EFFECTS OF WAX COATING ON POSTHARVEST QUALITY

OF 'SAI NAM PAUNG' MANDARIN

(*Citrus reticulata* BLANCO)

NI NI SHEIN

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Title

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ABSTRACT

Postharvest quality of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) was studied after coating with Teva wax (18% food grade shellac and polyethylene) and Rosy wax (18% w/v Polyethylene and resin) and kept in cold storage at 5 °C or ambient temperature (~ 28 °C) for a month. Percentage of weight loss, fruit height, shelf life, glossiness, off flavor development, total soluble solid, titratible acidity, pH and peel color were evaluated at one week intervals while respiration rate was determined on day 28th.

Coating the mandarins with Teva and Rosy waxes was shown to slow down the percentage of weight loss, respiration rate, fruit height, glossiness and shelf life reduction and peel color "a*" change. However, the concentration of wax had no effect on off flavor, TSS/TA ratio, pH, L, a* and b* value. Significant positive results were observed on the effect of storage temperature on percentage weight loss, fruit height, glossiness and shelf life of fruit. High respiration rate was detected in fruits stored at low temperature whereas TSS/TA ratio, pH, peel color were not affected. Fruits coated with Teva wax did not show any disease incidence during storage but those coated with Rosy wax showed stem end rot on 12 days after storage. At ambient temperature, wax coated fruit had shelf life of more than 20 days as compared to uncoated fruits which lasted about 9 days. For cold storage, wax coated fruits lasted up to 2 months as compared to uncoated fruit that lasted about a month.

This study suggested that low temperature was still necessary to store mandarin for 1 month without changing the appearance and sensory quality although commercial coating could be a good option to increase shelf life of 'Sai Nam Paung' mandarin. The combination of wax coating and storage temperature at 5 °C can be used successfully for long term storage of 'Sai Nam Paung' mandarin for 2 months.

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Abbreviations

° C	Degree Celsius
Assist.	Assistant
Assoc.	Associate
CA	Controlled Atmosphere
CI	Chilling Injury
CRD	Completely Randomized Design
DMRT	Duncan's multiple range test
e.g.	for example
et al.	And other people
FID	Flame ionization detector
g/gm	Gram
GC	Gas Chromatography
h/hr	hour
HCl	Hydrochloric acid
i.e.	that is
Inc.	incorporation
kg	Kilogram
L/Lit..l	Liter
M	molar
m	meter
mA	Milli ampere
mg	milligram
min	minute
ml	milliliter
mm	millimeter
mM	millimolar
mm^2	square of millimeter
nl	Nano liter

NS	Not significant
pH	potential of hydrogen
ppm	Parts per million
Prof.	Professor
RH	Relative humidity
sec	second
TA	Titratible Acidity
TCD	Thermo conductivity detector
TSS	Total Soluble Solid
VPD	Vapor pressure deficit

Chapter 1

Introduction

Mandarin (*Citrus reticulata* Blanco) is one of the commercially important species of citrus (Murata, 1997). It can be grown in both tropical and subtropical areas worldwide, although the best color and quality usually occurs in subtropical conditions (Sauls, 1998). Davies and Albrigo (1994) reported that among the mandarins, *C. reticulat*a Blanco was probably originated from Indo- China and South China and were carried to eastern India along with traders. Owing to its nutritive and therapeutic values along with its taste and flavour, citrus fruits have placed in the regular dietary list of the people living in modernized countries (Mukhopadhyay, 2004). The term "mandarins" is used throughout the most citrus producing regions, although tangerine is referred to the most deeply pigmented mandarins types (Sauls, 1998).

Mukhopadhyay (2004) reported that the mandarin tree is normally a small to large, composed of spiny, with a dense canopy of slender branches. Mandarin can be planted in density with 350-450 plants per hectare. Mandarins can start bearing from the fourth year but substantial yield can be expected only from sixth year onwards. It can produce 500-800 fruits per tree about 9-10 years after planting (n.p., 2008). The mature mandarin fruits are depressed, globose, yellow or reddish orange, with loose skin, hollow core and containing 10-14 separable segments (Mukhopadhyay, 2004). It can bear from early April through to late October. In general, Davies and Albrigo (1994) stated that mandarin can be harvested when the minimum TSS/TA ratio ranged from 7- 9:1 based on location and local standard.

Minimizing mandarin water loss and fruit wastage along with maximizing storage life and eating quality are important to citrus grower and packaging houses (Lawes and Prasad, 1999). Murata (1997) reported that citrus fruits had relatively longer postharvest life in comparison with other tropical and subtropical fruits. However, they deteriorate after harvest due to mainly desiccation and senescence (Perez-Gago et al., 2003). In addition, Hagenmaier (2005) reported that removing the surface waxes of the fruit by washing could result in postharvest weight loss due to more rapid dehydration. This results in much economic loss especially in developing countries. Therefore, Lawes and Prasad (1999) reported that citrus owners and exporters sought ways to minimize storage weight loss, to maintain quality and to reduce variability within and between harvest, handling, storage, transport and distribution.

Many storage techniques have been developed to extend the marketing distance and holding periods for fresh horticultural commodities after harvest. The current most common methods to reduce postharvest loss in citrus industry are surface coating and storage at low temperature.

Surface coatings have been used extensively on many fruits and vegetables to create an effective barrier against weight loss (Lawes and Prasad, 1999). Hagenmaier and Baker (1993) reported that wax coating could improve cosmetic features, reduce water loss and achieve modified internal atmosphere within the fruit, which help to delay ripening. Park et al. (1994) reported that the barrier properties of edible coating had been directly related to the coating solution's concentration. However, appropriate concentration of applied wax is a very important factor in postharvest quality, which extends the shelf life of harvested products. Hagenmaier and Shaw (1992) found that gas permeability of many commercial coating was low, leading to the development of off flavor in citrus fruit, especially after storage at marketing temperature. Therefore, citrus coatings used by the packaging house industry are not always successful in meeting these goals (Hagenmaier and Baker, 1995).

The fresh produce stored at an ambient temperature is critical important on the metabolic rate of the produce which determine the postharvest quality of the produce (Kays, 1991). Kim (2002) reported that if the fruits and vegetables are held just above their freezing point, the great reduction in respiration and thus longest shelf life can be obtained. In addition, the produce temperature is usually slightly higher than the ambient temperature due to heat produced from the respiratory process. This slight difference in temperature caused the moisture loss of the harvested product (Kays, 1991).

As a result, low temperature storage was used as the common way to extend the market life of fruits and vegetables. Kays (1991) also mentioned that if the fresh produce is to be maintained with their quality as close to the condition it was at harvest, low temperature storage is essential because it depresses the changes of quality of fresh produce caused by its metabolism. Salunkhe and Desai (1986) reported that storage of citrus fruits at low temperature is the most effective method to delay the development of decay and water loss from the fruits. However, many varieties of citrus fruit are susceptible to chilling injury. The lowest safe temperature for mandarin to prevent chilling injury during transport and storage is 5 °C (Kader and Rolle, 2004).

The combination of low temperature storage and surface coating could have more benefit results to extend marketability of the fruits than using either surface coating or low temperature storage (Perez-Gago et al., 2003; Navarro et al., 2005). Some concrete findings concerning surface coating would be able to apply as an input for developing a concept for increasing income of mandarin growers and acceptability of consumers by improving eating quality of the mandarin.

On the basis of these reviews, it was decided to carry out this study by investigating the combined effect of different types of coating wax at different concentrations and different storage temperature on postharvest quality of 'Sai Nam Paung' mandarin.

1.1 Objectives

The main objectives of this study wcre as follows.

1. To study the postharvest quality of mandarin after waxing.
2. To determine an appropriate storage temperature for mandarin after waxing.

Chapter 2

Literature Review

2.1 Citrus

Citrus is a very ancient crop and known to occur since over 4,000 years ago (Mukhopadhyay, 2004). It is the second most widely cultivated crop in the world (Salunkhe and Desai, 1986). It can grow in the wide range of climatic conditions and land situations, especially throughout the tropics and subtropics between 40° north and south latitude. Davies and Albrigo (1994) reported that Yunnan Province in the south central China may be the origin location due to being the place where the most diversity of species was found. Mukhopadhyay (2004) mentioned that domestication of Citrus is still in infant stage in Southeast Asia (Northeastern India, and neighboring regions of Burma (Myanmar) and China).

The fruits of genus *Citrus* are special kinds of berry (a hesperidium) composed of segments filled with spindle- shaped juice sacs. It belongs to the large plant family Rutaceae and subfamily Aurantioideae. It contains 33 genera and more than 215 species (Mukhopadhyay, 2004). Swingle and Reece (1967) reported that species within Rutaceae generally have four important characteristics: (1) the present of oil glands, (2) the ovary is raised on a floral (nectary) disc, (3) pellucid dots are present in the leaves and (4) the fruits have axile placentation. Fruit shape varies from spheroid (oranges) to oblate (grapefruit and mandarin) to prolate (lemon and lime). The peel contains numerous oil glands and varies in color from green- yellow (lemons, limes, and grapefruit) to orange and reddish (orange) to deep orange to red- orange (mandarins).

Commercial citrus species and related genera are primarily evergreen species originated from subtropical and tropical although best color and quality usually occurs in subtropical conditions (Sauls, 1998). They are orange [*Citrus sinensis*], mandarin (tangerine) [*Citrus reticulata* Blanco], Lemon [*Citrus limon*] and lime [*Citrus auranifolia*], grapefruit [*Citrus paradisi*], pomelo (pummelo) [*Citrus grandis*] and their hybrids (Murata, 1997).

The top producing countries of citrus were Brazil, United States, China, Spain and Japan (Murata, 1997). According to world citrus production in Marketing year (MY) 2005/06, the production of citrus in major producing countries was estimated at 72.8 million metric tons and total citrus consumption was estimated at 65.6 million tons, including 38.5 million tons of fresh consumption (Citrus - Special Feature Article, 2006). This is due to the facts that fruits contain high level of vitamin C and A (Murata, 1997) and nutritive and therapeutic values along with its taste and flavour that have placed it in the regular dietary list of the people living in advanced countries (Mukhopadhyay, 2004).

2.1.1 Mandarin

The mandarin orange (*Citrus nobilis* or *Citrus reticulata*) is considered to be the original type from the tangerine (cultivar Deliciosa) and satstuma (cultivar Unshiu) that were developed (Salunkhe and Desai, 1986). Among mandarins, Davies and Albrigo (1994) reported that *C. Reticulat*a Blanco was probably originated from Indo- China and South China. Snowdon (1990) stated that it is especially important in Japan, followed by Spain, Brazil, the USA, Pakistan, South Korea, Italy, Morocco, Turkey and China. Sauls (1998) mentioned that the term "mandarins" is used in most of the citrus producing regions, although deeply pigmented mandarins was called as tangerine.

Mandarins are characterized by bright peel and pulp color, the excellent flavor and easy-to-peel rind. There are several types of mandarins such as sutsuma mandarins group (*C. unshiu* Marc.), Common mandarins group (*C. reticulate* Blanco), Mediterranean 'Willowleaf' mandarin (*C. deliciosa* Te*n*.), naturally occurring hybrids such as temple orange and honey mandarin, and man made mandarins hybrids such as tangelos.

In general, mandarin fruits have short on-tree life, resulting in a short season and the tree being subject to alternate bearing (Seymour et al., 1993; Baxter and Jones, 1985). It should be harvested on clear, sunny day with low humidity by using clipper to avoid damage and plug. Baxter and Jones (1985) suggested that early mandarins should be harvested as soon as their skin turns color, although the late varieties could be left on the tree for 4 to 6 weeks. It is especially used for edible (fresh fruit, juice and concentrate, etc.), medicinal, rootstock and hybridization (Mukhopadhyay, 2004).

2.2 Factors affecting postharvest quality

External and internal qualities changes could occur in citrus fruit after it is harvested. Logically, transpiration and CO_2 production in the respiration process is the main cause of weight loss in fresh produce. The commercial deterioration of the orange fruit is decay, drying of the peel, softening, off-flavor, and rind disorder. However, shriveling of the fruit occurs before the fruit develops off-flavor. As a result, shriveling of the peel is the chief reason for the decreasing marketable yield of the orange.

