copper (mg)	0.110
Manganese (mg)	0.027
Selenium (µg)	0.6
Vitamin B-6 (mg)	27.7
Vitamin C (total ascorbic acid) (mg)	14
Beta carotene (µg)	445

Table 2.2 (continued)

Nutrient	100g
α- carotene (μg)	17
Beta Cryptoxanthin (μg)	11

Source USDA (2007)

2.4.1 Carbohydrate

Sucrose is the common form of carbohydrate produce during photosynthesis and transferred from source to sink, leading to an increase in TSS in fruit. During fruit ripening the reduction in nonreducing sugar content, mostly sucrose, is related with a rise in reducing sugars fructose and glucose, which results from increasing invertase action. All sucrose phosphate synthase and invertase were induced by the action of ethylene during the ripening process (Asghari & Aghdam, 2010). Mango fruit at matured green phase have some added starch which is mobilized throughout maturing (Subramanyam, Gouri & Krishnamurthy, 1976). Phenomenon is obvious in the chloroplast where the starch granules become progressive smaller as maturing continues (Morga, Lustre, Tunac, Balagot & Soriano, 1979). Furthermore, sucrose appears to be the main sugar that accumulates in the fruit throughout maturing (Castrillo, Kruger & Whatley, 1992). Sucrose and starch metabolism are facilitated by unlike enzymes, then in this sense, a-amylase has been found to rise at smallest fourfold in action throughout mango maturing (Majmudar, 1981; Mattoo, 1975). Sucrose synthesis appears to be the enzyme responsible for sucrose breakdown. It appears likely that sucrose accumulation throughout mango maturing is determined by a balance between synthesis and degradation. This would allow sucrose metabolism to respond sensitively to the stimuli occurring throughout maturing (Castrillo et al., 1992; Mattoo, 1975). Acid inverts action also rises throughout maturing in mango however it does not appear to contribute significantly to sucrose breakdown. In contrast neutral invertase does not change noticeably throughout maturing. Mango maturing attend by rises action of some gluconeogenic enzyme such as glucose-6-phosphatase and fructose-1-6-diphosphatase (Litz, 2003).

2.4.2 Phytonutrients Flavonoids and Carotenoids

2.4.2.1 Flavonoids

Flavonoids are big intimate of plant polyphenolic subordinate metabolites, flavonoids and anthocyanin, have been connected through human well-being. Flavonoids are extremely strong antioxidants, and defend against cardiovascular disease (Jenks & Bebeli, 2011).

2.4.2.2 Carotenoids

Carotenoids are organic pigments that naturally occur in both chloroplast of plant photosynthetic tissue and chromoplasts of non-photosynthetic plant tissue such as fruit and flowers. Carotenoids can be divided in to two groups: xanthophyll and carotenes. The former contain oxygen, whereas the latter are purely hydrocarbons and contain no oxygen (Carvalho, Fraser & Martens, 2013). Carotenoids are the pigments responsible for yellow, orange color of mango exocarp and mesocarp (Vásquez-Caicedo et al., 2002).

2.5 Change in Respiration Rate and Ethylene Production

Ethylene production is a well-known indicator of metabolic activity and has a tremendous impact on the shelf life and quality of mango fruit. During fruit ripening, there is an increase in ethylene production which modulates biochemical changes such as aroma, texture and color changes (Daisy, Nduko, Joseph & Richard, 2020). Khaliq, Mohamed, Ali, Ding and Ghazali (2015) reported that (10%) delayed ethylene climacteric peak by twenty-one days in 'Choke Anan' mango stored at 6°C. Khaliq et al. (2015) reported that ethylene is negatively correlated with firmness during fruit ripening. Reduced ethylene production slows fruit ripening and softening. Conversion of starch to sugar also increases the total soluble solid content, reduced titratable acidity, accumulation of aroma volatiles, increases CO_2 production and ethylene production rates (Ntsoane, Zude-Sasse, Mahajan & Sivakumar, 2019; Sudhakar Rao & Gopalakrishna Rao, 2008).

Endogenous ethylene production and its exogenous use, a gaseous plant hormone that controls fruit ripening in climacteric fruits, which is auto-catalytically synthesized when lightly applied and activates the change for faster and uniform ripening and fruit softening by triggering enzymes (Razzaq, Singh, Khan, Khan & Ullah, 2016). It impacts the gene expression accountable for chlorophyll degradation, carotenoid synthesis, and change of starch to sugars and cell wall inflection (Singh et al., 2013). Nevertheless, mangoes, being climacteric fruits, release comparatively little ethylene and reduce when the fruits are kept at low temperature or unprotected in controlled atmospheres, most of which have very low oxygen content. Therefore, low exogenous ethylene consumption may actually activate the ripening process (Masibo & He, 2008). The effect of ethylene on fruit ripening depends on the variety, ripening stage, storage temperature, exposure time, ethylene and carbon dioxide concentration (Lalel, Singh & Tan, 2003). The effect of ethylene on fruit is associated with climacteric respiration and changes in membrane parameters that include loss of phospholipids and increase in membrane permeability. In unripe fruit, ethylene concentration is lower than the lowest amount needed to initiate ripening to achieve protection against the growth of chilling injury symptoms (Ntsoane et al., 2019).

2.6 Compositional Changes during Fruit Maturation and Ripening

Several important metabolic changes occur during the maturation and ripening of mangoes, some of which are useful as maturity and quality indices (Ketsa, Phakawatmongkol, & Subhadrabhandhu, 1999; Yahia et al., 2006; Yahia, 2005). Sugar changes are very important for the organoleptic properties of the mango fruit. The taste of the fruit is usually a balance between the content of sugars and organic acids and aromatic volatiles (Medlicott, Bhogal & Reynolds, 1986; Yahia, 2005). The increase of soluble sugar is one of the most important changes during the ripening of the mango fruit. It is the most important change in composition related to the flavor of the mango, e.g., sweetness, starch content, which increases during the development of the mango fruit and is almost completely hydrolyzed to simple sugars during ripening (Yahia, 2005).

2.6.1 Quality Losses

Quality losses regularly occur in tightly packed fruit, due to improper transportation and inadequate field handling. Fruit losses during export can vary greatly depending on postharvest handling and the export situation, particularly in relation to decay rates, pests and physiological degradation (Yahia, 1998). Fruit picked earlier than optimal ripeness will moreover certainly not mature or not ever extent ideal quality. Mangoes picked at the matured and partial-matured phase ripen to good quality fruit whereas unripe fruit do not mature usually (Yahia, 2005). Fresh commodity, mango have also been found liable to postharvest fruit decay considerable losses of mango fruit quality has been infected by several postharvest pathogens which result in significant loss in fruit quality. Postharvest disease expansion is a key limitation to the quality and shelf life of mango fruit thus limits domestic and export market (Bally, Lu & Johnson, 2009; Majumdar, Mandal & Nath, 2020) as well as ensuing in substantial economic loss (Barkai-Golan, 2001). Similar outstanding to quick disease growth throughout storing and maturing (Prusky, Kobiler, Miyara & Alkan, 2009). Anthracnose (*Colletotrichum gloeosporioides*) is regarded one of the major postharvest diseases of mango (Bally et al., 2009). Stem end rot (SER) and black spots (i.e., *Alternaria* rot) have also been reported to cause significant postharvest decay in mango (Prusky et al., 2009).

2.6.2 Organic Acids

Organic acids decrease during maturation and ripening of mango fruit, the predominant acids in mature mango fruit are citric, malic and tartaric acids, citric acid being the most dominant and tartaric acid the lowest. Citric acid content increases steadily during fruit development in certain mangoes, reaching a maximum at the beginning of the endocarp hardening period and then decreases steadily (Ito, Sasaki & Yoshida, 1997).

2.6.3 Fruit Softening

Fruit softening and cell wall variations are evident changes related with mango fruit maturing. Softening of mango fruit is categorized by an increase solubility of cell wall pectin (Nasrijal, 1993). Overall water-soluble polysaccharide rises throughout maturing (Brinson, Dey, John & Pridham, 1988), nonetheless water and alkali soluble pectin drop in mangoes and ammonium oxalate soluble pectin rise as fruit becomes softer (Roe & Bruemmer, 1981).

Maturing in mango, as categorized by reduction tissue firmness, is introduced in inner mesocarp tissue near to the seed, and develops outward (Lazan, 1993). Pectin solubilization in inner and outer mesocarp tissue is similar, nevertheless it initiates prior in the inner than in the outer mesocarp (Lazan, Ali, Soh & Talkah, 1992). The outer mesocarp of certain variety of mangoes continue firm and longer than others, and the inner is softer than the outer mesocarp at respective stages of maturing in both cultivars (Mitcham & McDonald, 1992). Mangoes have looser associate to chelator soluble pectin, accumulate more soluble polyuronides and maintain more total pectin, at the ripening stage than other mangoes. The two varieties alike PG action which rises with maturing (Yahia, 2011). Fruit softening in mangoes happens as an outcome of degradation of protopectin and improved soluble pectin (Alves et al., 2004).

2.6.4 Pigment and Color Change

Mango peel color is essential for the observation of total quality and defining the proper ripeness for picking, handling and consumption (Jha, Chopra & Kingsly, 2007). Loss of green color and change in optimal peel color are indicative of mango fruit ripening in many mango varieties. Peel color may vary from dark to olive green, occasionally reddish-blue, which is related to anthocyanin during fruit ripening. Chlorophyll concentration decreases significantly in some mango varieties, while carotenoid concentration improves and anthocyanin decreases progressively in other varieties (Medlicott et al., 1986). The pulp carotenoid level is cultivar dependent. Tongdum mangoes, which ripen without changing color have three times more chlorophyll and slightly more beta carotenoid in the peel and have higher rate of ethylene production compared with Nam Dok Mai mangoes which change from green to yellow upon ripening (Ketsa et al., 1999).

2.6.5 Chilling Injury

Fruit exposure to extremely low temperature below 10°C in some cultivars at different maturity stage result in chilling injury (CI) when exposure for certain period (Singh, Jerath, Singh & Gillm, 2012). Tree ripe mangoes are reported to be less susceptible to CI when stored at 5°C for 2 weeks, while mature green mangoes exposure to temperature below 10°C can lead to abnormal ripening grayish scald like discoloration of the skin, skin pitting reductions in the level of carotenoids, aroma and flavor during ripening and susceptibility to fungal decay (Singh et al., 2013). Figure 2.2 shows the symptoms of chilly injury in 'Nam Dok Mai Si Thong' mango.

Figure 2.2 Chilly Injury Symptoms of 'Nam Dok Mai Si Thong' Mango

2.7 Postharvest Decay

Decay is one of the most important causes of postharvest losses in mango and the major problem in storage and marketing. Mango fruits are affected by several diseases, but the most important are anthracnose caused by *Colletotrichum gloeosporioides* stem-end rot caused by *Gloeosporium mangifera* or *Diplodia natalnensis* and soft blight caused by *Hendersonia creberrima* (Yahia, 2005).

2.7.1 Anthracnose

Anthracnose is the most serious disease in mango growing areas of the world with high rainfall. Infection can occur on the fruit, but also on flowers, leaves, twigs and young branches. Infection of the fruit occurs before harvest. In addition to infection via wounds, the organism can enter the fruit through the cuticle and natural openings on the fruit surface. In the fruit, the infection is latent and begins to develop as the fruit passes through its ripening stage (Figure 2.3) (Yahia, 2005).

Figure 2.3 Anthracnose Disease in Mango (*Mangifera indica* L.)

2.7.2 Stem-End Rot

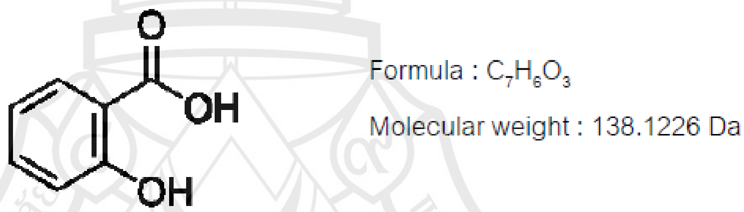
Stem-end rot is the second most common disease after anthracnose in many mango growing areas. The disease usually starts at the stem end of the fruit, but the fungus can affect any other part of the fruit, especially those that are injured during harvesting (Yahia, 2005).

2.8 Postharvest Treatments

The use of postharvest treatments is a fairly old practice of postharvest management, especially for perishable horticultural crops. Chemical treatments such as nitric oxide, salicylic acid, 1-MCP and oxalic acid are commercially used by the mango industry (Ding, Tian, Zheng, Zhou & Xu, 2007; Hong et al., 2014).

2.8.1 Salicylic Acid

Salicylic acid (SA) is an endogenous plant growth regulator that triggers a variety of metabolic and physiological responses in plants, influencing their growth and development (Figure 2.4). SA is a natural and safe phenolic compound that shows great potential in regulating postharvest fruit losses (Asghari & Aghdam, 2010). The use of exogenous SA on harmless application remains current by accumulative resilient to chilling injury trendy postharvest agricultural products, including tomatoes, peppers, cucumbers, peaches, and pineapples. SA is a plant hormone that normalizes several physiological processes in plants (Dempsey & Klessig, 2017). These physiological processes include fruit maturation, resistance to chilling injury and tolerance to postharvest diseases (Ding et al., 2007; Zheng, Tian, Gidley, Yue & Li, 2007). Low temperature storage of mango fruits induces free radicals such as hydrogen peroxide (H_2O_2) and superoxide radicals (O_2, causes oxidative stress and CI (Junmatong et al., 2015). Elevated ROS stages might cause lipid peroxidation leading to decrease membrane integrity and fruit firmness. Junmatong et al. (2015) reported that SA (1 mM) inhibited the accumulation of H_2O_2 and O_2 in 'Nam Dok Mai No. 4' mangoes stored at 5°C for forty-two days. These authors also found that SA treatment improved the actions of CAT, ascorbate peroxidase (APX) and SOD. SA is a signaling molecule that activates gene expression of CAT, SOD, and APX at cold temperatures.



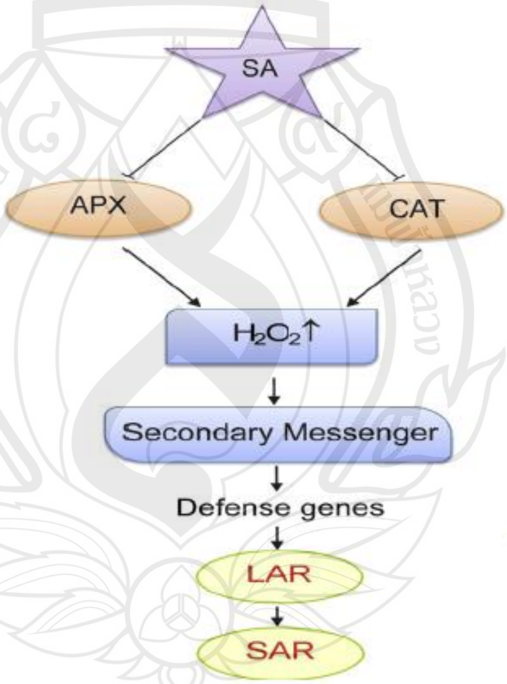
Source Salicylic acid (2020)

Figure 2.4 The Structure of Salicylic Acid

Few years ago, synthetic, fungicides were use as controlling postharvest decay however, the concern of the people about fungicide residues in fresh fruit and its harmful effect of chemicals on human health and environment caused scientists to search for a new alternative to chemical fungicide. The studies show that SA can be introduced as a potential alternative to chemicals as shown in Table 2.3 (Babalar et al., 2007).

Table 2.3 Some Physical Properties of Salicylic Acid

Salicylic acid	
Chemical name	2-Hdroxybenzoic acid
Chemical formula	$C_7H_6O_3$
Molecular mass	138.123g.mol^{-1}
Melting point	211 ^{0}C
Density	1.44g.cm^{-3} (at 20 ^{0}C)
pKa	2.97
CAS number	(69-72-7) a



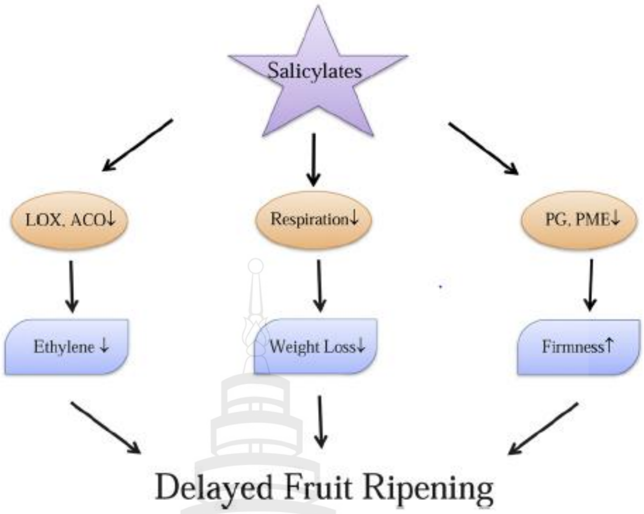
Source Asghari and Aghdam (2010)

Figure 2.5 View of How SA Trigger Resistance System in Plants Against Disease

SA reductions the occurrence of ascorbate peroxidase and catalase genes towards a substantial increase in H_2O_2, which remains crucial for triggering local acquired resistance and systematic acquired resistance as shown in Figure 2.5. Plants resistance for example local acquired resistant LAR and systemic acquired resistant SAR defend them in contradiction of pathogen occurrences (Vlot, Dempsey & Klessig, 2009). Salicylic acid is the major factor in the indicator transduction pathway of plants, which plays an essential role in disease resistance. LAR a systemic defense response is often triggered in plant parts to protect these undamaged tissues from subsequent invasion by pathogens (Asghari & Aghdam, 2010).