2.2.1 Transpiration

Fresh commodities loss water easily by transpiration, which depends on the gradient of vapor pressure deficit (VPD) (Salunkhe and Desai, 1986). Ben- Yehoshua (1969) reported that, 90 % of the total weight loss of the commodities was caused by transpiration. Commercial and physiological deterioration occur when fresh mandarins are transported to the fresh market in non controlled condition. Snowdon (1990) stated that there are many natural openings on the surface of the produce even it is covered with outer waxy cuticle. The relatively greater cuticular transpiration takes place than the stomatal transpiration in oranges. Kim (2002) reported that the rate of transpiration was also influenced by many environmental factors, such as temperature, relative humidity, air velocity and atmospheric pressure.

2.2.2 Respiration

Fresh commodities respire by using carbohydrate and fat by absorbing oxygen and releasing carbon dioxide. Therefore, the composition of storage atmosphere was changed due to respiration (Kim, 2002). If the supply of oxygen for respiration is not adequate, undesirable odors are produced. Additionally, the heat released during respiration is very important for postharvest storage life. As a result, Kim (2002) stated that the higher the respiration rate, the shorter the storage life of fruits and vegetables because senescence of the produce was hastened and flavor quality was reduced due to respiration. Wills et al. (1981) also reported that respiration rate of the produce was used as the excellent indicator to show the potential storage life of the produce. Kim

(2002) mentioned that respiration rates of the produce vary with the type of produce, cultivar, maturity, temperature, atmospheric composition and other stress factors. Davies and Albrigo (1994) reported that storage conditions are cultivars dependent and fruit quality changes occur during prolong storage although citrus fruits are non climacteric and have low respiration rate.

2.2.3 Fruit quality and disease

Fruits are attractive to the consumers due to their aesthetic qualities of flavors, color and texture (Seymour et al., 1993). Although, citrus fruit do not undergo physical or chemical changes after harvest from the tree (Salunkhe and Desai, 1986), the qualities of the fruit were changed during storage due to their biochemical changes inside fruit. Pectic enzymes of citrus fruits affect their juice quality. Maleveski et al. (1977) observed that TSS content and the fresh weight decreased with the storage time in Haden mango fruits. Sugar and organic acid were used as respiratory substrates. (Seymour et al., 1993) reported that the reduction of acid level during ripening is seemed to be utilization of organic acid as respiratory substrates in fruits. Ripening of the fruit is influenced by ethylene production. Salunkhe and Desai (1986) reported that the rise in ethylene production and respiration coincide with the color change in citrus fruit. Color change associated with ripening is related with the texture of the fruit, which determined eating quality of the fruit (Seymour et al., 1993). In addition, the appearance of the fruits was changed during storage. This is due to the quantity and quality of the natural waxes can change after harvest and during harvesting, transport, washing, grading and storage of fruit. Beside the internal quality changes, Salunkhe and Desai (1986) reported that the matured and harvested citrus fruits were highly susceptible to infection by pathogenic microorganisms due to the high moisture and nutrient content of the fruit. Fungal disease is the major source of postharvest fruit damage and losses. Davies and Albrigo (1994) reported that green mould and blue mould were the major sources of citrus fruit decay in postharvest storage. Davies and Albrigo (1994) also suggested that high humidity also promotes the growth of pathogenic organisms such as *Diplodia* spp: causing stem end rot in citrus fruits.

2.3 Postharvest treatments

The storage or marketable life of crops can be extended by various treatments such as low temperature, high temperature, chemical treatments and irradiation applied to produce (Thompson, 1996). Moreover, postharvest dipped or sprayed chemicals can improve fruit appearance or delay deterioration.

2.3.1 Control of water loss

Water vapor pressure deficit (VPD) in transpiration is the major cause of commercial and physiological deterioration. Therefore, it can be controlled by minimizing the humidity difference between the commodities and the surrounding air. Ben- Yehoshua (1969) reported that the VPD between the produce and the air can be reduced by lowering the temperature or by raising the humidity of the surrounding air. D'Aquino et al. (2003) observed that, high relative humidity played an important role than refrigeration for fresh product. However, it may predispose the produce to infection by microbial pathogens causing postharvest decay and rots (D'Aquino et al., 2003). Therefore, low temperature storage is the most effective method to reduce transpiration.

Perry (1999) found that citrus fruits with perfectly sound skin can store in cool, moisture storage for several weeks (38 to 48 $^{\circ}$ F, 85-95 % relative humidity). However, he reported that, fruit caused shriveling and developed off flavors within a week to 10 days in under dry conditions at room temperature. Similarly, Ben-Yehoshua (1969) mentioned that lowering the temperature of storage to 12 °C also reduced transpiration and delay drying of the fruit peel in orange fruit. Manzano et al. (1997) reported that wax coating in Haden mango fruits could not control shriveling at high storage temperature (25 °C).

The stomata of harvested citrus fruits were essentially closed to reduce water loss of the fruit (Ben- Yehoshua, 1969). Therefore, coating with commercial wax reduced water loss and improved the appearance of the fruit. Ben-Yehoshua et al. (1985) reported that well ordered of wax structure provides more resistant to the permeation of water. However, waxing partially or completely plugs the stomatal pores on the surface. Therefore, it barely affects transpiration. Although waxing increases water resistance by 25 % (Ben Yehoshua et al., 1985), the applications of skin coating can extend doubled storage life of the fruit by reducing transpiration (Ben- Yehoshua, 1969).

2.3.2 Control of respiration

Temperature influences the respiration rate and the deterioration rate of the produce. If the fruits and vegetables are held just above their freezing point, the commodities are greatly reduced in respiration and longest storage life (Kim, 2002). The more detrimental effect of high temperature on coated fruit was shown by the sharp decline in oxygen levels when fruit was transferred from cold storage to warm temperature (Lawes and Prasad, 1999).

The atmospheric composition with high carbon dioxide and low oxygen reduce the respiration rate and increase the storage life of the produce. Waxing increases the fruit resistance to CO_2, O_2 and ethylene by 140, 250 and 100 %, respectively. However, they still diffuse through the residual stomata opening depending on the relative diffusivity of each gas in the air (Ben Yehoshua et al., 1985). The flavedo portion of the orange fruit is the primary site for fruit resistance to CO_2 and O_2 diffusion (Ben- Yehoshua, 1969).

Perez-Gago et al. (2003) stated that the use of edible coating on fruits creates the modified internal atmosphere within the fruit and it reduces respiration rate of the fruit. However, the maintenance of a modified atmosphere by surface coating depends on the film permeability of coating material, uniformity of coating, imperfections (cracks, holes, and tears), respiration rate of the commodities, relative humidity and storage temperature. Thompson (1996) mentioned that coating on fruit restricts gas exchange between the fruit and surrounding atmosphere, which lead to a build up of carbon dioxide and a depletion of oxygen. Therefore, sufficient oxygen should be retained in the storage atmosphere to inhibit anaerobic respiration (Kim, 2002). The recommended modified atmosphere composition for orange is reported to be 5-10% oxygen and 0-5% carbon dioxide.

2.3.3 Control of fruit quality and disease

The quality of fruits and vegetables can be reduced by improper environmental conditions. Wax coating not only improves cosmetic features but also helps to delay ripening (Navarro et al., 2005). However, pitting around the stem end was observed in coated fruits held at high temperature (Petracek et al., 1998). Salunkhe and Desai (1986) suggested that storage of citrus fruits at low temperature is the most effective method to maintain fruit qualities and delay the development of decay. The maintenance of high relative humidity is also important to maintain the freshness of the product and conserve the fruit quality. However, D'Aquino et al. (2003) reported that fruits stored at high relative humidity may result in postharvest decay and rots caused by pathogens.

2.4 Current effective storage managements on mandarin

2.4.1 Wax coating

The natural waxes prevent moisture loss of fruit during storage by reducing water permeability through the skin. However, Hagenmaier (2005) reported that removing the surface waxes by washing could result in more rapid dehydration because washing removes the natural wax and increases rind permeability (Kaplan, 1986). Beside, Thompson (1996) stated that the layer of natural wax could be removed during harvesting, transport, washing and grading. Therefore, the application of commercial wax was still required to reduce water loss for prolong storage. Kays (1991) reported that fruit damages during or after harvest or cuticle removed by detergents was more susceptible to insect and fungal damage if it was not waxed.

2.4.2 The objectives of wax coating

The purposes of waxing or applying edible coating are to reduce respiration and transpiration rate, to generate modified internal atmosphere of the fruit, to enhance product gloss, to replace natural waxes removed during washing, to cure tiny injury and scratches on fruit surface and to aid uniform fungicide application (Kim, 2002). Lakshminarayana et al. (1974) found that wax coating reduce fruit weight loss and improve peel color glossiness and texture and handling resistance in citrus fruit. Kays (1991) reported that wax also serves as physical barrier to reduce gas exchange and decrease shrinkage. However, Petracek et al. (1998) reported that wax coating may cause off-flavor and peel disorder development such as pitting.

2.4.3 Synthetic wax application

Waxes are long - chain fatty acid (Newhall and Griersm, 1955). Waxing is a practical method to reduce water loss in citrus fruit. Hydrocolloids, lipids and composites are commonly used as edible film and coating. Natural wax, such as sugar cane wax, carnabura wax, shellac and various resins are preferred to coat on fruits. The hydrophobic nature of most fruit and vegetable cuticles makes difficult to apply uniform coating and films. Emulsifiers, surfactants and plasticizers are often needed for uniform coverage. Thompson (1996) suggested that the commodity should be dried before and after waxing to give good adhesion and retention of the wax.

2.4.4 Types of waxes

Hydrocolloids

Hydrocolloids are water based colloidal mixture of protein and/or polysaccharides. Water based colloidal mixture of proteins are casein, gelatin, gluten, corn, soy and whey protein and they are cellulose derivatives and alginates, pectin, and starches. The properties of hydrocolloids are poor resistance to water vapor, barrier to oxygen and carbon dioxide and mechanical stress (Saltveit, no date).

Lipids

Lipids are waxes, fatty acids, acetylated monoglycerides, sucrose fatty acid esters, and shellac. The advantages of lipids coating are barrier to water vapor, glossiness, but required supporting matrix. Many lipids exist in crystalline form. Liquid lipids have less resistance to gases and water vapor than crystalline lipids (Saltveit, no date).

Composite coating

Bi-layers and conglomerates are composite coatings. It has the integrated advantages of components, and lessens the disadvantages of components on the produce (Saltveit, no date).

Shellac

Shellac is a hard, tough, amorphous resin that has good water resistance and produce high lustrous finishes. It was commonly added in wax to provide a "fresh look" of the fruit for cosmetic purpose (Hagenmaier, 2000; Kaplan, 1986).It is soluble in alcohol, aqueous solution of alkali, and organic acid and ketones, but it is insoluble in water. It is used as an ingredient in edible fruit coating to limit water loss, prevent desiccation and weight loss and prevent entry of pathogens. Waxes which include shellac tend to restrict the gas exchange of O_2 and CO_2 between atmospheres and fruit. Shellac coatings are fairly impermeable to oxygen and water.

Shellac is easy to use, and it can be applied with a brush, pad, sprayer, or wiping cloth. Many different formulations of coating have been investigated and developed to provide different degree of gas and water permeability. According to the purpose, shellac content can be ranged from 2-45% (Hallman et al., 1994). On the other hand, over use of the shellac in fruit coating can lead to flavor and quality problem. So, shellac should be used as one ingredient in a formulated wax coating because it causes off flavor appearance at high shellac content in fruit coating formulations (OMRI, 2002).

Stafresh

Stafresh is a natural wax emulsion containing shellac and carnauba and it is the most suitable alternative for polyethylene wax. It can be applied on fruit by using spray nozzles over a suitable brush bed. Stafreshis same or better than tag with regard to cold damage, physiological disorders, post-harvest disease, external appearance, and shelf life (Kohne and Duvenhage, 1997). Sta-fresh 360 HS is a high gloss, low bushing, and it is used as protective coating for fresh citrus fruit. Additionally, it gives a highly attractive, durable shine to the fruit surface and also retards fruit shrinkage of the fruit. It is recommended for use on grape fruit, orange, tangerine, lemons and other citrus fruit (Igoe and Hui, 2008).

Polyethylene wax

Polyethylene waxes are manufactured from low molecular weight, high- density raw materials (Encyclopedia of wax, 2008). Food grade polyethylene is non-ionic/ anionic chemicals. Using a fatty acid in combination with an amine produces anionic emulsions. Anionic emulsions are film forming, especially as foil or metallic surface. It is suitable for fruit coating and other food application because it is made from food grade raw materials.

2.4.5 Method of application

The films and coating are applied by using dipping, spraying, foaming, dripping, brushing and casting. Chun et al. (1996) reported that the selection of coating methods should consider simultaneously on both peel permeability and fruit respiration rate and also on cultivars, temperature and type of coating. In addition, Long and Leggo (1959) suggested that very thin film of wax should be applied because thicker films can cause the development of fermentation odor and off- flavors in the fruit.

2.4.6 Effects of wax coating on postharvest quality

Reduction in fruit weight loss is the major advantage of coating. However, appropriate concentration of applied wax is very important factor in postharvest quality, which extends the shelf life of harvested products. Park et al. (1994) reported that the barrier properties of edible coating had been directly related to coating thickness through the coating solution's concentration. Davis and Hoffmann (1973) reported that ethanol builds up and off-flavors in juice were found after multiple coating of either water or solvent –soluble waxes on oranges. These results showed that the danger of over waxing.

Wax contain shellac has low permeability than wax without shellac and it leads to increase more pitting incidence and ethanol production (Petracek et al., 1998). This finding was supported by Hagenmaier (2002), who reported that coatings, which composed mainly of shellac and wood resin, showed a poor flavor and high juice-ethanol content in mandarin fruits at 21°C after storage for 7 days although shellac is good moisture barrier. Petracek et al. (1998) reported from their wax formulation studies that shellac and polyethylene waxes caused more pitting than carnauba based wax. In contrast with shellac coating, Krochta (1996) reported that coating containing protein or polysaccharide alone did not provide a good moisture barrier. The fruit coated with 'Tag' (water based polyethylene) on Galia-type melon slightly inhibited fruit ripening (Faillik et al., 2005). Baldwin et al. (1999) showed that the carnauba coating in mango reduced weight loss more effectively than cellulose- based polysaccharides coating.

In general, the lack of uniformity in the treatments leads to unclear conclusion based on the effect of composition on weight loss. Perez-Gago et al. (2003) reported that increasing total solid concentration from 4 % to 8 % did not influence weight loss of mandarin coated with 60 % bee wax emulsion. These results suggested that uniform layer of coating was the major factor to reduce weight loss of the fruit.

Advantages of wax coating

Coating commonly contains ingredients such as polyethylene, carnauba, or candelillas all of which reduces water vapor loss and also provide a vehicle for fungicide (Hagenmaier and Baker, 1995; Debeaufort et al., 1998; Alleyne and Hagenmaier, 2000 cited by Fallik et al., 2005). Consumer tends to prefer produce with a shiny or glossy appearance. Considerable research showed that edible surface coatings, such as waxes, are applied to improve the cosmetic of fruit and vegetables. (Hagenmaier and Baker, 1995; Debeaufort et al., 1998; Alleyne and Hagenmaier, 2000 cited by Fallik et al., 2005). According to Thompson (1996), crop such as citrus could be improved its appearance by synthetic wax application. Some producers may add dyes to the wax in order to modify the color as well as providing an enhanced shine.

Waxing also has been studied in relation to spoilage, especially chilling injury and browning. Hagenmaier and Shaw (1992) reported that waxed fruit showed less spoilage and lower respiration rate than uncoated sample. Coatings prevent spoilage by serving as a barrier to water vapor (Grierson and Wardowski, 1978; Morris, 1982 cited by Hagenmaier and Shaw, 1992). If waxing could reduce spoilage, it can be considered as a cost-effective substitute where refrigerated storage is unaffordable (Dalal et al., 1971 cited by Hagenmaier and Shaw, 1992).

Disadvantages of wax coating

The quality of fruits and vegetables is affected by interior concentrations of gases (Hagenmaier, 2005). Fruits and vegetables quickly become inedible and rot when a barrier blocks the interior O_2 to diffuse out and the accumulation of CO_2 concentration inside the fruit.

The permeability of wax to water vapour depends on lipid content and film polarity (Kamper & Fennema 1985). The uniform layer of coating on the fruit is more important than the thickness and its viscosity. The fine cracks in wax coating allow water loss via transpiration (Ben-Yehoshua et al. 1985). The resistance of water transport acrossed peel is 60 folds lower than O_2 and CO_2 do in oranges. Therefore, the ideal citrus coating should have high permeability to O_2, CO_2, and C_2H_4 to avoid the negative effects of coatings along with low permeability to water vapor to reduce transpiration (Lawes and Prasad, 1999). In addition, waxes can promote fruit injury and increase weight loss and shriveling (Da-Mota et al., 2003).

Coating may limit gaseous transfer across the peel barrier. The internal oxygen becomes too low and induces aerobic respiration of the fruit and resulting in the accumulation of ethanol and off-flavor (Ahmad et al., 1987). Not only the permeability of the gas but also the thickness, viscosity and uniformity of coating materials effects gas exchange (Perez-Gago et al., 2003).

Wax coated fruit developed off-flavors regardless of rootstock, maturity at harvest, or storage conditions (Cohen et al., 1985). At least 94% of the variation in a sensory flavor score of mandarin was explained by changes in the ethanol and acetaldehyde content (Ahmad et al., 1987). Gas exchange was reduced in coated fruit due to the coating plugs the opening on the peel. However, the gases are permeable through the cuticle when pores are closed (Ben- Yehoshua, 1969).

2.5 Cold Storage

Storage is essential for extending the consumption period of fruits, regulating their supply to the market and also for long distance transportation. The market life of fruits and vegetables can be extended through storage at low temperature. Kim (2002) mentioned that temperature management is the most effective tool for extending the storage life of fresh horticultural commodities. The metabolism of fresh commodities is slowed down by low temperatures. Moreover, citrus fruits are also low in starch reserves and thus undergo very slow changes in internal quality during storage.

Every 10 °C decrease in temperature will reduce respiratory activity. Another benefit of low temperature is to reduce ethylene production. As low temperature, the activity of ethylene synthesizing enzymes such as ACC oxidase and ACC synthase is low (Larrigaudiere et al., 1997 cited by Knee, 2002). Fruits are sensitive to ethylene at low temperature than at ambient temperature (Zhou et al., 2001 a).

The appearance of chilling injury was dependent on the preharvest and postharvest practices. Citrus such as grapefruit showed chilling injury symptoms such as skin pitting and discoloration (Purvis, 1980). According to Alia-Tejacal et al. (2007), the optimal storage temperature of sapote mamey depends on cultivar, harvest date, harvest season and maturity at the time of harvest.

Advantages of cold storage

The rate of water loss is governed by temperature and relative humidity. Because warm air can hold much more water vapour than cold air, low weight loss is easier to achieve at low temperature than high temperature. Temperature is the most important factor that influences the respiration rate. If the fruits and vegetables are held above the freezing point, the great reduction in respiration and thus the longest shelf life can be obtained (Kim, 2002). It also affects the slower rate of metabolism, the rate of growth and spread of pathogen and decay (Knee, 2002).

Low temperature storage is the most effective tool used to maintain quality and extend shelf life. As the storage temperature approaches the freezing point, enzyme reactions slow. Low temperature storage does not only decrease the production of ethylene, but also the rate of response of fruit tissue to the applied ethylene.

Disadvantages of cold storage

Low, non-freezing temperature is the single most important factor governing maintenance of postharvest quality in stored fruits and vegetables. It may reduce disease, control insect pest, or modify ripening process, but it may also cause chilling injury (CI). Chilling Injury (CI) is the postharvest storage problem when the commodities are stored at temperature below their critical temperature. The potential symptom of CI varies among crops. Common chilling symptoms are internal discoloration and browning, the formation of surface lesions, water-soaking, abnormal ripening and increased decay. Many varieties of citrus fruit are susceptible to chill. Lafuente et al. (2005) reported that Common chilling symptoms in citrus fruit are the formation of brown pit like depressions in the flavedo, the outer color part of the peel as those occurring in 'Fortune' mandarin or grapefruits. CI occurs at low temperatures ($\leq$ 10°C) and it can be suppressed by wax application. Susceptibility to chilling injury varies in subtropical fruits according to species and cultivar. For example grape fruit, lemon and lime are much more susceptible to chilling injury than orange and mandarin.

Chapter 3

Materials and Methods

3.1 Time and place of the study

Experiment -1: Effects of Teva wax (18% food grade shellac and polyethylene) coating on postharvest quality of 'Sai Nam Paung' mandarin storage at different temperatures was started in the first week of April 2007.

Experiment -2: Effects of Rosy wax (18% w/v Polyethylene and resin) coating on postharvest quality of 'Sai Num Paung' mandarin storage at different temperatures was started in the third week of June 2007.

Experiments were conducted in the laboratory at the Faculty of Agricultural Production, Department of Horticulture, Plant Science Laboratory, Maejo University, Chiang Mai, Thailand.

3.2 Design

The experimental design was 2 x 4 factorial in Complete Randomized Design (CRD). In this study, factor one was storage temperature; ambient temperature (~ 28 °C) and cold storage (5 °C) and factor two was concentration of wax; over recommended concentration (500 kg of fruits/ liter), recommended concentration (1000 kg of fruits /liter), under recommendation (1500 kg of fruits /liter) and uncoated (control). There were eight treatments combinations as follows with 3 replications in each treatment.

T1 = over recommended concentration of wax + ambient temperature

T2 = recommended concentration of wax + ambient temperature

T3 = under recommended concentration of wax + ambient temperature

T4 = uncoated (control) + ambient temperature

T5 = over recommended concentration of wax + 5 °C

T6 = recommended concentration of wax + 5 °C

T7 = under recommended concentration of wax + 5 °C

T8 = uncoated (control) + 5 °C

There were 5 fruits per replication used for non destructive measurements and 3 fruits per replication for destructive measurements.

3.3 Plant materials

'Sai Nam Paung' mandarins fruits used in this study (Figure 3.1) were purchased from a commercial orchard located in Chiang Mai province, Fang District. The harvested fruits were sent to the Plant Science Laboratory, Maejo University in the same day of harvest.

Figure 3.1 'Sai Nam Paung' mandarin fruits used in this experiment

Upon an arrival, the fruits were surface sterilized in 200 ppm chlorox solution for 3 to 5 minutes to eliminate the pathogen and to prevent the contamination of the diseases to the fruits (Suslow, 1997). The fruits were then rinsed in water. After washing, the fruits were left to dry on newspapers at ambient temperature over night (Figure 3.2). The following day, the fruits were selected to get a uniform size, appearance and absence of physical damage with weighing about 90 g to 100 g per fruit. Then, the selected fruits were randomly arraocated for the 8 treatment combinations.

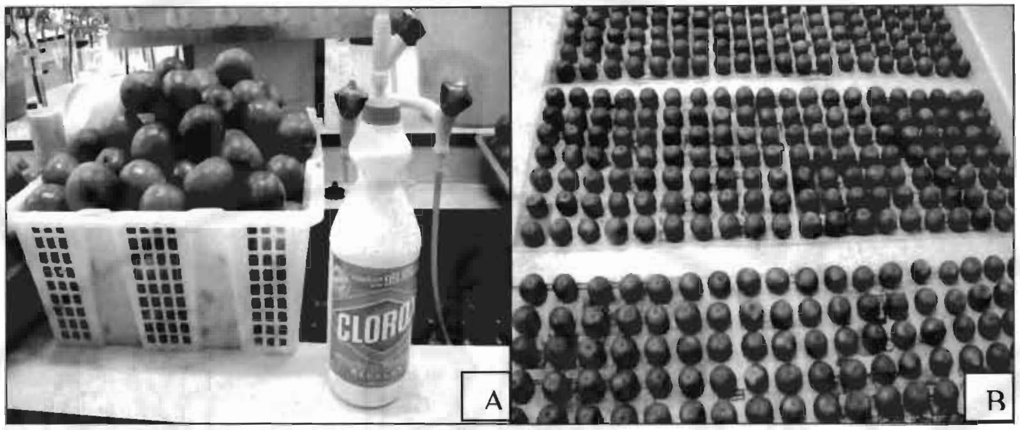


Figure 3.2 Washing 'Sai Nam Paung' mandarin fruits in 200 ppm Clorox for 3-5 minutes (A) and air dry on newspaper before wax coating (B)

3.4 Wax coating

Two experiments with different kinds of wax coating on the mandarin fruits were carried out in this study. Teva wax and Rosy wax were used in the first and second experiment respectively. These commercial coatings were obtained from the manufacturers and ready to be used for coating. The fruits were waxed uniformly by hand with rubber gloved with the following amount of wax emulsion were applied on each.