2.8.2 Salicylic Acid Delay Ripening

Ethylene plays a key role in fruit ripening and senescence. This hormone triggers the induction of cell wall hydrolyzing enzymes, resulting in an increase in respiration rate, fruit softening, and senescence (Fabi & do Prado, 2019). SA has delayed ripening of banana fruit, perhaps through inhibition of ethylene biosynthesis or act (Srivastava & Dwivedi, 2000). SA reduces ethylene production by reducing ACS and ACO creation and action. As described by (Xu, Chan, Xu & Tian, 2008). SA treatment decreased LOX effect in some fruits associated with free radical formation as well as ethylene biosynthesis. LOX effect via production of superoxide radicals definitely controls ethylene biosynthesis in some fruits. SA accumulated with lower LOX effect and production of superoxide free radicals as well as ACS and ACO effect and finally delayed climacteric ethylene biosynthesis (Todd, Paliyath & Thompson, 1990).



Source Asghari and Aghdam (2010)

Figure 2.6 Schematic Overview of Mechanisms by Which SA Delays Ripening and Extends Storage Life

The physicochemical properties and shelf life of tomato fruits preserved with gibberellic acid (250, 500 and 1000 mg L^{-1}) and SA at 0.2, 0.4 and 0.6 mM•L^{-1} as shown in Figure 2.6 were studied. SA at 0.4 mM•L^{-1} showed an important delay in the change of weight loss, titratable acidity, total soluble solids, decay percentage, sugar accumulation, chlorophyll degradation, carotenoids and lycopene accumulation at room temperature (Mandal, Laldingliana, Hazarika & Nautiyal, 2014).

2.9 Non-Chemical Treatments

Ultraviolet irradiation and heat treatment have been found to be effective in maintaining postharvest quality of mango. These treatments have been successfully used to control postharvest diseases and prolong storage life. Among these treatments, heat treatment is commercially used by mango industry as it is cost effective and easily adopted by mango producers (Sivakumar et al., 2011).

2.9.1 Hot Water Treatment

Post-harvest heat technology has been used on horticultural crops to disinfect and extend shelf life. Hot air (HAT) and hot water treatment (HWT) are some of the inexpensive and commonly used heat treatments. The use of heat as a postharvest treatment of mango fruits has been well researched and documented. For example, HWT at 55 °C for ten minutes suppressed respiration in 'Tainong' mango fruit during storage at 20 °C for six days (Zhang et al., 2012). Similarly, studies on 'Ivory' mango showed that one-minute hot water treatment at 60°C inhibited ethylene production and respiration rate (Wang et al., 2016).

The efficacy of HWT is closely related to its potential to regulate important enzymatic activities that affect the quality characteristics of fresh horticultural produce. The activities of ACC oxidase were shown to be inhibited in hot water treated (46°C, 90 min) 'Keitt' mangoes (Bender, Seibert & Brecht, 2003).

Increased firmness of fruits subjected to HWT prior to long-term cold storage has been reported (Ding & Mijin, 2013). Specifically, heat treatment may induce stress resistance by stimulating antioxidant activities and protective enzymes in treated fruits. Enzymes such as PG, β-galactosidase, α-mannosidase and β-hexosaminidase are involved in cell wall modification and softening in mango fruits (Hossain, Rana, Kimura & Roslan, 2014). HWT (60°C for 1 min) inhibits the cell wall degrading enzyme PG after ten days of storage at 25°C (Wang et al., 2016). Previous studies by Ketsa et al. (1999) showed that HWT at 33°C for three days increased the activity of β-galactosidase caused in 'Nam Dok Mai' mango after eight days of storage at 25°C. This suggests that β-galactosidase may play a greater role in mango fruit softening than PG Sripong et al. (2015) reported rapid fruit softening in 'Chok-Anan' mango immersed in 55°C for five minutes. Dautt-Castro et al. (2018) indicated that HWT (47°C for 5 min) upregulated cell wall genes of β-galactosidase (MiBGAL c23904), pectate lysase (MiPL c20761), polygalacturonases (MiPG c21885), ramnogalaturonase (MiRGL c23797) and small heat shock proteins (MiHSP20 c12121). The ramnogalaturonase gene MiRGL c23797 is involved in the degradation of rhamnogalacturonan and has a physiological role in abiotic stress. Up-regulation of these genes causes an increase in the associated enzymes, leading to rapid fruit softening and ripening. Variation in temperature and HWT time could trigger different responses in terms of gene expression and enzyme activities.

HWT has a tremendous influence on the organoleptic and physicochemical quality characteristics of mangoes. A recent study by Dautt-Castro et al. (2018) showed that HWT (47°C for 5 min) increased the accumulation of TSS in mango 'Ataulfo' during storage at 20°C for eight days. Hot water is known to upregulate the beta-amylase gene MiBAM c23077 involved in starch hydrolysis. The sucrose synthase gene MiSS, c10928, was upregulated by HWT. The upregulation of these genes could lead to rapid starch degradation, increased TSS accumulation and thus enhanced fruit ripening. However, it should be noted that the effect of heat treatments on some quality attributes is cultivar dependent. Le et al. (2010) reported that steam heat treatment at 46.5°C for 40 min had no effect on TSS accumulation in 'Tuu Shien' mango stored at 12°C for three weeks. Therefore, it is critical to develop an appropriate postharvest protocol for each mango cultivar. The same research showed that HWT preserves the color and appearance of the fruit skin. For example, 'Tuu Shien' mango fruit treated with hot water at 50°C for 10 mins retained green color during storage. Dautt-Castro et al. (2018) reported that hot water downregulated chloroplast-like (LHCIIb) (EC4.99.1.1) genes involved in chlorophyll biosynthesis. These researchers found that HWT increased gene expression of anthocyanin-5-aromatic (anthocyanin5a) (EC:2.3.1.144) and UDPglycosyltransferase 85a2-like (85A2) (EC:2.4.1.115), which are involved in anthocyanin accumulation. Increased chlorophyll degradation and anthocyanin production resulted in homogeneous color development of mango fruit.

Hot water treatment is effective in suppressing the severity of CI in mango fruit. Zhang et al. (2012) reported that HWT (55°C for10 min) reduced CI in 'Tainong 1' mango fruits during storage (21 days, 5°C and 5 days, 20°C). The HWT activates lipid-related metabolism in mango fruits during storage at low temperatures. Vega-Alvarez et al. (2020) observed high levels of linolenic acid in 'Keitt' mangoes treated with hot water (46.1°C for 90 min) and stored at 5°C for twenty-one days followed by seven days at 21°C. Similarly, Yimyong, Datsenka, Handa and Seraypheap (2011) observed high levels of lipoxygenase (LOX) in 'Okrong' mango treated with hot water (50°C for ten minutes) and stored at 8°C for fifteen days. The elevated levels of LOX and fatty acids could induce CI tolerance in mango fruits

Hot water treatment on mango fruits has been used over the years as an applicable disease control method hence it is natural, safe and non-chemical. It was later known that dipping of Mango fruits in hot water up to 55°C controlled decay and delay ripening (Zakariya & Alhassan, 2014). Heat treatment has produced firm and acceptance at an enormous scale since the high effectiveness in decreasing the postharvest disease as well as the little cost involve (Spalding, King & Sharp, 1988; Zakariya & Alhassan, 2014). As reported by Ezz and Awad (2011) that the quality of ‘Tommy Atkins’ and Keitt Mangoes are not affected when fruits were treated with hot water at 46°C for 90 min and store for 3 days at 13°C and successively ripe at 24°C.

It is critical to consider the various factors that influence the effectiveness of heat treatments. These factors include stage of maturity, varieties, exposure time, and temperature. Fruit size is another critical factor to consider when applying heat treatments. It is well known that small fruits are easily damaged compared to larger fruits (Sivakumar & Fallik, 2013). In addition, immature fruits are less heat tolerant than mature fruits; due to internal decay that may occur when exposed to heat (Sivakumar & Fallik, 2013; Sivakumar et al., 2011). Mechanical damage and poor quality have been reported after heat treatment. For example, Osuna-Garcia, Brecht, Huber and Nolasco-Gonzalez (2015) observed lens damage and dark browning spots in 'Kent' mangoes treated at 46.1 °C for 90 min. Increasing the temperature or exposure time may lead to heat-induced injury, firmness and weight loss resulting in rapid fruit deterioration. It is therefore important to consider all these factors when using heat as a treatment for fresh mango fruit.

CHAPTER 3

METHODOLOGY

3.1 Materials

3.1.1 Raw Material

Freshly harvested Nam Dok Mai Si Thong mangoes were used as a raw material which were purchased from a commercial farm in Phichit province, Thailand maturity was at 80-90% matured.

3.1.2 Chemicals

Ascorbic acid, metaphosphoric acid, acetic acid, sodium bicarbonate, 2, 6-dichloroindophenol, methanol, Folin-ciocalteu phenol reagent, sodium carbonate, gallic acid, carotenoid, hexane. All the chemicals and reagents were of analytical grade.

3.2 Preparation of Nam Dok Mai Mango Fruit

Freshly harvested Nam Dok Mai Si Thong mangoes were purchased from a commercial farm in Phichit province, Thailand and transported to postharvest laboratory at Mae Fah Luang University. Fruits of uniform size without any mechanical damage were selected and screened for maturity test by immerse in 10 liters of tap water added with 2% sodium chloride (NaCl) to determine the degree of ripeness. The samples sinking at the bottom were accepted, followed by the rejection of floating mango samples. After maturity test, selected mature mangoes were immersed in 200 ppm sodium hypochlorite for 5 min to remove microbial contamination and extraneous matter. All the washed mangoes free of impurities were allowed to dry at room temperature until fully dried.

3.3 Effect of Different SA Concentration and Combination with HW Treatment on Postharvest Quality of Nam Dok Mai Si Thong Mango

Prepared mango samples from 3.2 (120 fruits) were divided into four groups. First group was prepared without any treatment referred as 'control sample'. The second group of mangoes was treated with hot water (HW) at 49 °C for 10 minutes based on commercial used. The other two groups of mangoes were treated with 1 mM followed by HW and immersion of samples in 1 mM salicylic acid and 2mM salicylic acid (SA) solutions containing 0.1% Tween 80 for 10 minutes, respectively. Samples without and with treatment of HW and SA were dried at room temperature. All the mango sample treatments were given as follows:

1. Control (without any treatment)
2. HW (mango treated with HW at 49°C for 10 min)
3. 1 mM SA+HW (mango treated with 1mM SA for 10 min and HW at 49 °C for 10 min)
4. 2 mM SA + HW (mango treated with 2 mM SA and HW at 49 °C for 10 min)

Furthermore, the control and treated samples were packed in corrugated boxes and the quality of mango samples were evaluated with an interval of 5 days up 20 days of storage at 13 °C. Quality analysis were as the following firmness, weight loss, color, disease incidence, total soluble solid (TSS) and total acidity (TA).

3.3.1 Flesh Firmness

Fruit firmness was determined using a texture analyzer equipped with 10 mm cylindrical probe (TA, XT+, stable micro systems Texture Analyzer) Firmness was analyzed from the equatorial area of mango fruits at three equidistant regions. Puncture method was employed using a cylindrical probe and the result was express as Newton (N) as reported by Perumal, Nambiar, Sellamuthu and Emmanuel (2021).

3.3.2 Weight Loss

Weight loss was determined by weighing the fruits subjected to all treatments before and after the storage period using a digital weighing balance. Difference between the two values was calculated as weight loss, and the results were expressed as the percentage (%) of weight loss as detailed by Perumal et al. (2021).

$$\mathrm{WL}\ (\%) = \left(\frac{W_i - W_f}{W_i}\right) \times 100$$

Where, WL, Wi and W_f represented the percent weight loss, initial weight (g) and final weight (g) of mango samples during storage

3.3.3 Peel Color Values

Mango fruit skin color was measured at the middle part of the fruit by colorimeter (CM-600d Konica Minolta, INC, Japan). Color indices were presented as Chroma (C), hue angle (h°) L* (lightness values), a* (redness) and b* (yellowness) color values of the mango samples. The hue angle (h◦) and Chroma (C) values were calculated following the method of Perumal et al. (2021).

3.3.4 Disease Incidence

Disease incidence was analyzed as the number of disease fruit from the total fruit and calculated as % fruit disease.

3.3.5 Total Soluble Solid and Total Acidity

Total soluble solid (TSS) was recorded in juice extracted from mango using a portable refractometer (Model PAL, ATAGO, Japan) expressed in °Brix. An acidity of mango was determined by digital titratable acid kit (PAL-Easy ACID F5, ATAGO, Japan). The result was expressed as percentage (%).

3.4 Effects of SA and HW Treatments on Physical and Biochemical Quality of Mango during Postharvest Storage

The best concentration of SA was used in this study. Mango preparation was according to 3.2. The treatments were as follows, treatment 1; Control (untreated), treatment 2; HW 49°C, treatment 3; 2 mM SA, and treatment 4; 2 mM SA + HW 49°C. After the treatment mangoes were dried at room temperature, packed in the boxes, stored at 13°C for 20 days or 25°C for 12 days respectively. Changes of fruit quality were analysed for 5 days at 13°C and 3 days at 25°C. Quality analysis on changes of firmness, weight loss, color, disease incidence, total soluble solid (TSS) and total acidity (TA) were similar with 3.3.1 to 3.3.6. Moreover, changes of total phenolic compounds (TPC), vitamin C and carotenoid content in Nam Dok Mai mango during stored at 25°C or 13°C were analysed as the following.

3.4.1 Total Phenolic Content (TPC)

The mango pulp was extracted three times with methanol and analyzed for total phenolics. TPC was determined following the method of Singleton and Rossi (1965). Briefly, 0.50 mL of the diluted sample of mango pulp extract was reacted with 2.5 mL of 0.2 mol/L. The color solution was developed by mixing 250 µL of the sample extract, 1250 µL of 10% v/v Folic-Ciocalteu phenol reagent and 1000 µL of sodium carbonate solution. The sodium carbonate solution (7.5% w/v Na_2CO_3) was prepared by mixing 7.5 g of sodium carbonate with 100 mL of distilled water. The absorbance of the samples was taken at 765 nm after incubation at temperature for 1 h. Gallic acid was used as a reference standard, and the results were expressed as milligram gallic acid equivalent (mg GAE)/g fresh weight of mango pulp sample.

3.4.2 Ascorbic Acid Content

The contents of ascorbic acid (vitamin C) of control and treated mango samples were determined by titrating 10 g of mixed pulp sample against the standard 2, 6 dichlorophenol dye following the procedure outlined in AOAC (1990). Ascorbic acid reduces the indicator dye to a colorless solution. At the end point of titration of a sample containing ascorbic acid with dye, the excess unreduced dye in the acidic solution displays light pink color that marks the end point of titration.

3.4.3 Total Carotenoid Content

Total carotenoids of pulp were estimated following the method of (Anwar & Malik, 2007). Five grams of the sample and 2.5 mL of distilled water were mixed with 25 mL of 95% hexane homogenize for 1 minute. The mixtures were centrifuged at 2000 ×g, 4 °C for 5 min. The yellow layer was collected and the absorbance at 454 nm was measured using a spectrophotometer and calculated with the equation (1) as follows:

$$\text{Total carotenoid content } (\mu g/g) = \frac{A \times \text{volume (ml)} \times 10^4}{A_{1cm}^{1\%} \times \text{sample weight (g)}} \qquad (1)$$

Where, X, Y, A, $A_{1cm}^{1\%}$ represented the carotenoid concentration, absorbance at 454 nm and carotenoid content in µg/100 g, respectively.

3.5 Statistical Analysis

Experiments were conducted in a completely randomized design (CRD) with 5 replications for each treatment. Mean comparison among treatments were performed using the Duncan's multiple range tests at P<0.05 level of significance. All analysis were done using SPSS software package.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Effect of Different SA Concentration and Combination with HW Treatment on Postharvest Quality of Nam Dok Mai Si Thong Mango

4.1.1 Firmness

The firmness of a fruit is the most important quality characteristic in determining whether the product will be accepted by customers. The firmness of the untreated mango fruit in the control group decreased rapidly during the storage period. However, the decrease in firmness was much less in the fruit treated with 2 mM SA + HW. After 20 days of storage, the untreated mango fruit showed the lowest firmness value (5 N), while the treatment with 2 mM SA + HW showed significantly ($p \leq 0.05$) higher firmness compared to the control (Figure 4.1). The higher fruit firmness in the fruits treated with SA might be explained by the reduction in the activities of cell wall and membrane degrading enzymes due to the suppression of ethylene production (Cai, Li & Chem, 2006). This study agrees with Tareen, Abbasi & Hafiz (2012) that peaches immersion in 2 mM SA after harvest had higher fruit firmness than control during storage. As described by Valero et al. (2011), SA at a concentration of 1 mM-maintained fruit firmness and quality during storage on sweet cherry fruit. A feature of the ripening process common to most fruits is an increase in the activity of cell wall degrading enzymes responsible for softening the fruit and increasing membrane permeability (Roy et al., 2019). According to Asghari and Aghdam (2010), fruit firmness was maintained by SA treatments in many fruits.

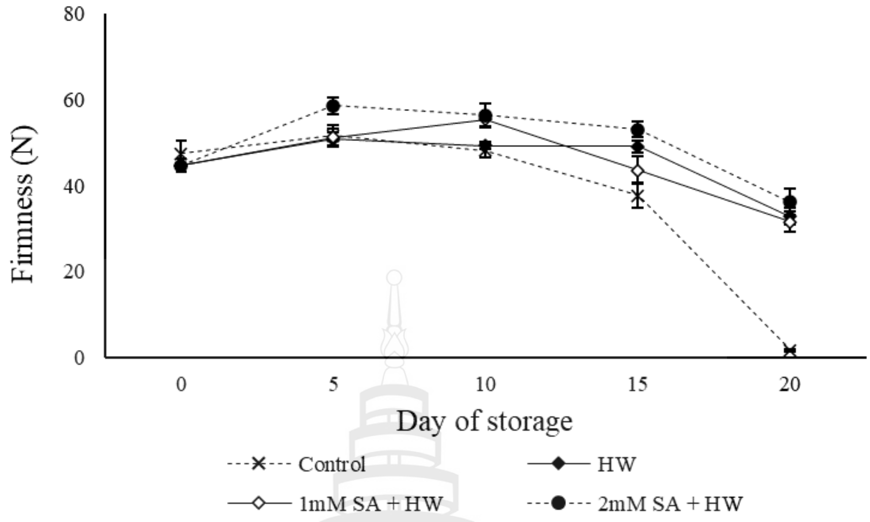


Figure 4.1 Effect of SA and HW Treatment on Fruit Firmness in Nam Dok Mai Si Thong Mango Stored at 13°C (Vertical Bars Represent the Standard Errors of Means and Are Invisible When Values Are Smaller Than the Symbols)

4.1.2 Weight Loss (WL)

The percentage of WL of both untreated and treated fruit increased with storage time, but the loss was most pronounced in fruit treated with HW (Figure 4.2). However, the fruits treated with SA + HW showed lower WL, which might be due to the fact that SA suppressed the transpiration and respiration rate of mango fruit by closing the stomata of the treated fruit. The result is in agreement with that of Zheng and Zhang (2002). This study was similar to a report by Ketsa et al. (1998), HW treatment could accelerate the softening of mango fruits, which is associated with the increase of polygalacturonase activity. Roy et al. (2019) and Haque (1985) reported that banana weight loss is due to the loss of water from the fruit and storage conditions such as temperature and humidity. High temperature increases weight loss but low temperature reduces weight loss during storage. As described by Mandal et al. (2014) and Kamal Kant, Singh & Kumar (2013), exogenous application of SA reduced weight loss in tomato fruit. Weight loss is mainly regulated by respiration, transpiration and metabolic activities. SA closes stomata, resulting in reduced respiration rate and minimizing fruit weight loss (Manthe, Schulz & Schnabl, 1992).

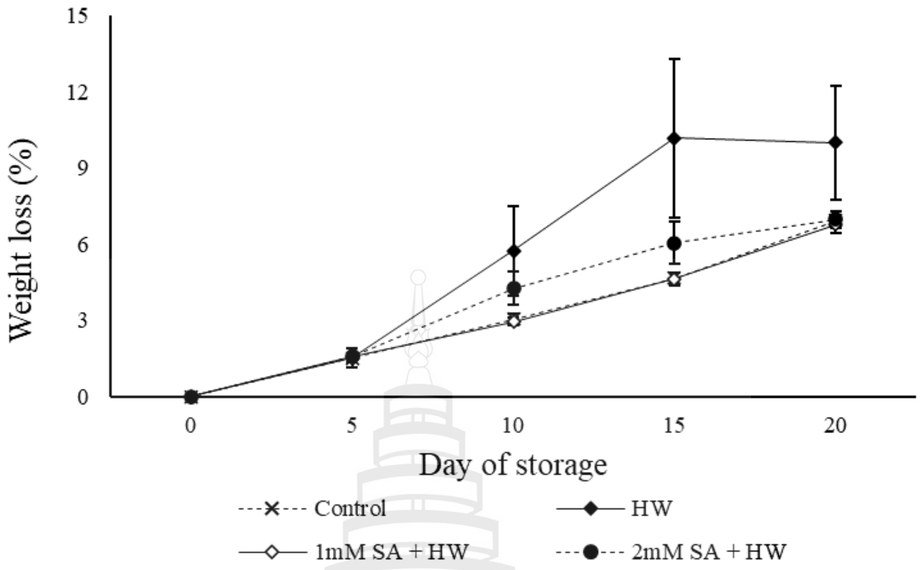


Figure 4.2 Effect of SA and HW Treatment on Weight Loss in Nam Dok Mai Si Thong Mango Stored at 13°C

4.1.3 Chroma Value

The color was directed for the quality of food and impacts to consumer acceptance. Change in color index, represented by the chroma value, increased progressively with an increase storage time. However, the rate of color change was highest in the untreated fruit compared with the other treatments (Figure 4.3).

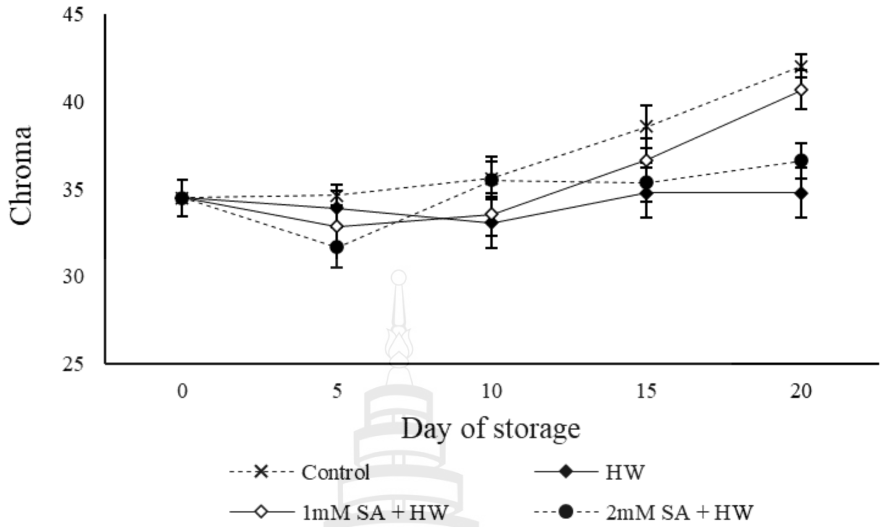


Figure 4.3 Effect of SA and HW Treatment on Chroma Values in Nam Dok Mai Si Thong Mango Stored at 13°C

4.1.4 Hue Angle Value

For the hue value, the greatest change was observed after 20 days of storage. The hue value of HW treatment was 82- and 2-mM SA + HW was 81.52 (Figure 4.4). The lower color changes in the treated mangoes could be related to the suppression of ethylene production and consequent lower degeneration of chlorophyll and reduced biosynthesis of carotenoids mainly in the peel Zaharah and Singh (2011) reported the same result in mango cv. Kensington Pride, SA treated fruits were able to maintain a higher hue value than untreated control fruits. As described by Wei, Liu, Su, Liu and Ye (2011), treatment with SA maintained the color change in asparagus. Moreover, Tareen et al. (2012) found that peach fruit developed less yellow color during cold storage when treated with SA.

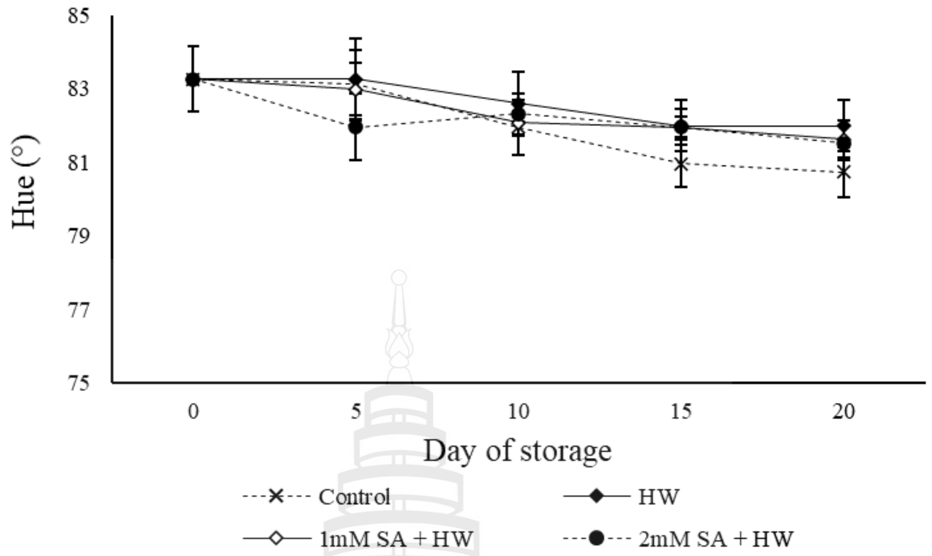


Figure 4.4 Effect of SA and HW Treatment on Hue Value in Nam Dok Mai Si Thong Mango Stored at 13°C

4.1.5 Total Soluble Solids (TSS)

An increase in TSS was observed in all treatments during storage (Figure 4.5). TSS was not significantly different between treatments throughout the storage period ($p \leq 0.05$). The increase in TSS content in the pulp was probably due to hydrolysis of polysaccharides and dehydration of the fruit during the storage period (Roy et al., 2019). Kiwifruit treated with MeSA can maintain a lower TSS value during cold storage compared to the control fruit Aghdam, Motallebiazar, Mostofi, Moghaddam and Ghasemnezhad (2011) suggested that MeSA reduces ethylene production, which may lead to decreased sucrose phosphate synthase activity, which in turn leads to a decrease in sucrose synthase and contributes to delayed accumulation of fructose and TSS. TSS could be increased throughout fruit maturing by the act of sucrose synthase, which is a significant enzyme in the biosynthesis of sucrose (Hubbard, Pharr & Huber, 2006). Moreover, the direct mechanism of SA on sucrose synthase and sugar metabolism needs to be further studied in mango fruit.

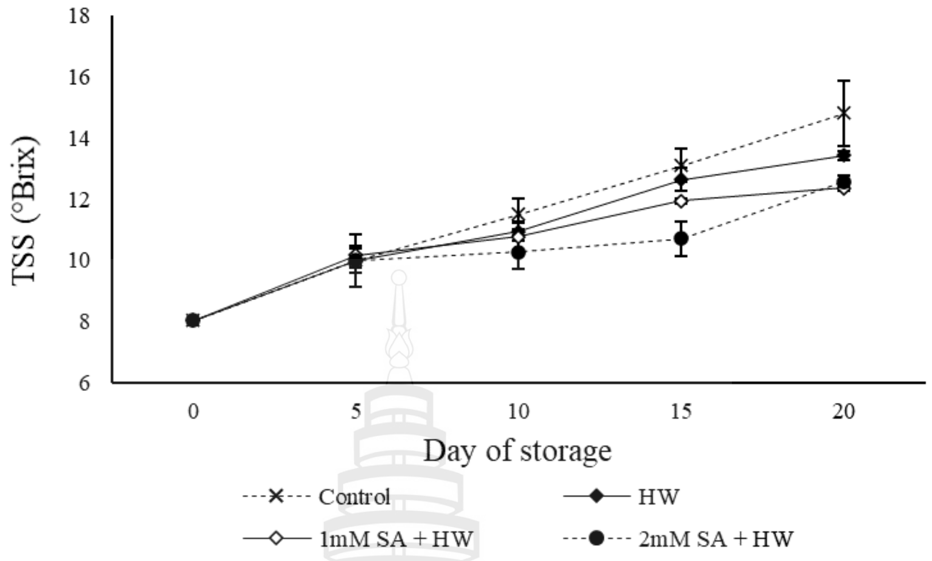


Figure 4.5 Effect of SA and HW Treatment on TSS Content in Nam Dok Mai Si Thong Mango Stored at 13°C

4.1.6 Total Acidity

Acidity was significantly ($p \leq 0.05$) higher in fruit treated with 2 mM SA + HW than untreated mangoes. However, there was no significant difference between the treatments of SA and HW (Figure 4.6). The percentage of acidity decreased with increasing storage time, which could be due to the increase in metabolic activity and conversion of various organic compounds to sugars that retard the ripening process. The trend of decrease in titratable acidity throughout the storage period on Fazil and Bombai varieties of mango was reported by Roy et al. (2019). Kamal et al. (2013) also found higher acidity in tomato fruit when treated with SA at 0.75 mM during storage. Similar study on SA with a concentration of 1mM delayed ripening and also higher acidity on sweet cherry fruit by Valero et al. (2011).

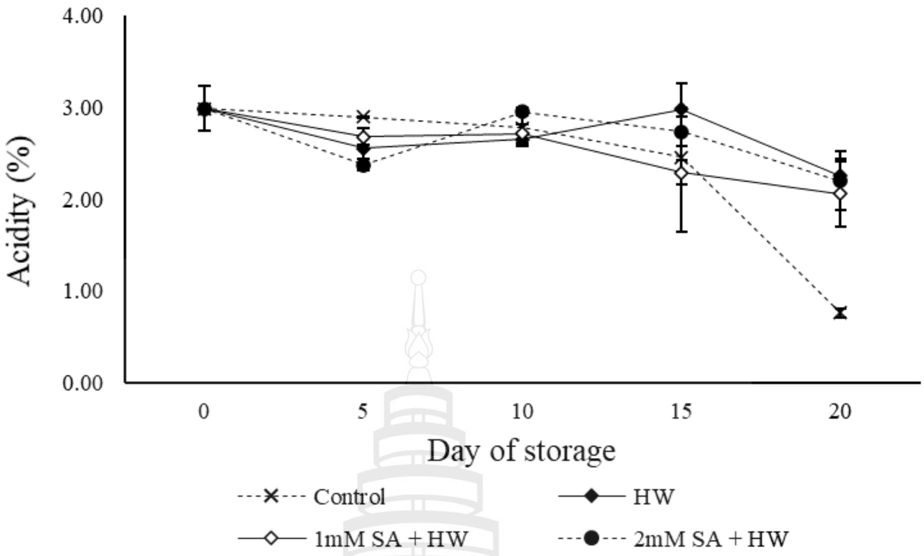


Figure 4.6 Effect of SA and HW Treatment on Acidity in Nam Dok Mai Si Thong Mango Stored at 13°C

4.1.7 Disease Incidence

Significant disease incidence ($p \leq 0.05$) was observed in control fruit, especially on day 10, while treatments SA + HW and HW showed no symptoms. No disease infestation was observed in the sample treated with 2mM SA + HW until the end of storage (Figure 4.7). Liu, Huang, Fu and He (1998) reported that the disease index of mango fruit caused by *Colletotrichum gloeosporioides* decreased significantly when the inflorescence was treated with SA, and they concluded that SA increase the resistance of mangoes to *Collectotrichum gloeosporioides*. SA is known to trigger the resistance system in plants against various diseases (Raskin, 1992). SA increases the production of H_2O_2 in plants, which acts as a signaling molecule and activates the systemic resistance of plants against pathogens (Barman et al., 2014). Fruits inoculated with *Collectotrichum gloeosporioides* and treated with SA showed 62.5% disease incidence as that of control in the fourth day and concluded that SA could increase resistance of mango fruits to anthracnose disease (Zeng & Jiang, 2006). Visual appearance of Nam Dok Mai mango on disease incidence at 13°C for 20 days was shown in Figure 4.8. The visual appearance when compared between untreated and SA treated fruit during storage, untreated fruit at day 15 had the highest disease incidence among the samples.