Concentration of wax	Amount per fruit (ml)
Under recommended (1500 kg of fruits/ liter)	0.06 – 0.07
Recommended (1000 kg of fruits/ liter)	0.09 – 0.10
Over recommended (500 kg of fruits/ liter)	0.18 – 0.20

After wax coating, the fruits were left to dry prior to storage to get good retention of the wax (Thompson, 1996) (Figure 3.3). Washed but uncoated fruits served as control. The initial qualities of the fruits were evaluated before storing at an ambient temperature and 5 °C.

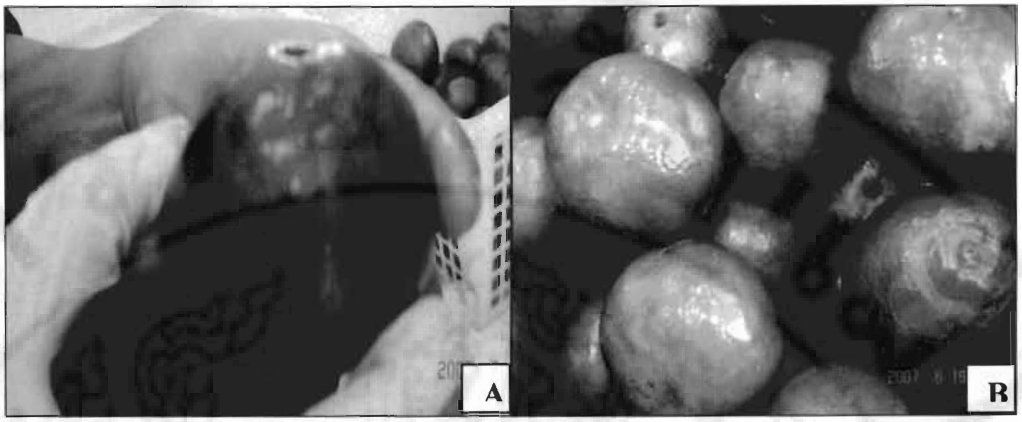


Figure 3.3 Coating wax evenly on the whole fruit surface of 'Sai Nam Paung' mandarin by hand with rubber gloved (A) and air dry at ambient temperature (B)

3.5 Storage condition

The fruits were stored in two storage conditions; [1] at an ambient temperature (28.38 °C day and 28.26 °C night temperature and 67.70 % relative humidity for Teva wax experiment and 29.78°C day and 29.21 °C night temperature and 64.28 % relative humidity for Rosy wax experiment) and [2] in a cold storage (5 °C) (Figure 3.4).

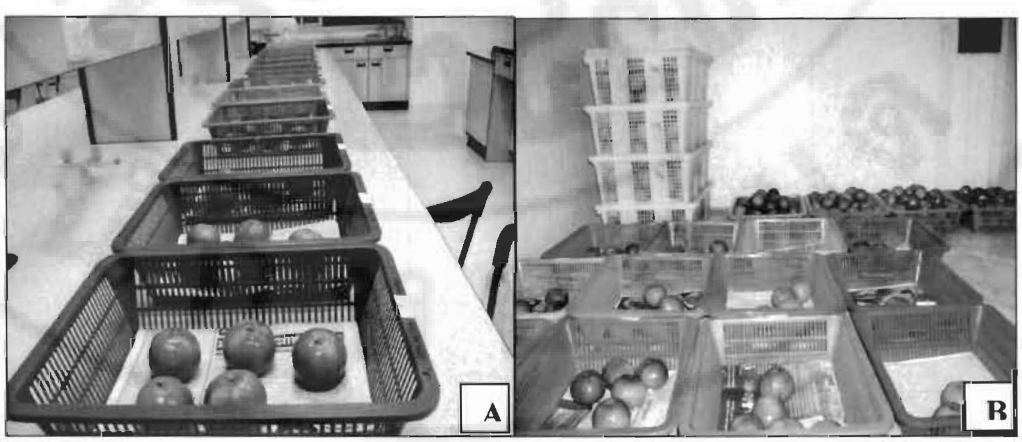


Figure 3.4 Wax coated 'Sai Nam Paung' mandarin stored at ambient temperature (~ 28 °C) (A) and cold storage (5 °C) (B)

3.6 Data Collection

Non-destructive and destructive data were collected from the representative samples one day after harvest and weekly. Sample of 5 and 3 fruits per replication were used for non destructive and destructive measurements respectively.

Non destructive measurement such as weight loss, fruit height, peel color changes, glossiness, shelf life and destructive measurements such as total soluble solid concentration (TSS), titratable acidity (TA), pH, and off flavor development were investigated at weekly interval. However, respiration rates of the fruit were measured only on day 28^{th}. Ethylene production of mandarin was investigated on day 28^{th} only in Rosy wax experiment. Ambient temperature and relative humidity were collected hourly with data locker.

3.6.1 Percentage of weight loss

'Sai Nam Paung' mandarin in each replication was weighted with digital balance to obtain fruit weight. Percentage of weight loss was recorded from the initial fruit weight. Relative weight loss was weight loss of treated fruit as a percentage of the weight loss of the control.

3.6.2 Fruit Height

Electronic digital caliper (Figure 3.5) was used to measure fruit height to observe the fruit turgidity during storage. The average fruit height for each replication was calculated from the sample units.

Figure 3.5 Electronic digital caliper used for measuring fruit height of 'Sai Nam Paung' mandarin

3.6.3 Peel Color changes

Different values (L*, a* and b*) of color change were used to evaluate the peel color changes of 'Sai Nam Paung' mandarin coated with different concentration of wax and stored at different storage temperature with the help of colorimeter model CR-10 (MINOLTA Co. Ltd.) (Figure3.6). For this purpose, the measurement was taken at the same spot on the same fruit at weekly interval. The colorimeter should make good contact with the fruit surface to get accurate measurements.

Figure 3.6 Colorimeter model CR-10 (MINOLTA Co. Ltd.) used for measuring color change of 'Sai Nam Paung' mandarin

3.6.4 Shelf life

The shrinkage scores obtained from the visual determination of the peel shrinkage of uncoated fruit held at ambient temperature were used to evaluate the shelf life of the fruits. In this study, the score of 3 was used as the end of shelf life.

The scores of peel shrinkage were described as follows (Figure 3.7).

1 = Fully fresh

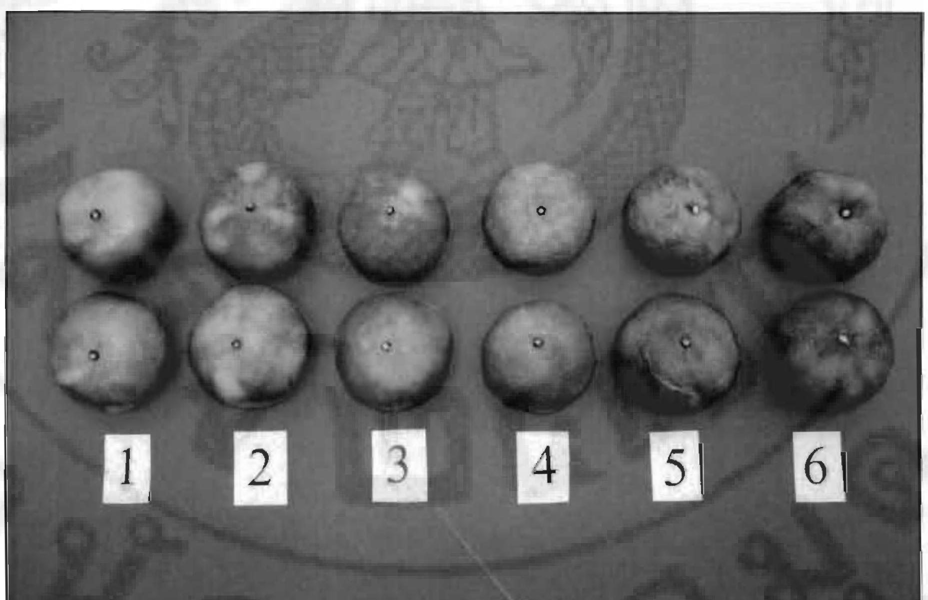
2 = Shrinkage of the fruit peel started from the stem end

3 = 50% shrinkage of the fruit peel (half fruit peel shrinkage)

4= 100% shrinkage of the fruit peel (whole fruit peel shrinkage)

5 = Fruit peel start hard and start to change from green or yellow to brown

6 = All fruit peel change to brown color



End of shelf life

Figure 3.7 Shrinkage scores evaluated in uncoated mandarins (Sai Nam Paung) held at ambient temperature

3.6.5 Respiration

Experiment – 1: Teva wax

The rate of respiration is a good index of the quality of fresh produce and can be measured nondestructively (Akinaga and Kohda, no date). In Teva wax experiment, the respiration rate of the fruit was measured by using the Kitagawa precision gas detector Model - 400 (Figure 3.8 B). For measuring respiration rate of the fruit, 3 replications, each containing five fruits, were prepared. Fruits in each replication were enclosed in a 2 liter air tight plastic container. Then, the container was covered with black polyethylene bag to prevent photosynthesis of the fruit and left 30 minutes before taking gas sample from the container (Figure 3.9 A).

Carbon dioxide detector tube used in Teva wax experiment can measure CO2 from 0.1 to 5.2 %. Both end of the carbon dioxide detector tube (Figure 3.8 A) was broken before inserted in the rubber tube inlet of the precision gas detector. Then, inserted the CO_2 detector tube into the pre drilled hole on the plastic air tight container and sealed with the color clay to prevent air leaching from the hole. Then, pull the handle of the gas detector pump at full stroke, which will draw 100 ml of gas pass through the detector tube. The gas detector was kept straight for good air flow into the pump for 5 minutes before reading the concentration of CO_2 from the scale of the tube (Figure 3.9 B). The formula used for the calculation of respiration rates was as follows;

$$\underset{\text{(mg /kg /hr)}}{\text{Respiration rate}} = \frac{(\Delta\, CO_2 \times 10)\ \text{(Free space volume of container in liters)}}{\text{(Fruit fresh weight in kg) (Time container is closed in hour)}}$$

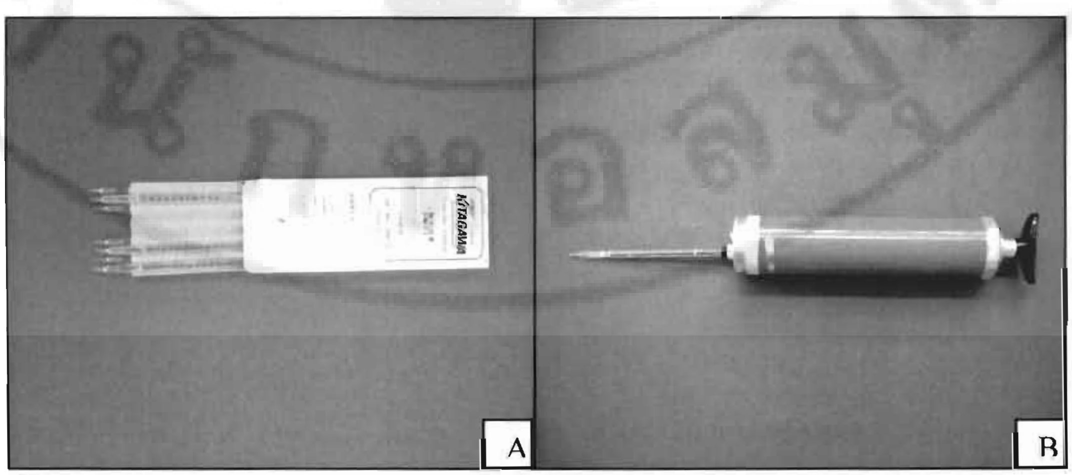


Figure 3.8 (A) the fresh CO_2 detector tube, (B) the Kitagawa Precision gas detector pump