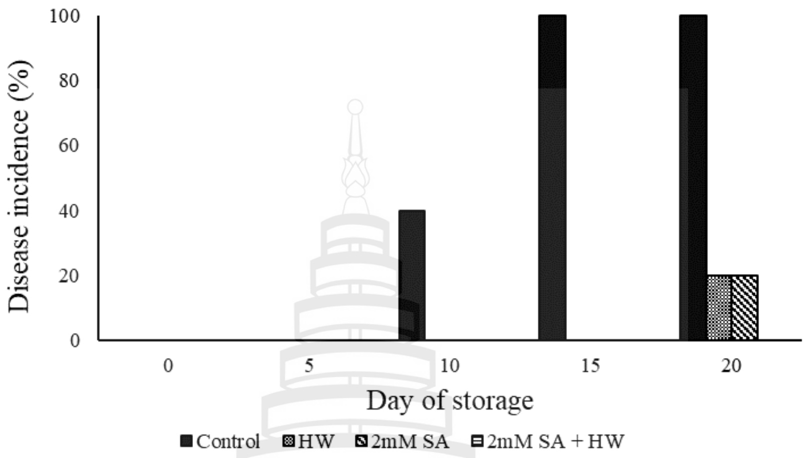


Figure 4.7 Effect of SA and HW Treatment on Disease Incidence in Nam Dok Mai Si Thong Mango Stored at 13°C

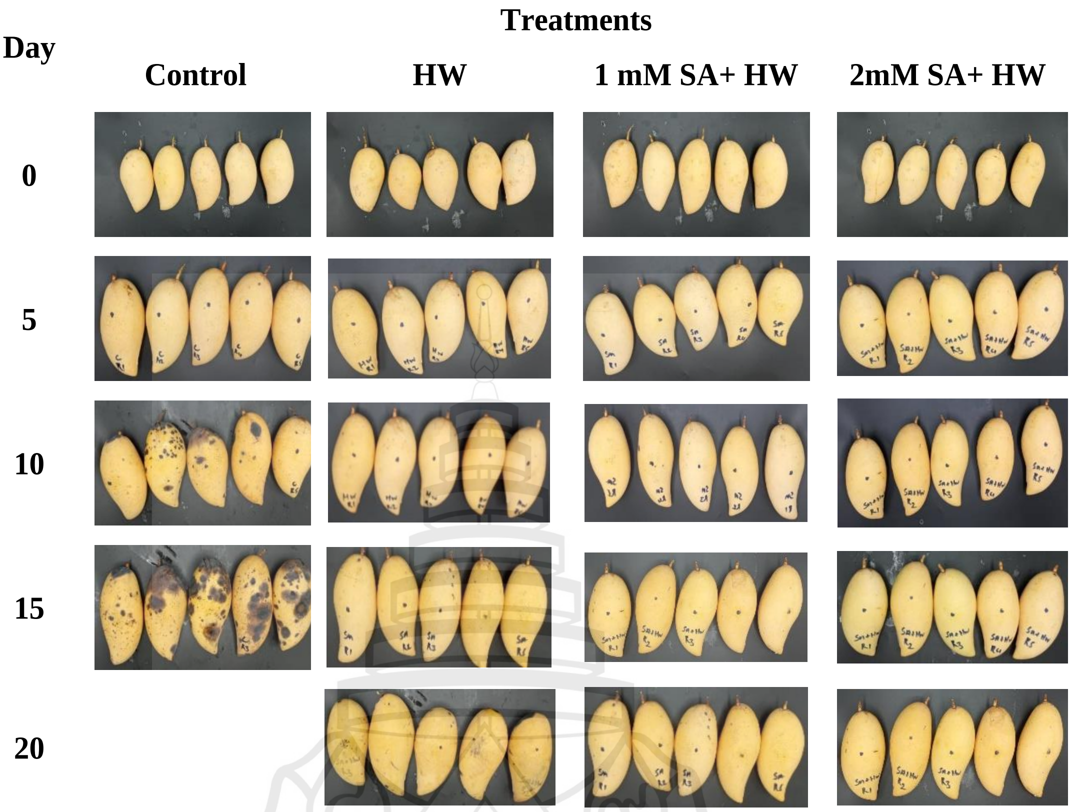


Figure 4.8 Visual Appearance of Nam Dok Mai Si Thong Mango on Disease Incidence During Stored at 13°C for 20 Days

4.2. Effect of SA and HW on Physiological and Biochemical Attribute of Nam Dok Mai Si Thong Mango

Nam Dok Mai Si Thong mango was treated with HW, 2 mM SA, 2 mM SA + HW (49°C) and control (non-treated). Fruit was stored at 13°C for 20 days or 25°C for 12 days respectively. Changes of physiological and biochemical of Nam Dok Mai Si Thong mango during storage were shown as in the following.

4.2.1 Firmness

The firmness of untreated control mango fruit decreased rapidly during the storage period (Figure 4.9). However, the decrease in firmness was much less in the fruit treated with 2 mM SA + HW. At 20 days of storage at 13 °C, the untreated mango fruit showed the lowest firmness value (4.92 N), while the treatment with 2 mM SA + HW showed significantly higher compared to control ($p \leq 0.05$).

According to Tareen et al. (2012) higher firmness was maintained on peaches treated with 2 mM SA. Valero et al. (2011) reported that firmness was enhanced when sweet cherry fruits were treated with 1mM SA during storage. Barman et al. (2014) reported that fruit treated with 2 mM SA and 1 mM SA maintained almost 40% and 23% higher firmness respectively, than control. The changes of fruit firmness were the same pattern as 13℃ and 25℃ during the storage time. The firmness of fruit stored at 25℃ was lower than 13℃ however, fruits treated with 2 mM SA + HW maintained higher fruit firmness.

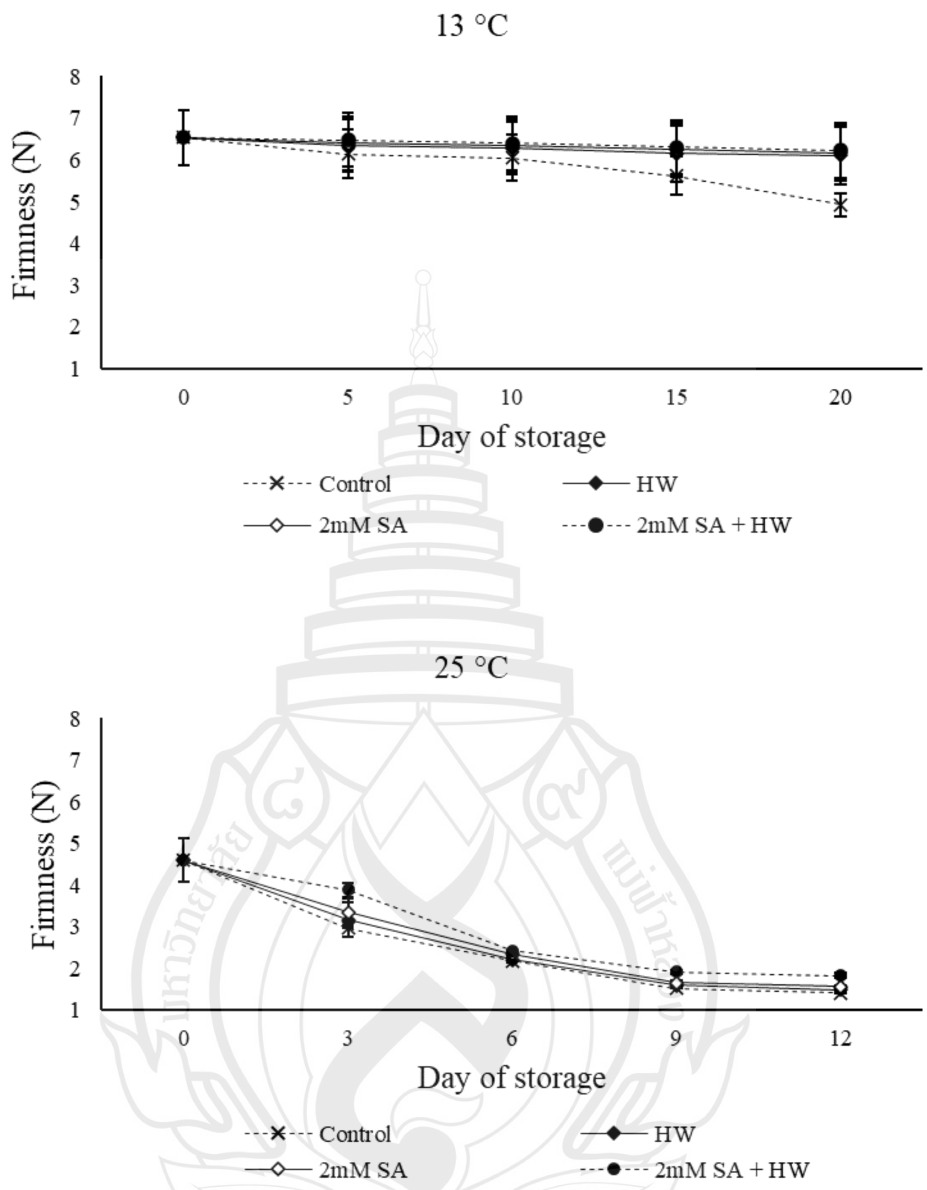
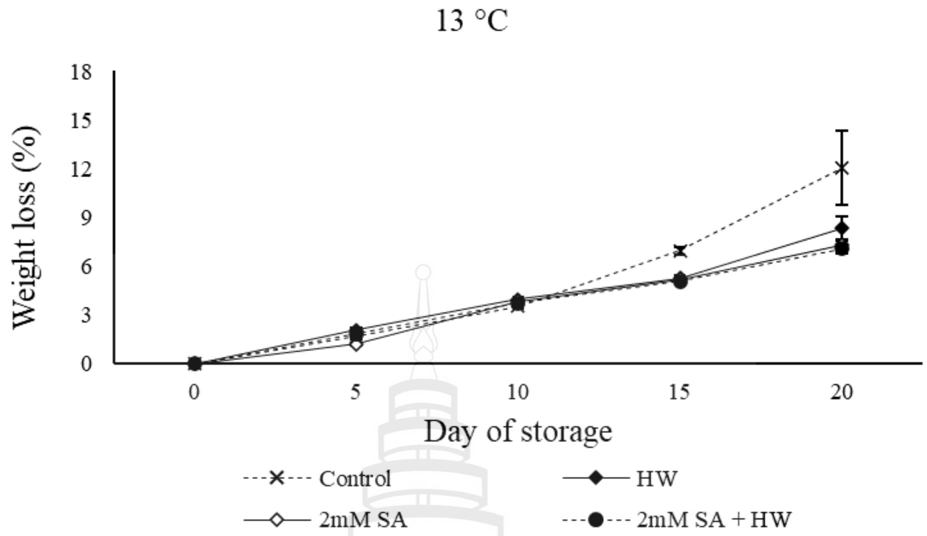


Figure 4.9 Firmness on Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively (Data Are the Means ± SE of 5 Replications from Each Treatment)

4.2.2 Weight Loss (%)

WL of both untreated and treated fruit increased with storage time at 13°C and 25°C, but the loss was most pronounced in untreated fruit (Figure 4.10). However, SA treated fruits showed lower WL which might be due to the fact that weight loss is mainly regulated by respiration, transpiration and metabolic activities. SA was reported to close stomata, resulting in suppression of respiration rate and minimizing fruit weight loss. The result is in agreement with Manthe et al. (1992). Aminifard, Mohammadi and Fatemi (2013) also found decreased weight loss on SA treated blood orange. Roy et al. (2019) and Haque (1985) reported that banana weight loss is due to the loss of water from the fruit and storage conditions such as temperature and humidity. The weight loss of Nam Dok Mai mango treated with 2 mM SA + HW and 2 mM SA treatments stored at both temperatures were significantly ($p \leq 0.05$) lower than the untreated. The trend is almost the same for the two temperatures but there was more weight loss at 25°C than 13°C this might be the water loss from the mango fruit results of storage environment and also high temperature which enhanced weight loss. SA treated fruits maintained the lower weight loss during the storage time.



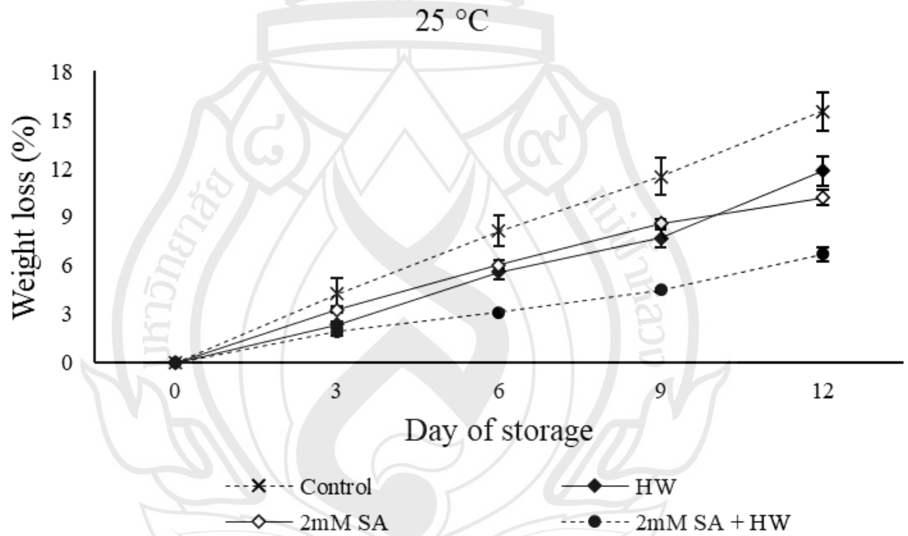


Figure 4.10 Weight Loss on Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively

4.2.3 Color Indices

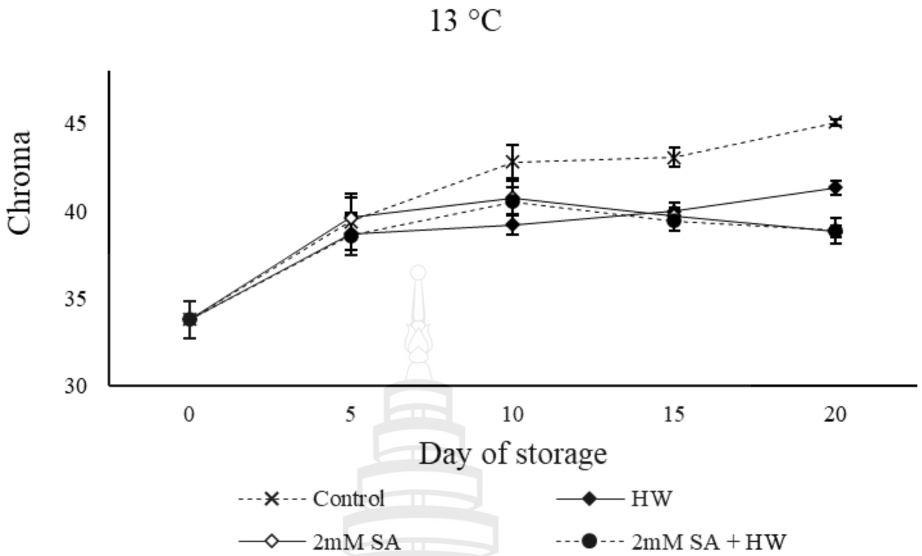
The change in color index, represented by the chroma value, it increased progressively with an increase storage time. The rate of color change was highest in the untreated fruit compared with other treatments (Figure 4.11). However, there was not significant difference between treatments at 25℃ ($p \leq 0.05$) but at 13℃ there was significant difference among treatments at the end of storage time.

In the hue value, the greatest change was observed after 20 days of storage at 13℃, the hue value of treatment SA was 77.10 and 2-mM SA + HW was 76.89, and they were significantly higher ($p \leq 0.05$) than the control (74.83) and HW (75.85). Moreover, the changes in hue value of fruits stored at 25℃ were of similar tendency as fruits stored at 13℃. However, there was no significant difference among the treatments (Figure 4.12). The lower color changes in the treated mangoes could be related to the delay in ethylene production lower degeneration of chlorophyll and reduced biosynthesis of carotenoids mainly in the peel. Zaharah and Singh (2011) reported the same result in mango cv. Kensington Pride. Tareen et al. (2012) found out that peaches treated with SA maintained higher skin color during storage. The storage period had a significant effect on the color change was observed that the color change was faster in the control than in the treated samples. The increase in color change during the storage period might be due to the increase in ripening as time progressed.

The b* value of Nam Dok Mai mango treated with SA was significantly higher than the untreated one ($p \leq 0.05$) at both temperatures (Figure 4.13). The untreated control was higher at 25℃ than at 13℃, but the untreated control retained a higher b* value than the other treatments at both storage temperatures, which could be due to a delay in the ripening process in the treated fruit.

In Figure 4.14, the color change of the a* value was increased in all treatments, but on day 20 of 13 °C and day 12 of 25 °C, there was a decrease in the untreated control sample at the end of the storage period. There was no significant difference among treatments at 13℃ and 25℃. The value of a* was higher at 25℃ than 13℃. However, SA+HW and SA treated fruits maintained higher a* value at both temperatures throughout the storage period.

The lightlessness of the treatments, referred to as L* value, remained constant on day 15 and 9 for both temperatures, but there was a slight decrease in the control sample when storage ended (Figure 4.15). The lightless value of SA + HW significant increased ($p \leq 0.05$) at day 20 and day 12 of both temperatures. SA and HW also had an increased at similar days of both temperature while the untreated control had the least L* compared to treated fruits. However, the rate of color change was more rapid in the untreated control fruits compared to other treatments.