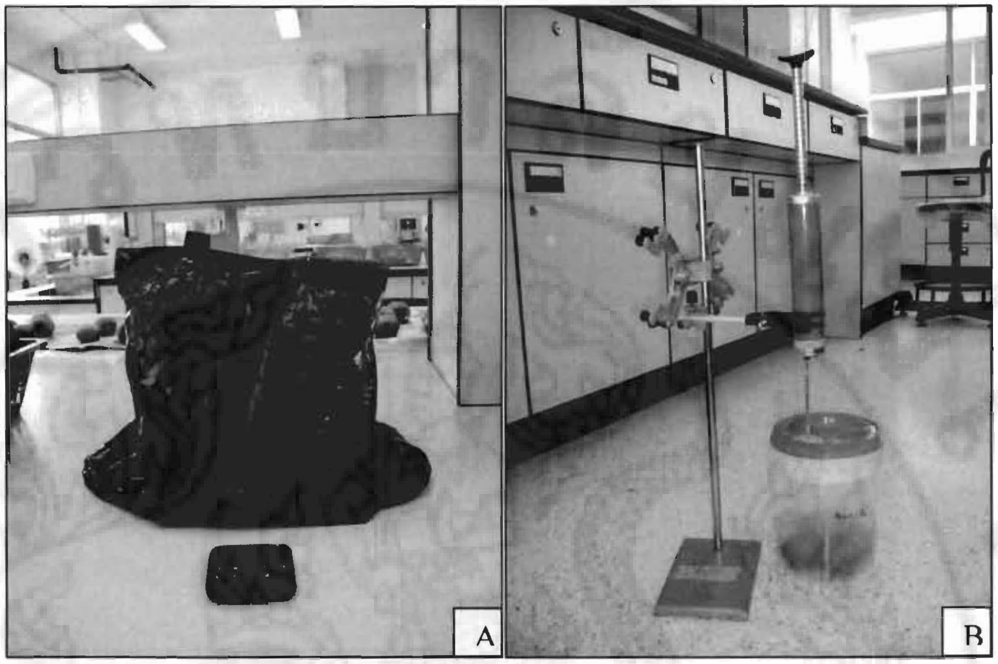


Figure 3.9 Measuring respiration rate of mandarin in the Teva wax experiment after storage for 28 days; (A) the air tight container with fruit was covered with black polyethylene bag, (B) measuring respiration rate of the sample fruits with gas detector

Experiment – 2: Rosy wax

In Rosy wax experiment, the respiration rate and ethylene production were measured by using gas chromatography (GC). Three replications, each containing 5 fruits of 'Sai Nam Paung' mandarin, were used. Fruits of each replication were enclosed in a 3 liter air-tight plastic container for 30 minutes. The measurements were carried out only on day 28^{th} of storage. For each sampling, 1 ml of headspace-air was withdrawn by using plastic syringes to determine both CO_2 (carbon dioxide) and C_2H_4 (ethylene) gases released by the fruits. One ml of 1 % CO_2 and C_2H_4 from standard gas cylinder was used as standard. The concentration of ethylene was assessed by using a gas chromatograph/GC (SHIMADZU GC-14 B, Japan) equipped with a flame ionization detector, FID (Figure 3.11 A). The column used was a 4 m, 3 mm inner diameter stainless steel tube, filled with 80/100 mesh activated alumina. The carrier gas N_2 (Nitrogen). The temperature setting for column oven was 60°C, 90°C for injector temperature and 100°C for detector temperature. The flow rate of N_2 carrier gas was 45 ml/min. The result was described as micro liter ethylene production per kg fresh weight per hour (μl C_2H_4 /kg/ hr).

Carbon dioxide concentration was determined by another gas chromatograph (SHIMADZU GC-14 B, Japan) equipped with thermal conductivity detector, TCD (Figure 3.11 B). The column used was a 2 m long, 3 mm inner diameter filled with 80/100 mesh porapak. Carrier gas used was He (Helium), auxillary temperature for TCD 100°C and current for TCD 100 mA for CO_2 detection. Column oven temperature, injector temperature, detector temperature and flow rate of carrier gas were the same as ethylene analysis.

The following formula was used for the calculation of respiration rates. In order to calculate the respiration rates, fresh weight (FW) of fruits, free–space/headspace of containers as well as the temperature of the laboratory were recorded during the experiment. Respiration rate was expressed as milligram CO_2 per kg fresh weight per hour (mg CO_2 /kg/ hr).

The formula used for the calculation of respiration rates was as followed;

$$V_1 = \frac{P_2 V_2 \times T_1}{P_1 \times T_2}$$

Here,

V_1 = Calculated volume of CO_2 in liter

V_2 = Volume of CO_2 in liter released by applied commodity (in diff. treatments)

P_1 = Standard pressure of ideal gas (i.e. 760 mm Hg)

P_2 = Pressure of air in GC lab (i.e. 720 mm Hg)

T_1 = Temperature of ideal gas (i.e. 273°C)

T_2 = Temperature of GC room (i.e. 273 + 28°C = 301°C)

Before using this formula, the volume of CO_2 (V_2) produced by the 'Sai Nam Paung' mandarin was calculated. Firstly, average area/value of headspace-air obtained from the gas chromatography in a specific time-line was converted into percentage (%) by dividing it by the average area of standard sample. Secondly, to obtain the real percentage of CO_2 released by the fruits, the percentage of CO_2 in the air of GC lab (0.035 %) was subtracted from the total percentage of CO_2. Thirdly, the percentage of CO_2 was converted into liter on the basis of volume of headspace available for each treatment and replication.

$$\text{Weight of } CO_2 = \frac{V_1 \times 44}{22.4}$$

where,

44 = Molecular weight of CO_2 (in gm)

22.4 = Volume of 1 mole of CO_2 at 0^0K (in Lit)

Value was in mg CO_2 produced by mass of applied commodity (after multiplied by 1000) Finally, the rate of respiration was calculated as mg CO_2 per kg FW per hr.

For the calculation of ethylene production, the same steps as mentioned above were used. To calculate of the volume of C_2H_4 (V_2) the value of ethylene production was converted into micro liter produced by one kg fresh weight of fruits per hour basis. There is no need to use any specific formula for ethylene production as for respiration rate.

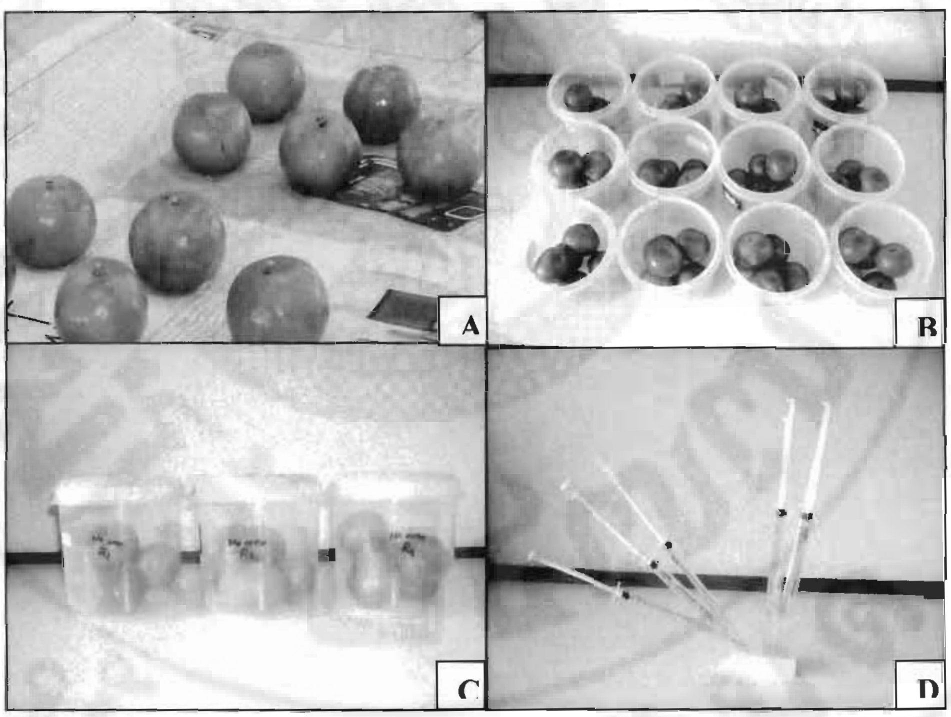


Figure 3.10 Measuring respiration rate and ethylene production of the Rosy wax coated 'Sai Nam Paung' mandarin on day 28^{th}: (A) air dry mandarins from cold storage on newspaper before fruits were enclosed in air tight plastic container, (B) Fruits in each replication in the containers, (C) Fruits enclosed in the containers, (D) the needle of micro syringe was inserted into eraser after taking gas sample from the container

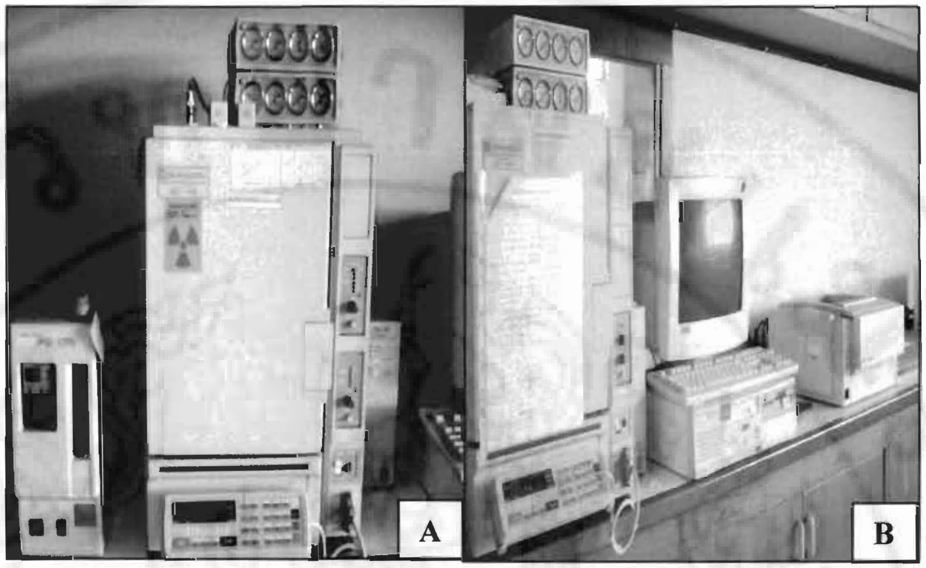


Figure 3.11 Gas chromatographs (SHIMADZU GC-14 B, Japan) equipped with a flame ionization detector, FID (**A**) and with thermal conductivity detector, TCD (**B**) for C_2H_4 and CO_2 detection, respectively

3.6.6 Appearance (glossiness)

Fruit glossiness was evaluated visually by untrained 5 persons using 1-3 scale: 1, no glossiness, 2, slightly/ moderately glossy, 3- very glossy.

3.6.7 Total soluble solid (TSS)

Digital Refractometer model PR -32 (ATAGO Co. Ltd.) (Figure 3.11) was used to measure total soluble solid. Juice was extracted from segment of the fruit fresh by juice squeezer. After measuring each fruit, the refractometer and the knife were cleaned with distilled water and dried with tissue paper to minimize contamination.

Figure 3.12 Digital Refractometer model PR -32 (ATAGO Co. Ltd.) used for measuring Total soluble solid (TSS) of 'Sai Nam Paung' mandarin

3.6.8 Titratable acidity (TA)

Fruit juice was analyzed for percentage acidity (% TA) by titrated with 0.1 N sodium hydroxide solution (NaOH). The 0.1 N NaOH reagent solution was prepared by dissolved 4g of NaOH pellet per 1 liter of distilled water. Two ml of fruit juice from each sample unit was extracted into a clean, dry beaker. Two ml of fruit juice was taken into the conical flask then added 80 ml of distilled water and 1 - 2drops of phenolphthalein indicator. After that titrated with 0.1 N sodium hydroxide solution until faint pink was notice. Repeated the titration 3 times for each treatment.

The acidity of the fruit juice was expressed as percent of citric acid.

The formula used for the calculation of Titratable acidity (TA) was as follows;

$$TA\ (\%) = \frac{T \times 0.1\ N \times \text{molecular weigh of citric acid} \times 100}{\text{Amount of juice used in titration}}$$

Here,

T = mean (ml) of 0.1 M sodium hydroxide solution required to neutralize the acidity in 2 ml of mandarin juice.

3.6.9 Panel Test

Taste (acceptability) test was performed by 5 untrained persons with 1- 3 scored of 1- no off flavor, 2- slightly off flavor, 3- strongly off flavor.