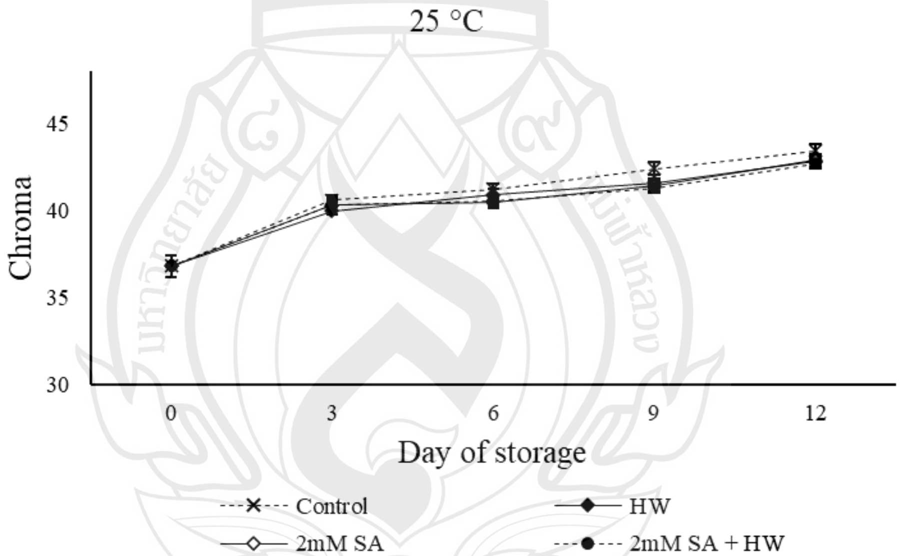


Figure 4.11 Changes of Color (Chroma) in Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively

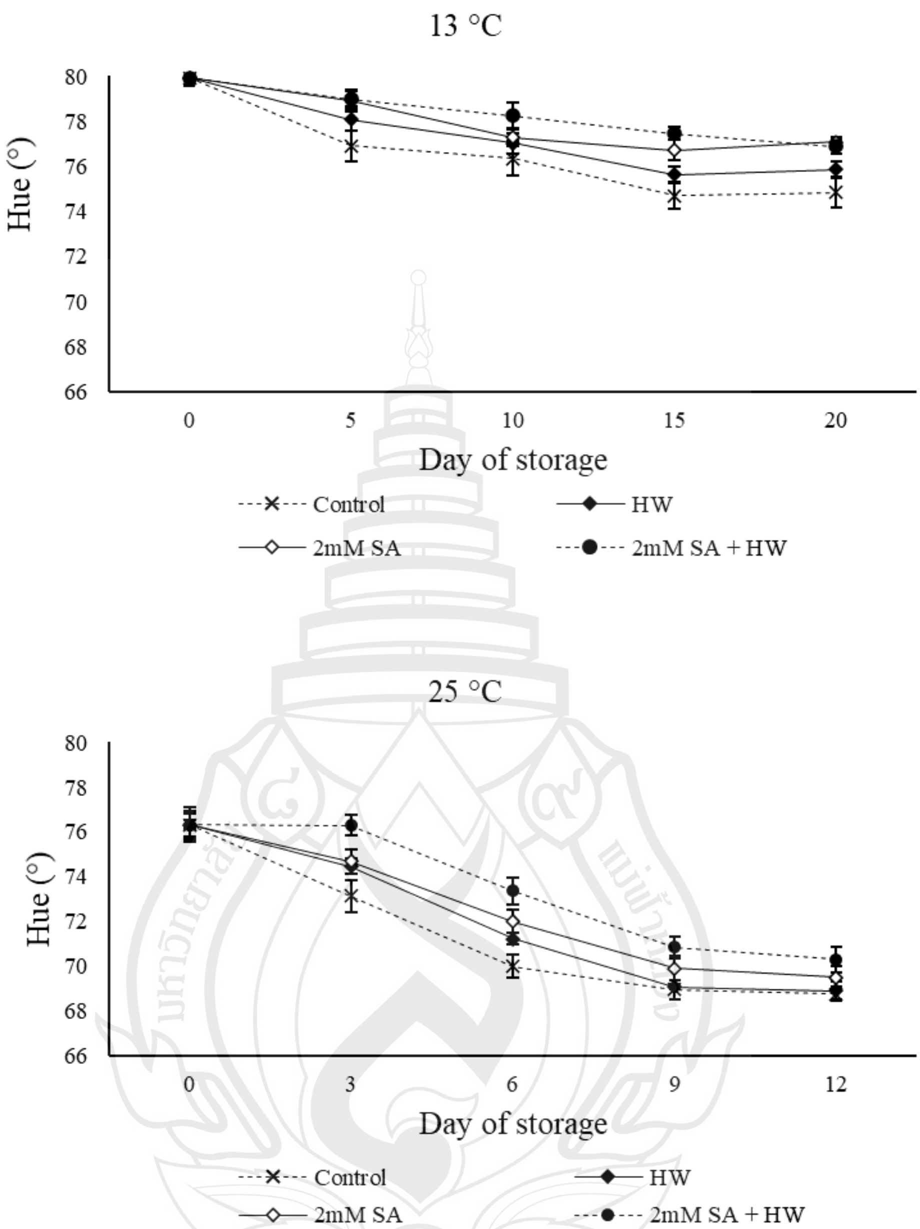


Figure 4.12 Hue Value of Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively

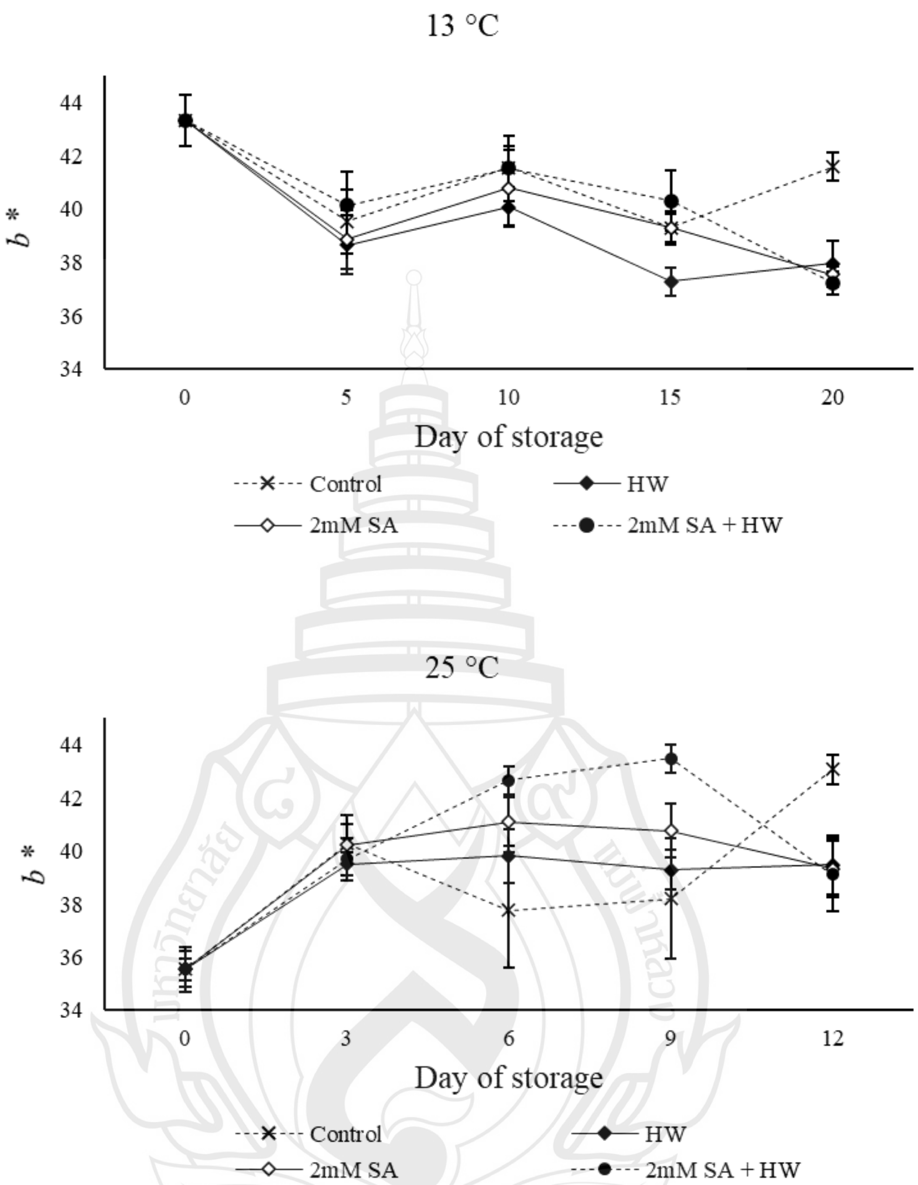


Figure 4.13 The b* Value of Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively

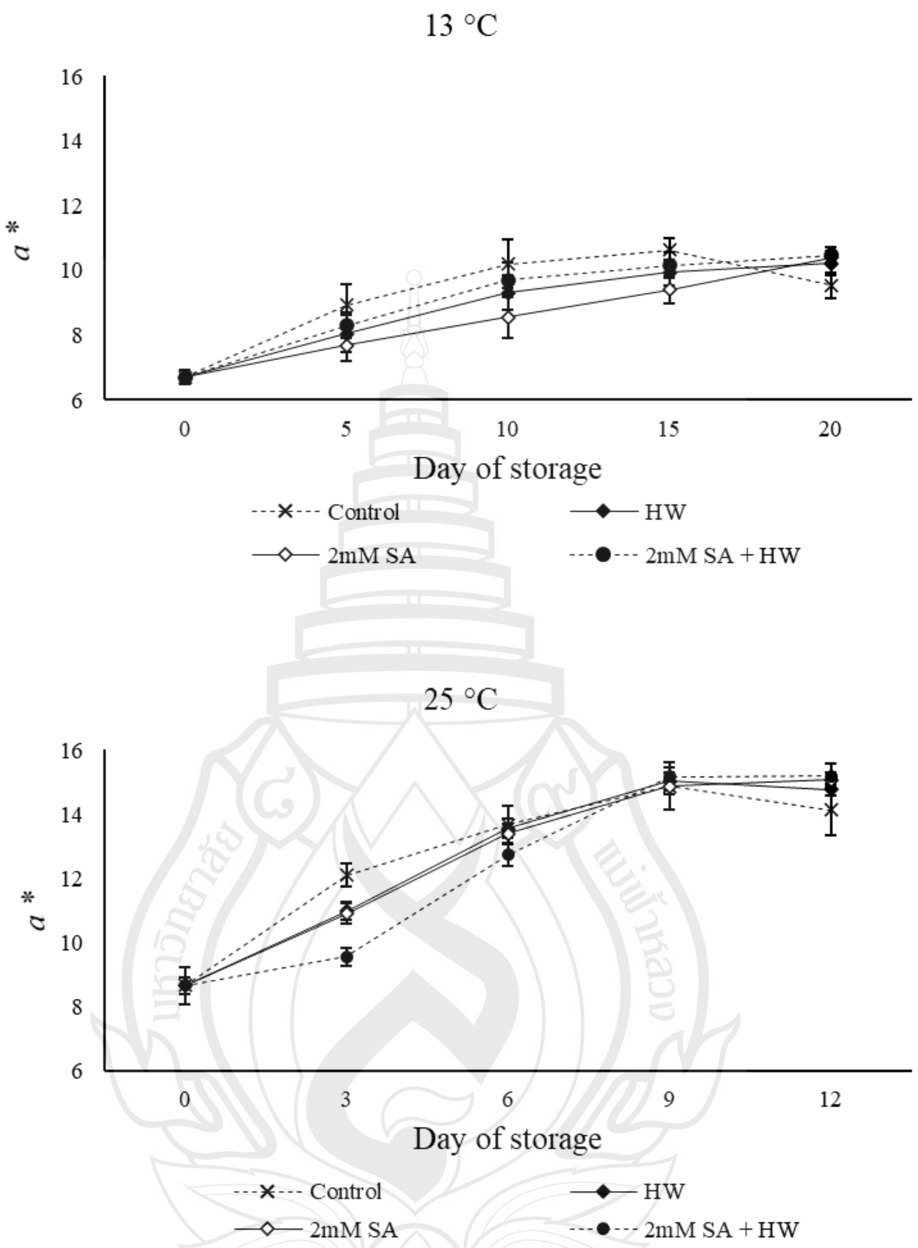
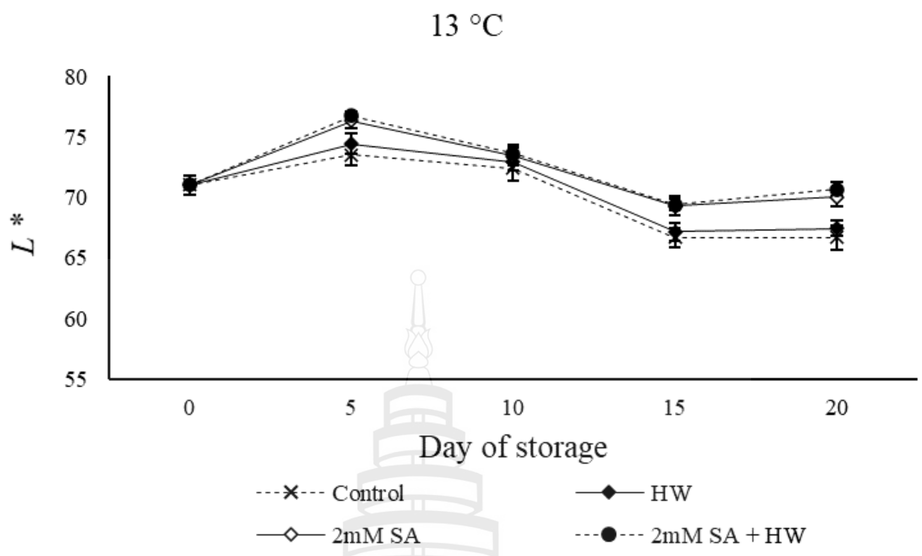


Figure 4.14 The a* Value of Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively



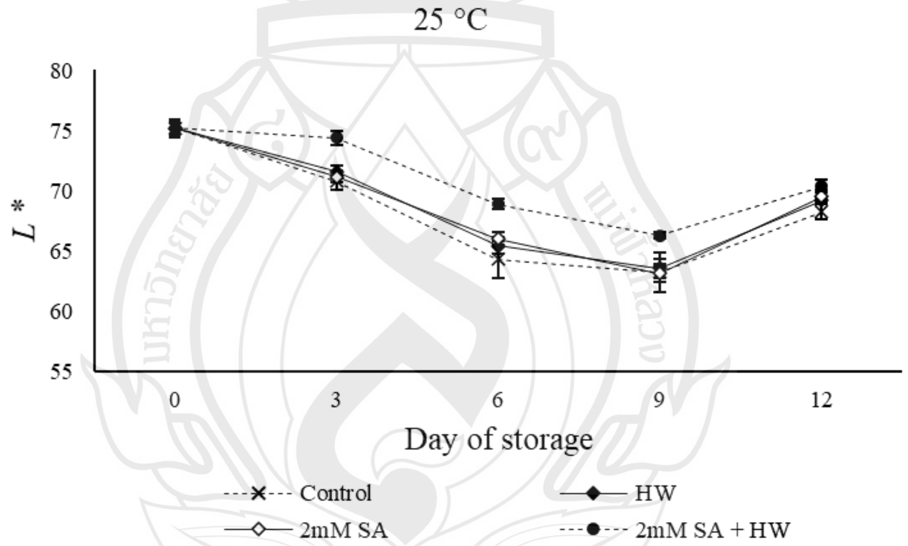


Figure 4.15 The L* Value of Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively

4.2.4 Total Soluble Solids (TSS) and Acidity (%)

An increase in TSS was observed in all treatments during storage (Figure 4.16). TSS was significant different between treatments throughout the storage period ($p \leq 0.05$). The increase in TSS content in the pulp was probably due to the hydrolysis of polysaccharides and dehydration of the fruit during the storage period (Roy et al., 2019) There was an increased in TSS content of untreated control at both temperatures. According to Srivastava and Dwivedi (2000), Low levels of invertase and reducing sugars were found during treatment with SA, indicating significant delay in ripening of banana as a result of starch breakdown.

Acidity was significantly higher in fruit treated with 2 mM SA + HW than untreated mangoes ($p \leq 0.05$). However, there was no significant difference between the treatments SA and HW (Figure 4.17). The percentage acidity decreased with increasing storage time, which could be due to the increase in metabolic activity and conversion of various organic compounds to sugars that retard the ripening process. The trend of decrease in titratable acidity throughout the storage period was reported by Roy et al. (2019). SA treatment increased total acidity on treated blood orange during storage (Aminifard et al., 2013). Percent acidity was higher on day 20 at 13℃ than on day 12 at 25℃, which could be due to the influence of temperature, as fruits ripen faster at higher temperatures than at lower temperatures. Although the treated fruits showed higher acidity during the storage period.