3.6.10 pH

The pHep (model HI 98107) pH- meter (Figure 3.12) was used to measure the pH of fruit juice. Before measuring the sample, the instrument was calibrated in pH 7.01 (HI 7007) and pH 4.01 (HI 7004) buffer solution. Immersed the pH meter electrode in the fruit juice and stirred gently and kept for 5 minutes before reading. The electrode of the pH meter was cleaned with distilled water and dried with tissue papers before measuring the next sample. After using, the electrode was rinsed with tap water and stored in the protective cap filled with 3M KCl solution.

Figure 3.13 The pHep (model HI 98107) pH- meter used for measuring pH of 'Sai Nam Paung' mandarin

3.7 Data Analysis

All parameters of the fruit quality were analyzed by using SAS statistical program (6.12 version) and mean comparisons were assessed by the Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$ levels.

Chapter 4

Results

4.1 Effects of Teva wax coating on postharvest quality of 'Sai Nam Paung' mandarin

4.1.1 Percentage of weight loss

Weight loss of mandarin was significantly affected by wax coating, storage temperature, and duration of storage. After storage for 28 days at ambient temperature, uncoated fruits showed the highest weight loss (37.02%) than that of wax coated fruits, 22.59 %, 24.31 % and 29.71 % for over recommended, recommended and under recommended concentration respectively (Table 4.1). Similar finding was observed in fruits stored in cold storage for 28 days, the highest weight loss (13.13%) was found in uncoated fruits where 6.51%, 7.45% and 8.77% were for the fruits coated with over recommended, recommended and under recommended concentration respectively. Overall coating treatments, over recommended and recommended concentration of wax maintained more freshness of the fruits than under recommended ones. In this study, fruits in cold storage (5 °C) significantly reduce weight loss more than the one stored at ambient temperature (28 °C). However, fruits from all treatments showed a progressive loss of weight as the duration of storage increase.

There was statistically interaction between concentration of wax and storage temperature on weight loss of mandarin. After storage for 28 days, the lowest weight loss (6.51 %) was observed in the treatment combination of over recommended concentration and cold storage. The highest weight loss (37.02 %) was observed in uncoated fruit at ambient temperature (Table 4.1).

Table 4.1 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on percentage of weight loss of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Treatment combinations	Days after storage (days)			
	7	14	21	28
Ambient temperature (28 °C)				
Uncoated	13.24 [a]	21.35 [a]	30.47 [a]	37. 02 [a]
1500 kg/l (under)	9.44 [b]	15.51 [b]	22.89 [b]	29.71 [b]
1000 kg/l (recommended)	8.54 [c]	13.88 [c]	20.50 [c]	24.31 [c]
500 kg/l (over)	7.83 [c]	12.37 [d]	18.08 [d]	22.59 [c]
Cold storage (5°C)				
Uncoated	3.29 [d]	6.62 [c]	9.84 [e]	13.13 [d]
1500 kg/l (under)	2.16 [c]	4.32 [f]	6.50 [f]	8.77 [e]
1000 kg/l (recommended)	1.83 [e]	3.64 [fg]	5.47 [fg]	7.45 [ef]
500 kg/l (over)	1.57 [e]	3.14 [g]	4.80 [g]	6.51 [f]
Temperature x Concentration of wax	**	**	**	**
C.V	7.02	5.64	5.16	6.03

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

** = highly significant different

4.1.2 Fruit height

The height of the fruits in all treatments decreased as the time of storage increase. The uncoated fruits showed significantly lower fruit height than the coated fruits in both storage conditions after 14 days of storage (Table 4.2). In addition, the reduction of fruit height negatively correlated with the concentration of wax on day 28 storage. The highest fruit height (44.44 mm) was observed in fruits coated with over concentration wax followed by the recommended concentration (44.24mm).

Low temperature reduced the reduction of fruit height loss. As a result, fruits stored at 5 °C showed significant higher fruit height (46.23 mm) than the fruits stored at ambient temperature (41.04 mm) throughout the storage (Table 4.2).

Table 4.2 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on fruit height of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Days after storage (days)			
	7	14	21	28
Storage temperature				
Ambient temperature (28 °C)	45.82^{b}	44.27^{b}	42.80^{b}	41.04^{b}
Cold storage (5°C)	48.55^{a}	47.81^{a}	47.24^{a}	46.23^{a}
Concentration of wax				
Uncoated	46.84	44.99^{b}	43.81^{b}	42.24^{c}
1500 kg/l (under)	47.07	46.08^{a}	45.08^{a}	43.62^{b}
1000 kg/l (recommended)	47.70	46.64^{a}	45.53^{a}	44.24^{ab}
500 kg/l (over)	47.12	46.46^{a}	45.65^{a}	44.44^{a}
Temperature	**	**	**	**
Concentration of wax	NS	**	**	**
Temperature x Concentration of wax	NS	NS	NS	NS
CV	1.39	1.44	1.48	1.27

Means within a column followed by the same letter were not significantly different at *P* <0.05 level by DMRT

** = highly significant different, and NS = not significant

4.1.3 Respiration

The respiration rates of all treatments only on day 28 were measured at the ambient temperature. The fruits coated with over recommended concentration of wax showed the lowest respiration rate among all treatments (Appendix .1). There was no interaction between storage temperature and concentration of wax on the respiration rate of mandarins on day 28 (Table 4.3).

In this study, significantly differences in the respiration rates of the fruits were observed among different storage temperatures. The higher respiration rate (47.48 mg/kg/l) was found in the treatment, which stored at 5 °C. Similarly, the highest respiration rate (42.86 mg/kg/l) was observed in uncoated fruits as compared with coated ones. However, there was no significantly difference among different wax concentration (Table 4.3).

Table 4.3 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on respiration rate of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Respiration rate (mg/kg/hr)
Storage temperature	
Ambient temperature (28 °C)	27.79[b]
Cold storage (5°C)	47.48[a]
Concentration of wax	
Uncoated	42.86[a]
1500 kg/l (under)	38.76[b]
1000 kg/l (recommended)	35.61[b]
500 kg/l (over)	33.30[b]
Temperature	**
Concentration of wax	*
Temperature x Concentration of wax	NS
C.V	14.07

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

** = highly significant different, * = significant different and NS = not significant

4.1.4 Glossiness

Wax coated mandarins had shown better appearance (glossiness) than the uncoated one throughout the experiment (Appendix 2). Although the glossiness of the fruit changed during the storage, the change of glossiness of fruit at 5 °C was slower than those at ambient temperature (Table 4.4 and 4.5).

The uncoated mandarins stored at ambient temperature had shown the lowest glossiness score (1.00) among all treatment combinations at day 7 of storage (Table 4.4). However, the fruits coated with over recommended and recommended wax concentration stored at ambient temperature had the same glossiness as all coated fruits at 5 °C. The moderately glossiness was still achieved up to day 28 in all coated fruits. However, all the wax coated treatments were not statistically different in glossiness after day 21 of storage (Table 4.5).

Table 4.4 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on glossiness of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 7.
1 = no glossiness, 2 = slightly/ moderately glossiness, 3 = high glossiness

Treatment combinations		Storage conditions	
		Ambient temperature (28 °C)	Cold storage (5°C)
Uncoated		1.0^{c}	1.6^{b}
1500 kg/l	(under)	1.4^{bc}	2.8^{a}
1000 kg/l	(recommend)	2.8^{a}	3.0^{a}
500 kg/l	(over)	2.6^{a}	3.0^{a}
Temperature x Concentration of wax		**	
C.V		15.76	

Means followed by the same letter were not significantly different at
P <0.05 level by DMRT

** = highly significant different

Table 4.5 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on glossiness of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.
1 = no glossiness, 2 = slightly/ moderately glossiness, 3 = high glossiness

Storage conditions	Days after storage (days)		
	14	21	28
Storage temperature			
Ambient temperature (28 °C)	1.90[b]	1.45[b]	1.55[b]
Cold storage (5°C)	2.50[a]	2.55[a]	2.40[a]
Concentration of wax			
Uncoated	1.60[c]	1.50[b]	1.30[b]
1500 kg/l (under)	2.30[b]	2.00[a]	2.10[a]
1000 kg/l (recommended)	2.20[b]	2.20[a]	2.10[a]
500 kg/l (over)	2.80[a]	2.30[a]	2.40[a]
Temperature	**	**	**
Concentration of wax	**	**	**
Temperature x Concentration of wax	NS	NS	NS
C.V	21.73	18.78	24.30

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

** = highly significant different, and NS = not significant

4.1.5 Off flavor

There was no interaction between storage temperature and concentration of wax on off flavor development of mandarin during the 28 days storage. Additionally, at any storage temperature there was no significant difference of off flavour development among any treatments. Interestingly, waxing did not significantly induce off flavor development either at ambient temperature or low temperature (Table 4.6). By the end of storage period, slightly eating quality changes was observed in all treatments (Table 4. 6).

Table 4.6 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on off flavour development of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.
1 = no off flavour, 2 = slightly/ moderately off flavour, 3 = strong off flavour

Storage conditions	Days after storage (days)			
	7	14	21	28
Storage temperature				
Ambient temperature (28 °C)	1.10	1.25	1.10	1.15
Cold storage (5°C)	1.15	1.10	1.20	1.25
Concentration of wax				
Uncoated	1.10	1.20	1.10	1.30
1500 kg/l (under)	1.10	1.20	1.00	1.00
1000 kg/l (recommend)	1.20	1.20	1.10	1.10
500 kg/l (over)	1.10	1.10	1.40	1.40
Temperature	NS	NS	NS	NS
Concentration of wax	NS	NS	NS	NS
Temperature x Concentration of wax	NS	NS	NS	NS
CV	20.57	30.09	29.62	34.68

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

NS = not significant

4.1.6 Shelf life

The storage life of mandarin was significantly affected by wax coating and storage temperature (Appendix 3). No interaction was observed between storage temperature and concentration of wax on the shelf life of mandarin. In this study, storage at low temperature (at 5 °C) was efficiently extend the shelf life of the fruits up to 7 times longer than at ambient temperature (Table 4.7). Additionally, wax coated fruits were observed to have 10 - 19 days longer shelf life than the uncoated ones. Although shelf life of all coated fruits was not statistically differently difference from each other, the over recommended concentration of wax coated fruits could store up to 48 days.

Table 4.7 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on shelf life of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage.

Storage conditions	shelf life (days)
<u>Storage temperature</u>	
Ambient temperature (28 °C)	10.23^{b}
Cold storage (5°C)	70.02^{a}
<u>Concentration of wax</u>	
Uncoated	28.47^{b}
1500 kg/l (under)	39.00^{a}
1000 kg/l (recommend)	45.25^{a}
500 kg/l (over)	47.80^{a}
Temperature	**
Concentration of wax	**
Temperature x Concentration of wax	NS
C.V	17.06

Means within a column followed by the same letter were not significantly different at *P* <0.05 level by DMRT

** = highly significant different, and NS = not significant

4.1.7 TSS/TA ratio

Any interaction of storage temperature and concentration of wax on the TSS/ TA ratio during storage was not found in this study (Table 4.8). At the end of the storage period, slightly changes in TSS/ TA ratio was observed in all storage temperature or wax coating. However, there was no statistically difference in TSS/TA ratio between treatments.

Table 4.8 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on TSS/TA ratio of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Days after storage (days)			
	7	14	21	28
Storage temperature				
Ambient temperature (28 °C)	16.07	16.06	18.31	18.11
Cold storage (5°C)	15.29	16.09	16.88	17.16
Concentration of wax				
Uncoated	15.13	16.21	17.63	16.64
1500 kg/l (under)	16.09	15.78	17.97	18.04
1000 kg/l (recommend)	15.50	15.88	17.60	17.55
500 kg/l (over)	16.00	16.42	17.18	18.32
Temperature	NS	NS	NS	NS
Concentration of wax	NS	NS	NS	NS
Temperature x Concentration of wax	NS	NS	NS	NS
C.V	9.28	11.19	12.14	6.8

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

NS = not significant

4.1.8 pH

The pH of mandarin fruit juice was not different at any storage temperature during 28 days storage except on day 7 when pH of fruit juice kept at 5°C (pH 4.00) was significantly higher than those kept at ambient temperature (pH 3.83). There was no interaction between storage temperature and concentration of wax on the pH of fruits juice during storage (Table 4.9).

Table 4.9 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on pH of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Days after storage (days)			
	7	14	21	28
<u>Storage temperature</u>				
Ambient temperature (28 °C)	3.83[b]	3.55	3.62	4.07
Cold storage (5°C)	4.00[a]	3.60	3.64	4.08
<u>Concentration of wax</u>				
Uncoated	3.93	3.55	3.65	4.02
1500 kg/l (under)	3.95	3.57	3.60	4.02
1000 kg/l (recommend)	3.98	3.57	3.65	4.13
500 kg/l (over)	3.80	3.63	3.62	4.13
Temperature	*	NS	NS	NS
Concentration of wax	NS	NS	NS	NS
Temperature x Concentration of wax	NS	NS	NS	NS
C.V	4.43	3.51	3.53	3.01

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

* = significant different, and NS = not significant

4.1.9 Peel color

The changes of (a*) values were obviously found in mandarins stored at ambient temperature rather than those observed at 5 °C (Appendix 4). Similarly, the changes of peel color a* in all wax coated fruits were slightly slower than those of control (uncoated fruits) (Appendix 4). However, any statistical interaction was not observed between storage temperatures and concentrations of wax on peel color (a*) during storage. In addition, any significantly differences were not observed in changes of peel color a* values of mandarins in any treatments during storage (Table 4.10). No significantly difference was not observed in changes of peel color b* and L* values of mandarins in any treatments during storage (Table 4.11 and 4.12).

Table 4.10 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on peel color a* of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Days after storage (days)			
	7	14	21	28
<u>Storage temperature</u>				
Ambient temperature (28 °C)	3.85	2.64	1.36	0.14
Cold storage (5°C)	4.39	3.84	3.38	2.22
<u>Concentration of wax</u>				
Uncoated	3.57	1.86	0.74	1.50
1500 kg/l (under)	4.34	3.52	2.49	2.52
1000 kg/l (recommend)	4.82	4.22	3.62	1.67
500 kg/l (over)	3.74	3.35	2.63	2.03
Temperature	NS	NS	NS	NS
Concentration of wax	NS	NS	NS	NS
Temperature x Concentration of wax	NS	NS	NS	NS
C.V	-41.17	-62.54	-97.87	-223.87

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

NS = not significant

Table 4.11 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on peel color b* of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Days after storage (days)			
	7	14	21	28
Storage temperature				
Ambient temperature (28 °C)	35.31	36.44[a]	36.61	36.05
Cold storage (5°C)	34.15	34.16[b]	34.79	35.11
Concentration of wax				
Uncoated	34.82	36.63	37.11	36.87
1500 kg/l (under)	36.30	36.42	37.09	36.17
1000 kg/l (recommend)	33.62	33.96	34.47	35.36
500 kg/l (over)	34.20	34.20	34.14	33.92
Temperature	NS	*	NS	NS
Concentration of wax	NS	NS	NS	NS
Temperature x Concentration of wax	NS	NS	NS	NS
C.V	6.52	6.08	6.56	7.54

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

* = significant different, and NS = not significant

Table 4.12 Effect of Teva wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on peel color L* of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Day after storage (days)			
	7	14	21	28
Storage temperature				
Ambient temperature (28 °C)	40.88	41.25	41.03	40.75
Cold storage (5°C)	40.79	40.58	40.94	41.39
Concentration of wax				
Uncoated	40.08	40.92	41.05	41.02
1500 kg/l (under)	41.00	40.97	41.69	40.75
1000 kg/l (recom)	40.12	40.27	40.45	41.04
500 kg/l (over)	41.53	41.51	41.74	41.47
Temperature	NS	NS	NS	NS
Concentration of wax	NS	NS	NS	NS
Temperature x Concentration of wax	NS	NS	NS	NS
C.V	3.88	3.62	3.56	3.63

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

NS = not significant

4.2 Effects of Rosy wax coating on postharvest quality of 'Sai Nam Paung' mandarin

4.2.1 Percentage of weight loss

Wax coating reduced percentage of weight loss of the mandarins stored at ambient temperature (29 °C) and cold storage (5 °C) for 28 days. There was no statistically interaction between the storage temperature and the concentration of wax on weight loss of mandarin.

Uncoated fruit showed the highest weight loss (29.35%) than the coated fruits, 16.50%, 17.20 % and 18.03% for over, recommended and under recommended concentration of wax respectively (Table.4.13). However, no significantly difference was observed among Rosy wax coated treatments on the weight loss of fruits after storage for 28 days.

Regardless of waxing, fruit stored at 5 °C showed lower weight loss than fruit storage at ambient temperature (Table 4.13). After storage for 28 days, the lower percentage of weight loss (11.93 %) was observed in fruit stored at 5 °C compared with 28.61% in fruit stored at ambient temperature. However, fruits from all treatments showed progressive loss of weight during storage.

Table 4.13 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on weight loss percentage of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Days after storage (days)			
	7	14	21	28
Storage temperature				
Ambient temperature (29 °C)	8.33[a]	14.30[a]	13.38[a]	28.61[a]
Cold storage (5°C)	3.66[b]	6.32[b]	5.17[b]	11.93[b]
Concentration of wax				
Uncoated	10.05[a]	16.62[a]	13.19[a]	29.35[a]
1500 kg/l (under)	5.26[b]	9.47[b]	9.03[b]	18.03[b]
1000 kg/l (recommend)	4.55[b]	7.89[b]	7.76[c]	17.20[b]
500 kg/l (over)	4.14[b]	7.26[b]	7.12[c]	16.50[b]
Temperature	**	**	**	**
Concentration of wax	*	**	**	**
Temp x Concentration of wax	NS	NS	NS	NS
CV	50.07	26.64	9.44	20.07

Means within a column followed by the same letter were not significantly different at $P < 0.05$ level by DMRT

** = highly significant different, * = significant different and NS = not significant

4.2.2 Fruit height (mm)

The height of the fruit was significantly affected by wax coating, storage temperature and duration of storage. There was no interaction between storage temperature and concentration of wax on fruit height of mandarins during storage for 28 days. The wax coated fruit showed significantly higher fruit height than that of uncoated fruit during storage (Table 4.14). After storage for 28 days, the uncoated fruits showed the lowest fruit height (41.23 mm) while the fruit height of wax coated fruit were 45.44, 44.69 and 44.28 mm for over, recommended and under recommended wax concentration respectively. However, different wax concentrations had not significant effect on fruit height. Fruit which stored at 5 °C maintain its height better than those stored at ambient temperature (Table 4.14). The fruit stored at ambient temperature was only fruit height of 40.87 mm high whereas the fruit stored at 5 °C was 46.95 mm high at day 28. However, gradual reductions of fruit height were observed in all treatments throughout the storage.

Table 4.14 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on fruit height of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Days after storage (days)			
	7	14	21	28
Storage temperature				
Ambient temperature (29 °C)	46.36^{b}	44.23^{b}	42.80^{b}	40.87^{b}
Cold storage (5°C)	49.31^{a}	48.51^{a}	47.75^{a}	46.95^{a}
Concentration of wax				
Uncoated	46.21^{b}	44.15^{b}	42.86^{b}	41.23^{b}
1500 kg/l (under)	48.79^{a}	47.65^{a}	46.68^{a}	45.44^{a}
1000 kg/l (recommend)	48.04^{a}	46.84^{a}	45.96^{a}	44.69^{a}
500 kg/l (over)	48.30^{a}	46.85^{a}	45.61^{a}	44.28^{a}
Temperature	**	**	**	**
Concentration of wax	**	**	**	**
Temperature x Concentration of wax	NS	NS	NS	NS
CV	2.04	2.23	2.31	2.57

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

** = highly significant different, and NS = not significant

4.2.3 Respiration rate

Respiration rate of all treatments were measured at ambient temperature on day 28. The fruit stored at ambient temperature showed the same respiration rate as those in cold storage (Appendix 5). There was no interaction between storage temperature and concentration of wax on the respiration rate of mandarins. The respiration rates of mandarins were not significantly different between the uncoated or wax coated treatments (Table 4.15). Actually, fruits stored at ambient temperature should have higher respiration rate than that of fruits stored at 5 °C. However, there was no significantly difference in respiration rate between the fruits stored at ambient temperature and those at 5 °C.

Table 4.15 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on respiration rate (mg/kg/hr) of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Respiration rate (mg/kg/hr)
Storage temperature	
Ambient temperature (29 °C)	36.86
Cold storage (5°C)	42.66
Concentration of wax	
Uncoated	40.41
1500 kg/l (under)	37.32
1000 kg/l (recommend)	42.25
500 kg/l (over)	39.05
Temperature	NS
Concentration of wax	NS
Temperature x Concentration of wax	NS
C.V	38.10

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

NS = not significant

4.2.4 Glossiness

Wax coated mandarin had shown better appearance (glossiness) than the uncoated one throughout the experiment. After 21 days of storage, there was interaction between storage temperature and concentration of wax on the appearance of mandarins (Table 4.16). Fruit coated with under concentration of wax had better appearance when stored at 5 °C than at ambient temperature. Other wax concentration had good appearance both at low and ambient temperature.

There was no interaction of storage temperature and concentration of wax at day 7, 14 and 28 (Table 4.17). After storage for 28 days, the fruits stored at 5 °C maintained more glossiness with the score of (2.25) as compared with the glossiness score (1.40) in the fruits stored at ambient temperature. Moreover, wax coated fruits showed more glossiness than uncoated fruits during storage although they were not significant different in glossiness within coating treatments.

Table 4.16 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on glossiness of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 21. 1 = no glossiness, 2 = slightly/ moderately glossiness, 3 = high glossiness

Treatment combinations	21 days after storage	
	Ambient temperature (29 °C)	Cold storage (5 °C)
Uncoated	1.10^{b}	1.00^{b}
1500 kg/l (under)	1.20^{b}	2.40^{a}
1000 kg/l (recommended)	2.20^{a}	2.80^{a}
500 kg/l (over)	2.60^{a}	2.60^{a}
Temperature x Concentration of wax	**	
C.V	22.74	

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

** = highly significant different

Table 4.17 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on glossiness of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28. 1 = no glossiness, 2 = slightly/ moderately glossiness, 3 = high glossiness

Storage conditions	Days after storage (days)		
	7	14	28
<u>Storage temperature</u>			
Ambient temperature (29 °C)	2.40	2.25	1.40^{b}
Cold storage (5 °C)	2.60	2.45	2.25^{a}
<u>Concentration of wax</u>			
Uncoated	1.90^{b}	1.50^{c}	1.40^{b}
1500 kg/l (under)	2.60^{a}	2.40^{b}	2.10^{a}
1000 kg/l (recommended)	2.60^{a}	2.60^{ab}	1.80^{a}
500 kg/l (over)	2.90^{a}	2.90^{a}	2.00^{a}
Temperature	NS	NS	**
Concentration of wax	**	**	**
Temp x Concentration of wax	NS	NS	NS
C.V	17.48	17.89	21.84

Means within a column followed by the same letter were not significantly different at $P < 0.05$ level by DMRT

** = highly significant different, and NS = not significant

4.2.5 Off flavor

There was no interaction between storage temperatures and concentrations of wax on off flavor development of mandarin (Table 4.18). However, after storage of 14 days, the fruit coated with recommended concentration of wax showed the highest off flavor score (1.60) among all treatments. There was no significant difference among any treatment in off flavor measurement at any storage temperature after storage for 28 days. However, slightly eating quality changes was observed in all treatments by the end of storage period.

Table 4.18 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on off flavor development of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.
1 = no off flavour, 2 = slightly/ moderately off flavour, 3 = strong off flavour

Storage conditions	Days after storage (days)			
	7	14	21	28
Storage temperature				
Ambient temperature (29 °C)	1.55	1.25	1.45	1.70
Cold storage (5°C)	1.55	1.35	1.55	2.00
Concentration of wax				
Uncoated	1.30	1.10[b]	1.40	1.70
1500 kg/l (under)	1.40	1.20[b]	1.30	1.50
1000 kg/l (recommend)	1.70	1.60[a]	1.70	2.20
500 kg/l (over)	1.80	1.30[ab]	1.60	2.00
Temperature	NS	NS	NS	NS
Concentration of wax	NS	*	NS	NS
Temperature x Concentration of wax	NS	NS	NS	NS
CV	33.61	30.49	33.92	31.98

Means with in a column followed by the same letter were not significantly different at P <0.05 level by DMRT

NS = not significant

4.2.6 Shelf life

There were interactions between storage temperature and concentration of wax on the shelf life of mandarin. The longest shelf life (74 days) was observed in fruits coated with over recommended concentration of wax at 5 °C, whereas, uncoated fruit stored at ambient temperature showed the shortest shelf life of 9 days.