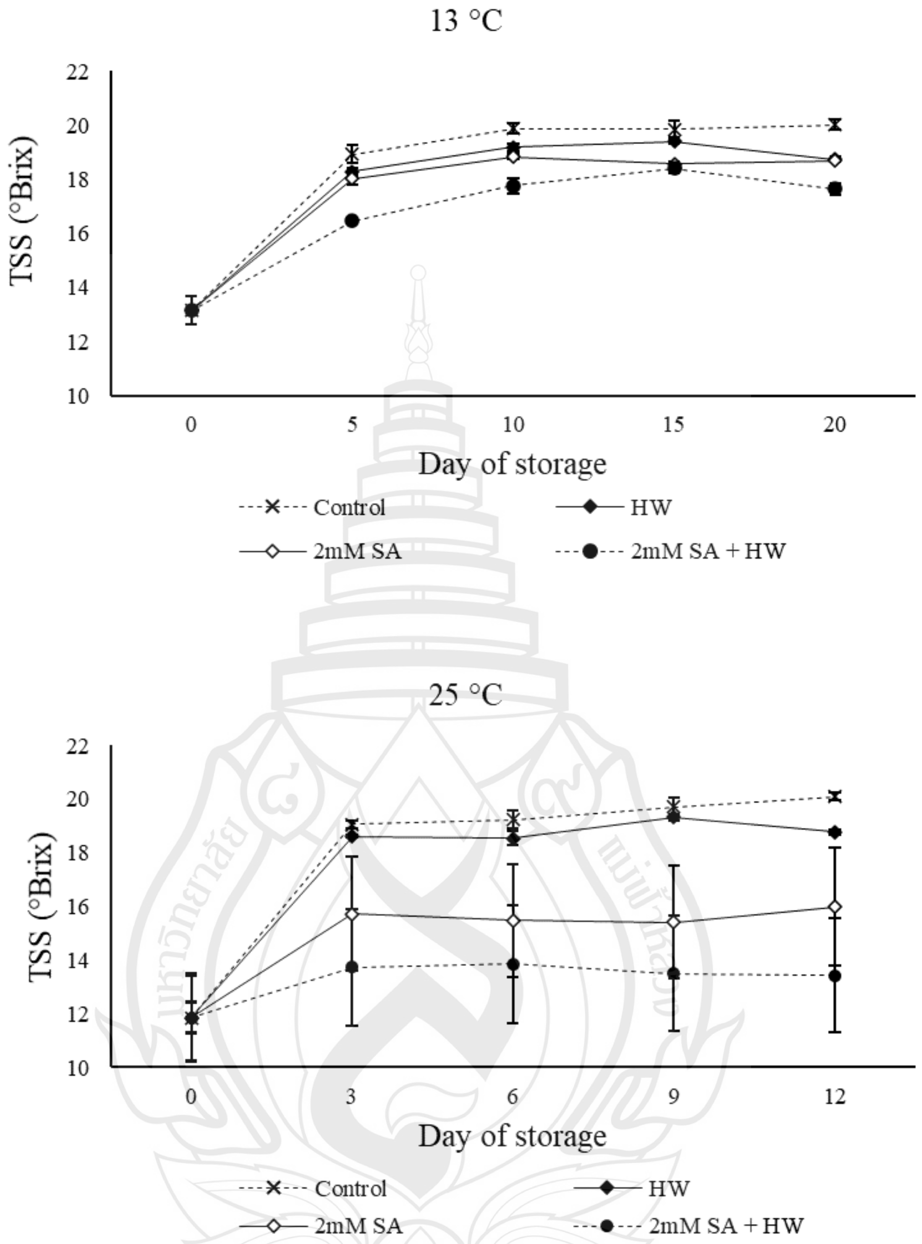
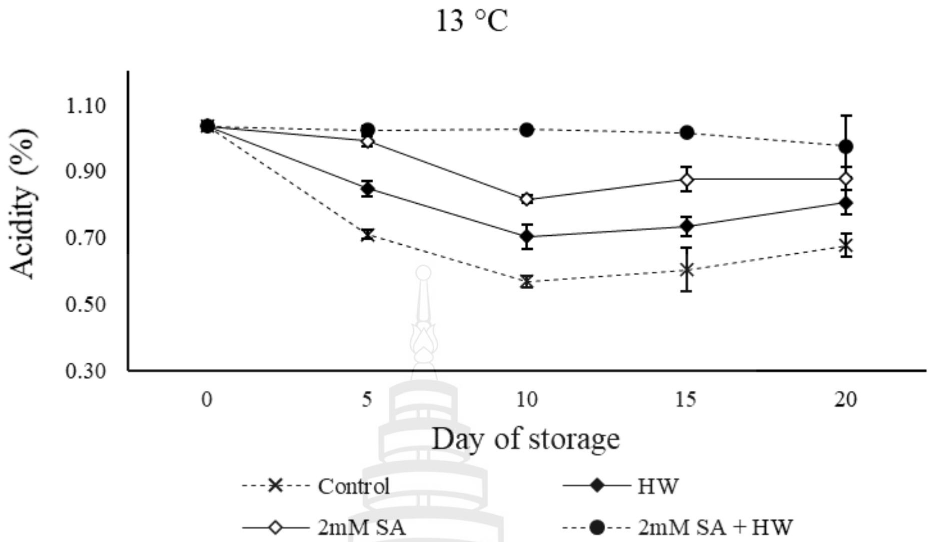


Figure 4.16 TSS on Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively



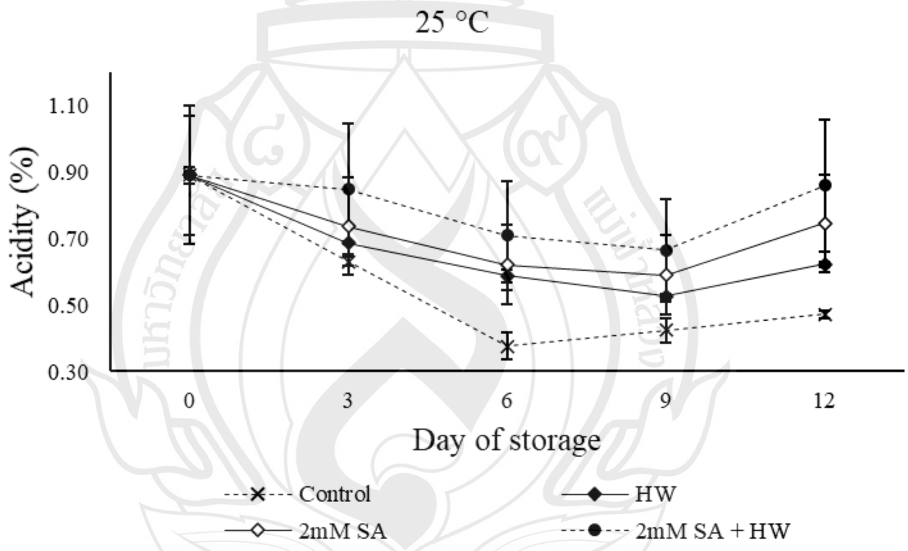
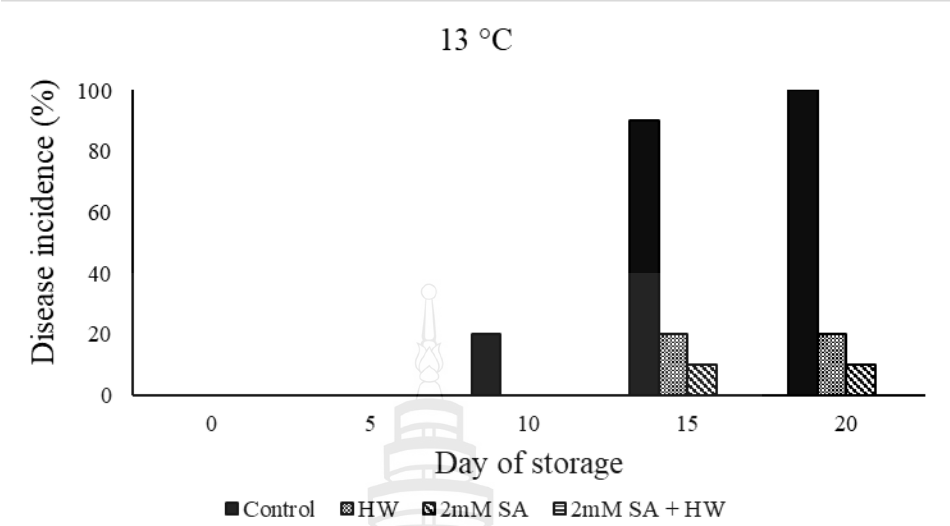


Figure 4.17 Total Acidity of Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively

4.2.5 Disease Incidence on Nam Dok Mai Si Thong Mango

Significant increase of disease incidence was observed in control fruits, especially on day 10, while treatments of SA + HW and HW showed no symptoms ($p \leq 0.05$). No disease infestation was observed in the sample treated with 2 mM SA + HW until the end of storage however, at 25℃ symptoms appeared on 2 mM SA + HW at the end of storage time (Figure 4.18). A report by Liu et al. (1998) indicated that the disease index of mango fruit caused by *Colletotrichum gloeosporioides* decreased significantly when the inflorescence was treated with SA, and they concluded that SA may increase the resistance of mangoes to *Colletotrichum gloeosporioides*. As described by Zeng et al. (2006), SA at a concentration of 1 mM reduced disease incidence in mango at 13℃ throughout the storage period. Higher disease incidence was observed at 25℃ than at 13℃ during the storage period, which could be due to the fact that fruits ripened rapidly at high temperatures, which may lead to fruit decay. SA treated fruit showed lower disease incidence throughout the storage period.



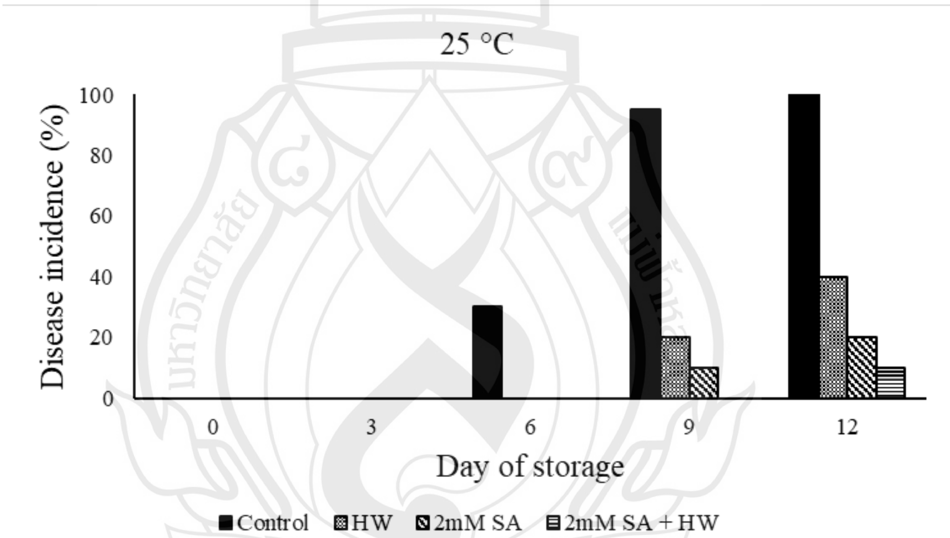


Figure 4.18 Disease Incidence of Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively

4.2.6 Bioactive Compounds

Total phenolic content (TPC) gradually decreased irrespective of treatments as the storage period progressed (Figure 4.19). However, this decrease was slower in the fruit treated with SA than in the control. Among the different treatments, fruit treated with SA (2 mM + HW) retained the highest phenolic content at day 20 (87.9.8 mg GAE/100 g FW), compared to control (53.0 mg GAE/100 g FW). The study is in concord with Barman et al. (2014) which indicate that decline was slower in mango fruit treated with SA, compared to control. Fruit treated with SA (2 mM) maintained highest phenolics content (356.30 μg GAE/gFW) while it was lowest (281.28 μg GAE/ g FW) in control fruit. The higher content of phenolic compounds in SA-treated fruit might be due to lower activity of polyphenol oxidase (PPO) and higher activity of phenylalanine ammonialyase (PAL) enzymes. Barman et al. (2014) and Huang, Xia, Lu, Hu and Xu (2008) found that preharvest treatment of navel oranges with SA resulted in higher TPC at harvest. TPC was also high at cold temperature than room temperature however, SA+HW and SA treatments obtained higher TPC throughout the storage period.

Among the treatments SA treated fruit delayed the formation of carotenoid pigments compared to the control ($p \leq 0.05$) (Figure 4.20). However, the control fruit showed a rapid increase in total carotenoid content from the 5 days of storage. In this study, the total carotenoid content in the control fruit increased rapidly compared to the SA treated mango. The lower content of carotenoids in SA treated fruit might be due to the fact that SA delayed the ripening process, the study is in agreement with Babalar et al. (2007). As described by Caggin and Lewis (1962), tomato fruit treated with SA at a concentration of 4 mM had high chlorophyll content, low carotenoids and lycopene compared to the control. Pila, Neeta and Rao (2010) found that tomato fruit exhibited low carotenoid and lycopene accumulation during storage when treated with 4 mM SA. Carotenoid content was higher in untreated control than SA treated fruit during storage at 13°C and 25°C.

The vitamin C content increased steadily towards the end of the storage period. Among all the treatments, maximum vitamin C (22.6 mg/100g) was observed in mango fruit treated with 2 Mm SA + HW followed by 2 Mm SA (20.6 mg/100g) at the end of storage period and minimum (19.0 mg/100g) in the untreated fruit (control) (Figure

4.21). Similar retaining of ascorbic acid in SA treatment was also reported in apricots (Ardakani Davarinejad & Azizi, 2013), kiwifruit (Zhu, Hu, Song, Pan & Liu, 2010) and plum (Sharma, 2014). Huang et al. (2008) reported that the application of SA effectively reduced the respiration rate and ethylene production and maintained a higher amount of ascorbic acid. Vitamin C content was found to be higher at cold temperature than at room temperature, possibly due to the fact that ripening is faster at room temperature than at cold temperature. In addition, the SA +HW and SA treatments retained higher ascorbic acid content at 13°C and 25°C, respectively.

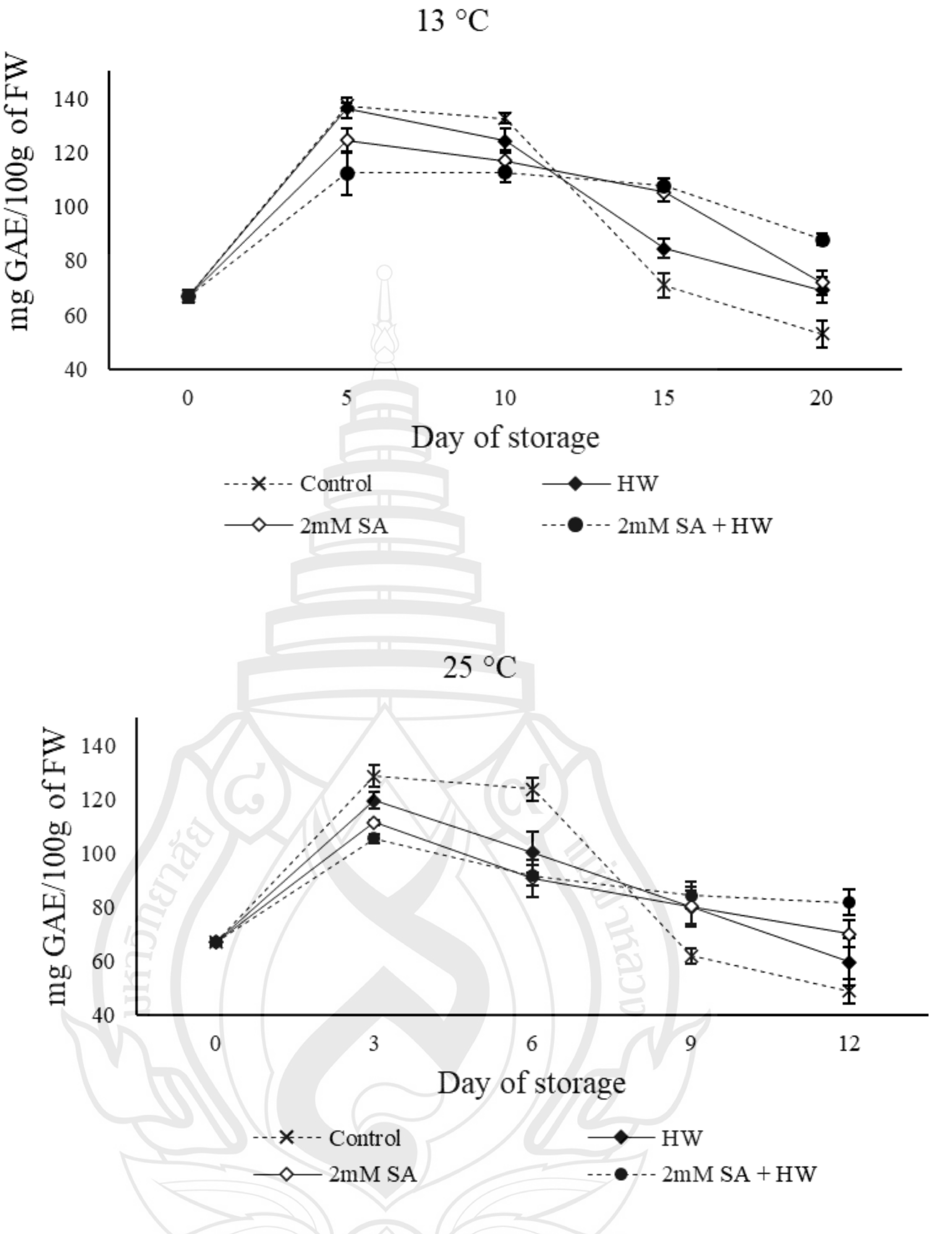
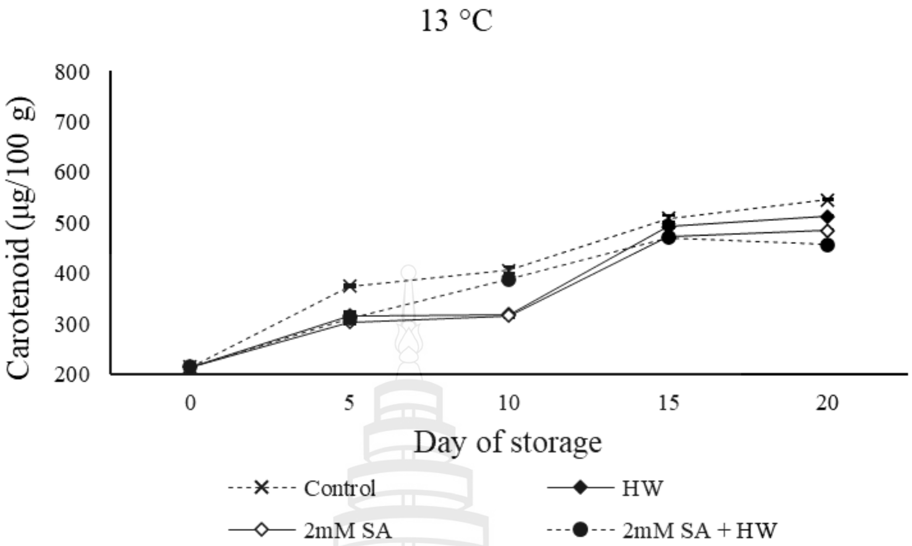


Figure 4.19 TPC of Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively



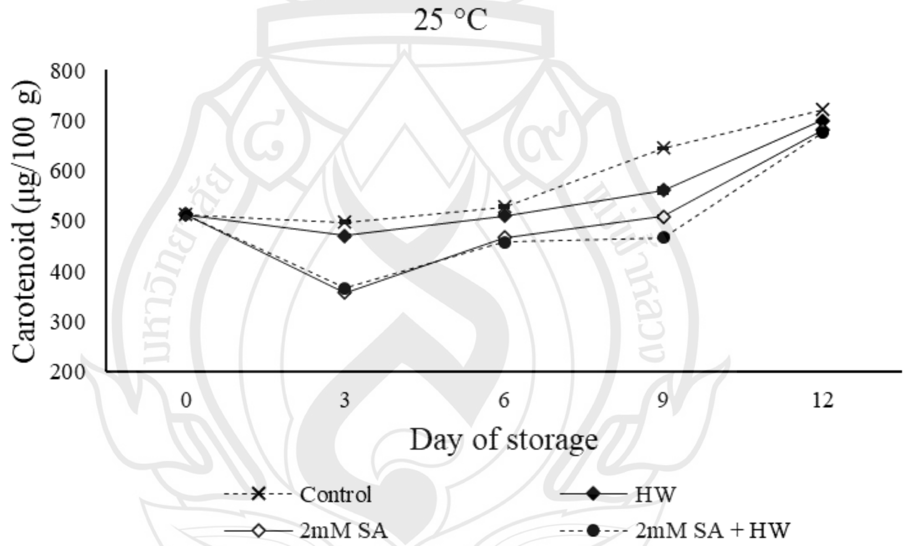


Figure 4.20 Carotenoid Content of Nam Dok Mai Si Thong Mango Stored at 13°C and 25°C for 20 and 12 Days, Respectively

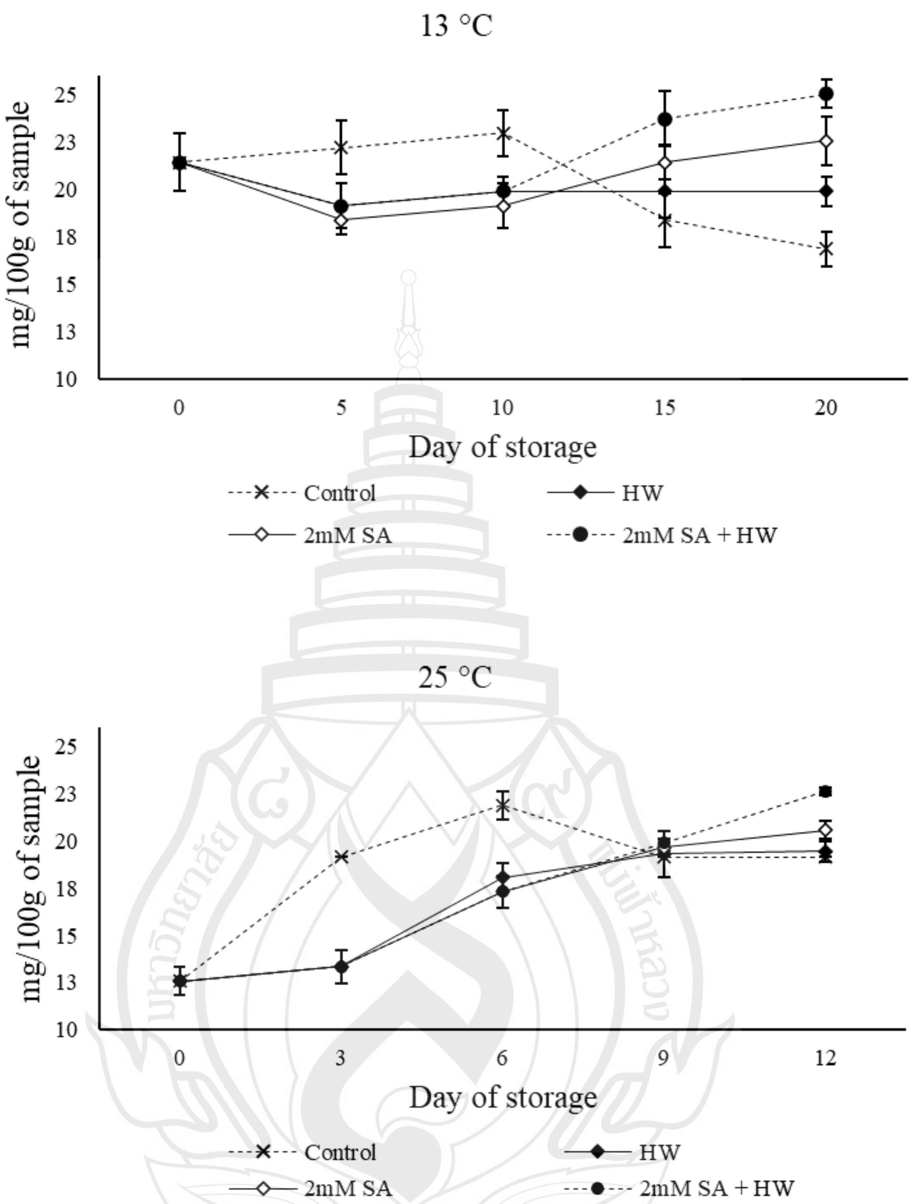


Figure 4.21 Vitamin C Content of Nam Dok Mai Si Thong Mango Stored at 13°C and 25 °C for 20 and 12 Days, Respectively

CHAPTER 5

CONCLUSION

Application of 2 mM SA + HW had a significant effect on decay incidence throughout the storage period of 13℃ for 20 days. The treated Nam Dok Mai Si thong mango maintained higher firmness and reduced weight loss during storage. The increased levels of TA and decreased levels of TSS were also maintained in the treated fruits to delay fruit ripening and prolong storage life.

Application of 2 mM SA + HW was effective at both 13℃ and 25℃, but was most effective at 13℃ than at 25℃. At 13℃ SA, 2 mM+ HW had an effect on bioactive compounds such as TPC and vitamin C in both temperatures for 20 days and 12 days, respectively. Carotenoids were found to be ineffective in treated fruits due to delay in ripening. However, disease incidence was significant in both temperatures throughout the storage period, but the symptom appeared on SA 2 mM+ HW at the end of the storage period. The treatment, especially SA 2 mM+ HW application subsequent by storage at 13℃, could be used commercially as postharvest treatments for mango. While 25℃ would be applicable for small scale farmers to practice the treatment which might be for short time but may improve their level of income thus minimize postharvest losses

CHAPTER 6

SUGGESTION

1. The proper application and mechanism of SA + HW on quality attribute and bioactive compounds need further investigation in mango.
2. The extension of storage time in different varieties of mango on quality attributes and bioactive compounds need further study.

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APPENDIX

APPENDIX

SATATISTICAL ANALYSIS

Table 1 Effect of SA and HW treatment on fruit firmness in Nam Dok Mai si Thong mango stored at 13°C

Treatments	Day storage time at 13°C				
	Day 0	Day 5	Day 10	Day 15	Day 20
Control	47.44±6.92[a]	51.67±5.00 [b]	48.10±3.51 [b]	37.68±6.36 [c]	1.70±0.51 [b]
HW	44.65±3.49[a]	50.81±3.76 [b]	49.29±1.74 [b]	49.05±3.22 [ab]	32.82±4.18 [a]
1mM SA + HW	44.65±3.49[a]	51.16±4.64 [b]	55.37±3.39 [a]	43.52±7.27 [bc]	31.57±5.47 [a]
2mM SA + HW	44.65±3.49[a]	58.51±4.14 [a]	56.32±6.44 [a]	53.03±4.05 [a]	36.14±6.76 [a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 2 Effect of SA and HW treatment on weight loss in Nam Dok Mai si Thong mango stored at 13°C

Treatments	Day storage time at 13°C				
	Day 0	Day 5	Day 10	Day 15	Day 20
Control	0±0.00 [a]	1.51±0.92 [a]	3.04±0.50 [a]	4.66±0.57 [ab]	6.92±0.57 [a]
HW	0±0.00 [a]	1.51±0.46 [a]	5.73±3.50 [a]	10.16±6.98 [a]	10.0±4.47 [a]
1mM SA + HW	0±0.00 [a]	1.58±0.16 [a]	2.95±0.36 [a]	4.62±0.60 [b]	6.78±0.80 [a]
2mM SA + HW	0±0.00 [a]	1.58±0.14 [a]	4.26±1.63 [a]	6.05±2.00 [ab]	6.97±0.74 [a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 3 Effect of SA and HW treatment on Chroma values in Nam Dok Mai si Thong mango stored at 13°C

Treatments	**Day storage time at 13°C**				
	Day 0	**Day 5**	**Day 10**	**Day 15**	**Day 20**
Control	34.49±2.54 [a]	34.61±1.61 [a]	35.59±2.99 [a]	38.56±3.02 [a]	42.03±1.65 [a]
HW	34.49±2.54 [a]	33.88±2.48 [a]	33.05±3.57 [a]	34.78±3.54 [a]	34.78±3.54 [a]
1mM SA + HW	34.49±2.54 [a]	32.86±2.97 [a]	33.53±2.99 [a]	36.66±3.03 [a]	40.66±2.75 [a]
2mM SA + HW	34.49±2.54 [a]	31.65±2.75 [a]	35.49±2.57 [a]	35.35±2.71 [a]	36.60±2.48 [a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 4 Effect of SA and HW treatment on hue value in Nam Dok Mai si Thong mango stored at 13°C

Treatments	**Day storage time at 13°C**				
	Day 0	**Day 5**	**Day 10**	**Day 15**	**Day 20**
Control	83.26±2.18 [a]	83.12±2.31 [a]	81.95±1.86 [a]	80.96±1.57 [a]	80.74±1.67 [a]
HW	83.26±2.18 [a]	83.26±2.71 [a]	82.59±2.10 [a]	82.00±1.71 [a]	82.00±1.71 [a]
1mM SA + HW	83.26±2.18 [a]	82.99±1.72 [a]	82.08±0.78 [a]	81.96±0.70 [a]	81.62±1.23 [a]
2mM SA + HW	83.26±2.18 [a]	81.96±2.25 [a]	82.33±1.36 [a]	81.95±1.21 [a]	81.52±1.15 [a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 5 Effect of SA and HW treatment on TSS content in Nam Dok Mai si Thong mango stored at 13°C

Treatments	**Day storage time at 13°C**				
	Day 0	**Day 5**	**Day 10**	**Day 15**	**Day 20**
Control	8.03±0.25 [a]	10.00±1.49 [a]	11.50±0.87 [a]	13.10±0.95 [a]	14.80±1.82 [a]
HW	8.03±0.25 [a]	9.97±0.35 [a]	10.93±0.55 [a]	12.63±0.67 [a]	13.43±0.25 [a]
1mM SA + HW	8.03±0.25 [a]	10.17±0.49 [a]	10.77±0.81 [a]	11.93±0.12 [a]	12.37±0.15 [a]
2mM SA + HW	8.03±0.25 [a]	10.00±0.70 [a]	10.27±0.93 [a]	10.70±1.00 [a]	12.57±0.38 [a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 6 Effect of SA and HW treatment on acidity in Nam Dok Mai si Thong mango stored at 13°C

Treatments	Day storage time at 13°C				
	Day 0	Day 5	Day 10	Day 15	Day 20
Control	2.99±0.42 [a]	2.90±0.01 [a]	2.78±0.34 [a]	2.46±1.40 [a]	0.76±0.08 [b]
HW	2.99±0.42 [a]	2.55±0.37 [a]	2.65±0.08 [a]	2.98±0.02 [a]	2.25±0.33 [a]
1mM SA + HW	2.99±0.42 [a]	2.68±0.16 [a]	2.71±0.18 [a]	2.29±0.23 [a]	2.06±0.62 [a]
2mM SA + HW	2.99±0.42 [a]	2.37±0.11 [a]	2.95±0.07 [a]	2.73±0.28 [a]	2.20±0.56 [a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 7 Effect of SA and HW treatment on disease incidence in Nam Dok Mai si Thong mango stored at 13°C

Treatments	Day storage time at 13°C				
	Day 0	Day 5	Day 10	Day 15	Day 20
Control	0±0.00	0±0.00	40±0.00	100±0.00	100±0.00
HW	0±0.00	0±0.00	0±0.00	0±0.00	20±0.00
1mM SA + HW	0±0.00	0±0.00	0±0.00	0±0.00	20±0.00
2mM SA + HW	0±0.00	0±0.00	0±0.00	0±0.00	0±0.00

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 8 Effect of HW and SA treatment on firmness in Nam Dok Mai mango stored at 13 ℃ during storage

Treatments	Storage time at 13°C				
	Day 0	Day 5	Day 10	Day 15	Day 20
Control	6.54±0.66	6.14±0.59[a]	6.04±0.56[a]	5.62±0.47[a]	4.92±0.29[a]
HW	6.54±0.66	6.33±0.62[a]	6.28±0.62[a]	6.15±0.68[a]	6.10±0.68[a]
2mM SA	6.54±0.66	6.39±0.64[a]	6.34±0.64[a]	6.24±0.65[a]	6.17±0.66[a]
2mM SA + HW	6.54±0.66	6.47±0.64[a]	6.40±0.64[a]	6.31±0.64[a]	6.23±0.65[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 9 Effect of HW and SA treatment on firmness in Nam Dok Mai mango stored at 25 °C during storage

Treatments	**Storage time at 25°C**				
	Day 0	**Day 3**	**Day 6**	**Day 9**	**Day 12**
Control	4.60±0.51	2.97±0.00[a]	2.18±0.00[b]	1.53±0.00[c]	1.42±0.00[c]
HW	4.60±0.51	3.16±0.41[a]	2.21±0.05[b]	1.60±0.01[bc]	1.50±0.03[bc]
2mM SA	4.60±0.51	3.35±0.32[a]	2.36±0.05[a]	1.67±0.03[b]	1.57±0.03[b]
2mM SA + HW	4.60±0.51	3.89±0.16[a]	2.42±0.04[a]	1.93±0.05[a]	1.83±0.06[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 10 Effect of HW and SA treatment on weight loss in Nam Dok Mai mango stored at 13 °C during storage

Treatments	**Storage time at 13°C**				
	Day 0	**Day 5**	**Day 10**	**Day 15**	**Day 20**
Control	0	1.69±0.17[b]	3.52±0.15[a]	6.93±0.26[a]	12.03±2.29[a]
HW	0	2.07±0.10[a]	3.96±0.17[a]	5.24±0.19[b]	8.33±0.76[b]
2mM SA	0	1.19±0.06[ab]	3.83±0.13[a]	5.16±0.20[b]	7.31±0.35[b]
2mM SA + HW	0	1.85±0.08[ab]	3.74±0.13[a]	5.06±0.18[b]	7.05±0.29[b]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 11 Effect of HW and SA treatment on weight loss in Nam Dok Mai mango stored at 25 °C during storage

Treatments	**Storage time at 25°C**				
	Day 0	**Day 3**	**Day 6**	**Day 9**	**Day 12**
Control	0	4.28±0.96[a]	8.14±0.94[a]	11.51±1.16[a]	15.51±1.17[a]
HW	0	2.36±0.19[b]	5.61±0.47[ab]	7.70±0.56[bc]	11.84±0.90[ab]
2mM SA	0	3.28±0.21[ab]	6.06±0.31[ab]	8.61±0.25[ab]	10.21±0.50[bc]
2mM SA + HW	0	1.93±0.22[b]	3.14±0.14[b]	4.49±0.15[c]	6.72±0.45[c]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 12 Effect of HW and SA treatment on color as Chroma in Nam Dok Mai mango stored at 13 °C during storage

Treatments	Storage time at 13°C				
	Day 0	Day 5	Day 10	Day 15	Day 20
Control	33.78±1.09	39.40±1.59[a]	42.82±0.93[a]	43.05±0.54[a]	45.07±0.20[a]
HW	33.78±1.09	38.69±1.24[a]	39.22±0.58[b]	40.00±0.49[b]	41.34±0.41[b]
2mM SA	33.78±1.09	39.61±1.17[b]	40.75±0.99[ab]	39.75±0.43[b]	38.83±0.36[c]
2mM SA + HW	33.78±1.09	38.59±1.14[a]	40.55±0.81[ab]	39.45±0.58[b]	38.87±0.75[c]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 13 Effect of HW and SA treatment on color as Chroma in Nam Dok Mai mango stored at 25 °C during storage

Treatments	Storage time at 25°C				
	Day 0	Day 3	Day 6	Day 9	Day 12
Control	36.84±0.61	40.64±0.11[a]	41.24±0.36[b]	42.42±0.36[a]	43.44±0.39[a]
HW	36.84±0.61	40.01±0.20[a]	40.93±0.36[a]	41.63±0.24[ab]	42.82±0.30[a]
2mM SA	36.84±0.61	40.31±0.33[a]	40.51±0.22[a]	41.44±0.32[a]	42.90±0.36[a]
2mM SA + HW	36.84±0.61	40.33±0.55[a]	40.54±0.34[a]	41.34±0.25[a]	42.72±0.26[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 14 Effect of HW and SA treatment on color as Hue° in Nam Dok Mai mango stored at 13 °C during storage

Treatments	Storage time at 13°C				
	Day 0	Day 5	Day 10	Day 15	Day 20
Control	79.91±0.32	76.90±0.69[b]	76.35±0.77[a]	74.71±0.58[c]	74.83±0.68[b]
HW	79.91±0.32	78.06±0.48[ab]	77.02±0.46[ab]	75.64±0.37[bc]	75.85±0.37[ab]
2mM SA	79.91±0.32	78.92±0.47[a]	77.29±0.41[ab]	76.72±0.46[ab]	77.10±0.21[a]
2mM SA + HW	79.91±0.32	78.99±0.34[a]	78.25±0.59[a]	77.44±0.28[a]	76.89±0.32[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 15 Effect of HW and SA treatment on color as Hue° in Nam Dok Mai mango stored at 25 ℃ during storage

Treatments	Storage time at 25°C				
	Day 0	Day 3	Day 6	Day 9	Day 12
Control	76.32±0.53	73.14±0.71[b]	70.01±0.51[c]	68.97±0.43[b]	68.78±0.33[a]
HW	76.32±0.53	74.47±0.33[b]	71.23±0.25[bc]	69.08±0.11[b]	68.91±0.40[ab]
2mM SA	76.32±0.53	74.68±0.55[b]	72.01±0.50[ab]	69.92±0.53[ab]	69.51±0.51[ab]
2mM SA + HW	76.32±0.53	76.30±0.46[a]	73.36±0.58[a]	70.85±0.48[a]	70.32±0.57[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 16 Effect of HW and SA treatment on color as *b** in Nam Dok Mai mango stored at 13 ℃ and 25 ℃ during storage

Treatments	Storage time at 13°C				
	Day 0	Day 5	Day 10	Day 15	Day 20
Control	43.35±0.97	39.55±1.20[a]	41.56±0.81[a]	39.31±0.52[ab]	41.60±0.51[a]
HW	43.35±0.97	38.65±1.11[a]	40.07±0.75[a]	37.28±0.55[a]	37.96±0.87[b]
2mM SA	43.35±0.97	38.86±1.12[a]	40.80±1.43[a]	39.31±0.53[ab]	37.54±0.31[b]
2mM SA + HW	43.35±0.97	40.14±1.27[a]	41.54±1.24[a]	40.31±1.13[a]	37.23±0.43[b]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 17 Effect of HW and SA treatment on color as *b** in Nam Dok Mai mango stored at 25 °C during storage

Treatments	Storage time at 25°C				
	Day 0	Day 3	Day 6	Day 9	Day 12
Control	35.55±0.70	40.27±0.73[a]	37.77±2.18[b]	38.20±2.27[b]	43.07±0.55[a]
HW	35.55±0.70	39.52±0.41[a]	39.81±1.01[ab]	39.81±0.75[b]	39.47±1.12[b]
2mM SA	35.55±0.70	40.23±1.14[a]	41.10±0.91[ab]	40.76±1.02[ab]	39.33±1.04[b]
2mM SA + HW	35.55±0.70	39.69±0.81[a]	42.66±0.55[a]	43.48±0.52[a]	39.12±1.38[b]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 18 Effect of HW and SA treatment on color as *a** in Nam Dok Mai mango stored at 13 °C during storage

Treatments	Storage time at 13°C				
	Day 0	Day 5	Day 10	Day 15	Day 20
Control	6.70±0.21	8.94±0.64[a]	10.20±0.75[a]	10.62±0.35[a]	9.54±0.39[a]
HW	6.70±0.21	8.05±0.56[a]	9.31±0.54[a]	9.93±0.39[a]	10.21±0.38[a]
2mM SA	6.70±0.21	7.68±0.49[a]	8.55±0.66[a]	9.40±0.43[a]	10.39±0.12[a]
2mM SA + HW	6.70±0.21	8.29±0.40[a]	9.70±0.53[a]	10.16±0.39[a]	10.48±0.24[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 19 Effect of HW and SA treatment on color as *a** in Nam Dok Mai mango stored at 25 °C during storage

Treatments	Storage time at 25°C				
	Day 0	Day 3	Day 6	Day 9	Day 12
Control	8.66±0.42	12.10±0.36[a]	13.68±1.59[a]	14.87±0.74[a]	14.13±0.79[a]
HW	8.66±0.42	10.98±0.28[b]	13.55±0.31[a]	15.02±0.28[a]	14.77±0.17[a]
2mM SA	8.66±0.42	10.91±0.30[b]	13.40±0.30[a]	14.88±0.24[a]	15.07±0.24[a]
2mM SA + HW	8.66±0.42	9.57±0.28[c]	12.73±0.34[a]	15.16±0.31[a]	15.18±0.41[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 20 Effect of HW and SA treatment on color as L* in Nam Dok Mai mango stored at 13 °C during storage

Treatments	Storage time at 13°C				
	Day 0	Day 5	Day 10	Day 15	Day 20
Control	71.0±0.77	73.50±0.86[c]	72.38±1.06[a]	66.68±0.82[b]	66.70±1.02[b]
HW	71.0±0.77	74.43±0.81[bc]	72.92±0.71[a]	67.14±0.71[b]	67.46±0.64[b]
2mM SA	71.0±0.77	76.31±0.58[ab]	73.39±0.72[a]	69.31±0.79[a]	70.04±0.73[a]
2mM SA + HW	71.0±0.77	76.75±0.29[a]	73.61±0.69[a]	69.40±0.45[a]	70.67±0.55[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 21 Effect of HW and SA treatment on color as L* in Nam Dok Mai mango stored at 25 °C during storage

Treatments	Storage time at 25°C				
	Day 0	**Day 3**	**Day 6**	**Day 9**	**Day 12**
Control	75.16±0.53	70.78±0.71[b]	64.28±1.53[b]	63.22±1.67[a]	68.22±0.62[b]
HW	75.16±0.53	71.57±0.55[b]	65.40±0.72[b]	63.55±0.79[a]	69.17±0.24[ab]
2mM SA	75.16±0.53	71.14±0.49[b]	65.98±0.52[b]	63.14±0.75[a]	69.52±0.51[ab]
2mM SA + HW	75.16±0.53	74.36±0.58[a]	68.86±0.40[a]	66.23±0.27[a]	70.36±0.54[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 22 Effect of HW and SA treatment on TSS in Nam Dok Mai mango stored at 13 °C during storage

Treatments	Storage time at 13°C				
	Day 0	**Day 5**	**Day 10**	**Day 15**	**Day 20**
Control	13.16±0.53	18.92±0.33[a]	19.88±0.20[a]	19.86±0.30[a]	20.02±0.19[a]
HW	13.16±0.53	18.28±0.16[ab]	19.18±0.12[b]	19.40±0.09[a]	18.74±0.09[b]
2mM SA	13.16±0.53	18.02±0.21[b]	18.84±0.09[b]	18.58±0.09[b]	18.70±0.05[b]
2mM SA + HW	13.16±0.53	16.46±0.09[c]	17.76±0.27[c]	18.40±0.15[b]	17.64±0.22[c]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 23 Effect of HW and SA treatment on TSS in Nam Dok Mai mango stored at 25 °C during storage

Treatments	Storage time at 25°C				
	Day 0	**Day 3**	**Day 6**	**Day 9**	**Day 12**
Control	11.85±1.09	19.06±0.13[a]	19.24±0.34[a]	19.72±0.34[a]	20.10±0.14[a]
HW	11.85±1.09	18.63±0.05[ab]	18.55±0.26[ab]	19.33±0.13[ab]	18.78±0.11[b]
2mM SA	11.85±1.09	15.73±2.14[b]	15.47±2.11[b]	15.42±2.12[bc]	15.99±2.18[b]
2mM SA + HW	11.85±1.09	13.73±2.18[c]	13.86±2.20[b]	13.50±2.14[c]	13.42±2.13[c]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 24 Effect of HW and SA treatment on acidity in Nam Dok Mai mango stored at 13 °C during storage

Treatments	**Storage time at 13°C**				
	Day 0	**Day 5**	**Day 10**	**Day 15**	**Day 20**
Control	1.04±0.01	0.71±0.01^{c}	0.57±0.02^{d}	0.60±0.07^{d}	0.68±0.03^{b}
HW	1.04±0.01	0.85±0.02^{b}	0.70±0.04^{c}	0.73±0.03^{c}	0.81±0.04^{ab}
2mM SA	1.04±0.01	0.99±0.02^{a}	0.82±0.01^{b}	0.88±0.04^{b}	0.88±0.03^{a}
2mM SA + HW	1.04±0.01	1.02±0.01^{a}	1.03±0.01^{a}	1.02±0.01^{a}	0.98±0.09^{a}

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 25 Effect of HW and SA treatment on acidity in Nam Dok Mai mango stored at 25 °C during storage

Treatments	**Storage time at 25°C**				
	Day 0	**Day 3**	**Day 6**	**Day 9**	**Day 12**
Control	0.89±0.00	0.63±0.01^{c}	0.38±0.04^{c}	0.42±0.04^{c}	0.47±0.01^{a}
HW	0.89±0.00	0.69±0.00^{bc}	0.59±0.02^{b}	0.53±0.01^{b}	0.62±0.01^{c}
2mM SA	0.89±0.00	0.74±0.15^{b}	0.62±0.12^{ab}	0.59±0.12^{ab}	0.75±0.15^{b}
2mM SA + HW	0.89±0.00	0.85±0.20^{a}	0.71±0.17^{a}	0.67±0.15^{a}	0.86±0.20^{a}

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 26 Effect of HW and SA treatment on TPC in Nam Dok Mai mango stored at 13 °C during storage

Treatments	**Storage time at 13°C**				
	Day 0	**Day 5**	**Day 10**	**Day 15**	**Day 20**
Control	66.72±2.43	137.19±1.16^{a}	132.55±2.00^{a}	70.90±4.60^{c}	52.97±5.03^{c}
HW	66.72±2.43	136.44±3.75^{a}	124.38±4.58^{ab}	84.56±3.62^{b}	69.14±4.65^{b}
2mM SA	66.72±2.43	124.39±4.68^{ab}	116.87±3.97^{bc}	105.35±3.30^{a}	71.88±4.44^{b}
2mM SA + HW	66.72±2.43	112.36±8.16^{b}	112.63±3.54^{c}	107.80±2.78^{a}	87.90±2.14^{a}

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences ($P \leq 0.05$) within treatment.

Table 27 Effect of HW and SA treatment on TPC in Nam Dok Mai mango stored at 25 °C during storage

Treatments	Storage time at 25°C				
	Day 0	Day 3	Day 6	Day 9	Day 12
Control	67.02±1.28	128.56±3.91[a]	123.61±4.30[a]	61.95±2.80[b]	48.88±4.45[c]
HW	67.02±1.28	119.46±3.17[bc]	100.16±7.56[b]	79.94±6.31[a]	59.59±8.69[bc]
2mM SA	67.02±1.28	111.26±1.11[c]	90.74±6.84[b]	80.12±7.59[a]	70.06±5.09[ab]
2mM SA + HW	67.02±1.28	105.41±1.72[c]	91.66±3.78[b]	84.35±5.03[a]	81.58±4.76[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 28 Effect of HW and SA treatment on carotenoid in Nam Dok Mai mango stored at 13 °C during storage

Treatments	Storage time at 13°C				
	Day 0	Day 5	Day 10	Day 15	Day 20
Control	214.62±5.64	374.11±2.95[a]	405.90±6.52[a]	508.06±5.54[a]	545.26±1.79[a]
HW	214.62±5.64	315.93±4.44[b]	318.13±2.40[b]	492.50±2.95[a]	512.79±1.35[a]
2mM SA	214.62±5.64	302.91±2.25[b]	315.93±4.74[c]	471.53±3.58[a]	484.38±1.79[a]
2mM SA + HW	214.62±5.64	310.52±12.35[b]	387.64±4.22[c]	470.17±4.88[a]	455.97±5.54[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 29 Effect of HW and SA treatment on carotenoid in Nam Dok Mai mango stored at 25 °C during storage

Treatments	Storage time at 25°C				
	Day 0	Day 3	Day 6	Day 9	Day 12
Control	178.82±2.00	133.89±2.78[a]	124.15±2.54[a]	64.63±0.31[b]	48.37±2.20[d]
HW	178.82±2.00	121.31±3.33[b]	103.91±3.05[b]	85.91±6.24[a]	62.05±2.83[c]
2mM SA	178.82±2.00	111.21±1.43[c]	101.03±1.50[b]	83.33±2.15[a]	72.29±1.70[b]
2mM SA + HW	178.82±2.00	103.90±1.06[d]	96.95±3.55[b]	86.46±1.73[a]	88.25±2.10[a]

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 30 Effect of HW and SA treatment on ascorbic acid in Nam Dok Mai mango stored at 13 °C during storage

Treatments	Storage time at 13°C				
	Day 0	**Day 5**	**Day 10**	**Day 15**	**Day 20**
Control	21.46±1.53	22.22±1.43^{a}	22.99±1.21^{a}	18.39±1.43^{b}	16.86±0.94^{c}
HW	21.46±1.53	19.16±1.21^{ab}	19.92±0.77^{ab}	19.92±1.43^{ab}	19.92±0.77^{b}
2mM SA	21.46±1.53	18.39±0.77^{b}	19.16±1.21^{b}	21.46±0.94^{sb}	22.58±1.29^{ab}
2mM SA + HW	21.46±1.53	19.16±1.21^{ab}	19.92±0.77^{ab}	23.76±1.43^{a}	25.08±0.77^{a}

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

Table 31 Effect of HW and SA treatment on ascorbic acid in Nam Dok Mai mango stored at 25 °C during storage

Treatments	Storage time at 25°C				
	Day 0	**Day 3**	**Day 6**	**Day 9**	**Day 12**
Control	12.57±0.75	19.16±0.00^{a}	21.92±0.75^{a}	19.16±0.00^{a}	19.16±0.00^{c}
HW	12.57±0.75	13.33±0.86^{b}	18.08±0.75^{b}	19.31±1.22^{a}	19.44±0.57^{bc}
2mM SA	12.57±0.75	13.33±0.86^{b}	17.32±0.86^{b}	19.66±0.45^{a}	20.59±0.50^{b}
2mM SA + HW	12.57±0.75	13.33±0.86^{b}	17.32±0.86^{b}	19.90±0.25^{a}	22.63±0.22^{a}

Note The values are expressed as mean ± SE (n=5). Different letters represent significant differences (P ≤ 0.05) within treatment.

CURRICULUM VITAE

CURRICULUM VITAE

NAME	Mrs. Fatou Darboe
DATE OF BIRTH	05th August `1967
ADDRESS	Department of agriculture Cape Point Bakau Cape St Mary Gambia

EDUCATIONAL BACKGROUND

1998	Diploma Agriculture Gambia college
1987-1989	Certificate in Agriculture

WORK EXPERIENCE

2016-Present	Principal Agricultural Officer Department of Agriculture
2009-2015	Senior Agricultural Officer Department of Agriculture

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