Low temperature significantly extended the storage life of the fruit compared to ambient temperature (Appendix 6). Even uncoated fruit, low temperature (at 5 °C) efficiently extend the shelf life of the fruits from 9 to 22 days (Table 4.19). Similar results were found on wax coated fruits, which stored at 5 °C that extended the shelf life of the fruits significantly longer than fruits stored at ambient temperature.

Wax coated fruits had significantly longer shelf life than the uncoated fruits stored both at 5 °C and ambient temperature (Table 4.19). In addition, the storage life of the fruits depended on the concentration of applied wax at low but not at high temperature storage. At 5 °C, the uncoated fruit showed significantly shorter shelf life (22 days) than 74 days, 63 days and 52 days for over, recommended and under recommended concentration of wax.

Table 4.19 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on shelf life of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage.

Treatment combinations	shelf life (days)	
	Ambient temperature (29 °C)	Cold storage (5 °C)
Uncoated	9.60^{d}	22.13^{c}
1500 kg/l (under)	18.60^{cd}	53.06^{b}
1000 kg/l (recommended)	20.40^{cd}	63.33^{ab}
500 kg/ l (over)	23.27^{c}	74.53^{a}
Temperature x Concentration of wax	**	
C.V	19.26	

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

** = highly significant different

4.2.7 TSS/TA ratio

No interaction was observed in TSS/TA ratio of all treatments up to day 21 (Table 4.20). Also, there was no statistically difference in TSS/TA ratio among the wax coated treatments. However, there were interactions between storage temperature and concentration of wax on TSS/TA ratio of mandarin after storage for 28 days (Table 4.21). The lowest TSS/TA ratio (18.76) was found in the uncoated fruit and the highest TSS/TA ratio (23.08) in over concentration of wax coated fruits stored at ambient temperature.

Table 4.20 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on TSS/TA ratio of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 21.

Storage conditions	Days after storage (days)		
	7	14	21
Storage temperature			
Ambient temperature (29 °C)	18.48	19.35	18.22
Cold storage (5 °C)	18.48	18.15	19.01
Concentration of wax			
Uncoated	18.91	17.61	16.97
1500 kg/l (under)	18.52	18.72	17.16
1000 kg/l (recommend)	18.86	19.07	17.72
500 kg/l (over)	17.61	19.59	18.62
Temperature	NS	NS	NS
Concentration of wax	NS	NS	NS
Temperature x Concentration of wax	NS	NS	NS
C.V	7.77	9.66	9.85

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

NS = not significant

Table 4.21 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on TSS/TA ratio of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Treatment combinations	28 days after storage	
	Ambient temperature (29 °C)	Cold storage (5 °C)
Uncoated	18.76[b]	20.84[ab]
1500 kg/l (under)	22.00[ab]	18.89[ab]
1000 kg/l (recommended)	19.65[ab]	21.54[ab]
500 kg/l (over)	23.08[a]	19.48[ab]
Temperature x Concentration of wax	*	
C.V	8.14	

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

* = significant different

4.2.8 pH

There was no interaction between storage temperature and concentration of wax on pH of mandarin juice during storage. It was observed that wax coating did not affect pH of the fruit throughout the storage (Table 4.22). In contrast with wax coating, it was found that fruit stored at ambient temperature had higher pH than fruits stored at 5 °C at day 14 and day 21. However, no significantly difference was observed on pH of fruit juice in both storage temperatures on day 7 and day 28 storage (Table 4.22).

Table 4.22 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on pH of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Days after storage (days)			
	7	14	21	28
Storage temperature				
Ambient temperature (29 °C)	3.65	4.14[a]	3.73[a]	4.19
Cold storage (5°C)	3.62	4.02[b]	3.59[b]	4.14
Concentration of wax				
Uncoated	3.70	4.02	3.58	4.10
1500 kg/l (under)	3.60	4.05	3.67	4.18
1000 kg/l (recommend)	3.67	4.12	3.68	4.17
500 kg/l (over)	3.60	4.12	3.72	4.22
Temperature	NS	**	**	NS
Concentration of wax	NS	NS	NS	NS
Temperature x Concentration of wax	NS	NS	NS	NS
C.V	4.90	2.30	3.02	2.35

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

** = highly significant different, and NS = not significant

4.2.9 Peel color

No statistical interaction was observed between storage temperatures and concentrations of wax on peel color a*, b* and L* during storage. However, the changes of (a*) values were obviously found in mandarins stored at ambient temperature rather than those observed at 5 °C (Table 4. 23). This study showed that the changes of peel color a* in all wax coated fruits were not significantly different from those of uncoated fruits. The peel color b* of mandarin were not significantly different both in storage temperature and wax coating up to day 21 (Table 4.24). However, it was found that significantly higher peel color b* was observed in fruits stored at 5 °C than that of fruits stored at ambient temperature at day 28 (Table 4.24). Changes of peel color b* in uncoated and coated mandarins were not significantly different after storage for 28 days. No significant difference was observed in changes of L* values of mandarins in any treatments during storage (Table 4.25).

Table 4.23 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on peel color a* of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Days after storage (days)			
	7	14	21	28
<u>Storage temperature</u>				
Ambient temperature (29 °C)	-4.43[a]	-3.04	-0.81[a]	-0.83[a]
Cold storage (5°C)	-5.70[b]	-4.62	-4.70[b]	-3.92[b]
<u>Concentration of wax</u>				
Uncoated	-4.75	-2.88	-1.53	0.56
1500 kg/l (under)	-5.16	-3.99	-3.57	-2.72
1000 kg/l (recom)	-5.19	-3.96	-3.78	-1.51
500 kg/l (over)	-5.17	-4.49	-3.42	-2.51
Temperature	*	NS	**	**
Concentration of wax	NS	NS	NS	NS
Temperature x Concentration of wax	NS	NS	NS	NS
C.V	-28.59	-52.38	-80.14	-165.66

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

** = highly significant different, * = significant different and NS = not significant

Table 4.24 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on peel color b* of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Days after storage (days)			
	7	14	21	28
Storage temperature				
Ambient temperature (29 °C)	28.25	28.72	27.85	26.67^{b}
Cold storage (5°C)	28.57	29.06	29.75	30.88^{a}
Concentration of wax				
Uncoated	28.62	30.11	30.75	30.39
1500 kg/l (under)	29.88	29.87	30.77	30.87
1000 kg/l (recom)	26.74	27.17	26.41	25.37
500 kg/l (over)	28.38	28.40	27.27	28.46
Temperature	NS	NS	NS	*
Concentration of wax	NS	NS	NS	NS
Temp x Concentration of wax	NS	NS	NS	NS
C.V	9.62	11.46	12.81	14.60

Means within a column followed by the same letter were not significantly different at $P < 0.05$ level by DMRT

* = significant different, and NS = not significant

Table 4.25 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on peel color L* of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Days after storage (days)			
	7	14	21	28
Ambient temperature				
Ambient temperature (29 °C)	37.45	37.58	36.83	36.62
Cold storage (5°C)	37.88	38.12	38.45	38.76
Concentration of wax				
Uncoated	36.95	37.67	37.81	37.23
1500 kg/l (under)	38.82	38.69	38.98	38.77
1000 kg/l (recommended)	37.24	37.29	36.60	36.68
500 kg/l (over)	37.88	37.77	37.17	38.06
Temperature	NS	NS	NS	NS
Concentration of wax	NS	NS	NS	NS
Temperature x Concentration of wax	NS	NS	NS	NS
C.V	5.07	5.32	5.91	6.70

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT

NS = not significant

4.2.10 Ethylene production

The rate of ethylene production was measured only on day 28th with Gas chromatography. No statistical interaction was observed between storage temperatures and concentration of wax on ethylene production was found (Table 4.26). Fruit coating with Rosy wax and low temperature storage did not affect ethylene production of mandarin.

Table 4.26 Effect of Rosy wax at different concentration (500 kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (29 °C and 5 °C) on ethylene production rate (nl/kg/l) of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) storage for day 28.

Storage conditions	Ethylene production rate (nl/kg/hr)
Storage temperature	
Ambient temperature (29 °C)	0.035
Cold storage (5°C)	0.028
Concentration of wax	
Uncoated	0.039
1500 kg/l (under)	0.041
1000 kg/l (recommend)	0.017
500 kg/l (over)	0.029
Temperature	NS
Concentration of wax	NS
Temperature x Concentration of wax	NS
C.V	57.29

Means within a column followed by the same letter were not significantly different at P <0.05 level by DMRT
NS = not significant

4.2.11 Disease incidence

Teva wax coated fruit did not show any symptom of disease during storage either at ambient temperature or 5° C. In contrast, stem end rot caused by fungus (*Diaporte citri*) was observed in Rosy wax coated fruit stored at ambient temperature on day 12th of storage (Appendix 7). Disease incidence was more serious in wax coated fruit than with the uncoated ones.

Chapter 5

Discussion

5.1 Effects of wax coating on postharvest quality of 'Sai Nam Paung' mandarin

5.1.1 Percentage of weight loss and fruit height

Wax coating and low temperature storage were used as the common methods to control water loss from the fruits during storage and transit (Kester and Fennema, 1986). In Teva wax experiment, the treatment combination of over recommended concentration of wax and cold storage showed the lowest weight loss (6.51 %) while the highest weight loss (37.02%) was observed in the of uncoated fruit at ambient temperature stored for 28 days. This result was supported by the previous finding that different coating combined with cold storage reduced fruit weight loss. Such coatings were edible coating on Fortune mandarin (Perez-Gago et al., 2003) and on 'Angeleno' plums (Navarro et al., 2005) and shellac- based commercial coating on mandarin (Lawes and Prasad, 1999). In Rosy wax experiment, the highest weight loss (29.35%) was also observed in the uncoated fruits. Perez-Gago et al. (2003) found that coated mandarin had lower weight loss than uncoated 'Fortune' mandarin indicating the effectiveness of coating as a moisture barrier. Hernandez-Munoz et al. (2005) also reported that coating the strawberries with 1.5 % chitosan effectively reduced water loss by retarding the dehydration of the fruit. Therefore, Teva and Rosy wax coating act as the effective moisture barriers by increasing the surface resistant of the fruit peel.

The effect of Teva wax on percentage of weight loss dependent on the concentration used on but Rosy wax did not (Table 4.1 and 4.13). It was observed that high concentration of Teva wax was negatively correlated with fruit weight loss by reducing peel permeability. It could be that shellac in Teva wax resisted water loss from the fruit better than wax without shellac. Perez-Gago et al. (2003) found that increasing Beewax content of coating formulation from 20 % to 60 % caused the reduction of weight loss in mandarins. However, Rosy wax on weight loss percentage was not dependent on its concentration used (Table 4.13). This could be due to the wax surface might have many pits and cracks (Ben-Yehoshua et al., 1985). Perez-Gago et al. (2003) reported that uniform layer of coating was the major factor to reduce weight loss of the fruit rather than the coating solution's solid concentration and viscosity.

In addition to wax coating, low temperature storage reduced water loss from the fruits by minimizing vapor pressure deficit (VPD) between the fruit and the storage environment was found in both experiments (Kays, 1998). Yaman and Bayoindirli (2002) reported that weight loss of cherries in cold storage was statistically lower than those stored at ambient temperature. Fisk et al. (2008) also reported that cold temperature storage at 2 °C effectively delayed weight loss of hardy kiwifruit (*Actinidia arguta* 'Ananasnaya') compared to fruit held at 22 °C.

Mandarins from all treatments showed a progressive loss of weight during storage in both experiments. Bringas-Taddei et al. (2005), also reported an increased in weight loss with storage time in 'Kent' mango uncoated and coated with calcium or wax or both. It was observed that the reduction of weight loss of wax coated or cold storage or both was related with fruit height reduction, appearance and shelf life.

Generally, coating with Teva and Rosy waxes efficiently control water loss from mandarin in this study. However, fruit coated with Teva wax maintain better fruit freshness at low temperature storage than did Rosy wax. Both types of wax could maintain fruit freshness up to 3 days at ambient temperature. Rosy wax coated fruit did not benefit from keeping in cold storage while fruit coating with Teva wax retain fruit freshness even better if stored at low temperature.

The uncoated fruits showed significant lower fruit height than the wax coated fruits during 28 days storage. This indicated that waxing reduced the fruit height reduction by maintaining fruit freshness (Hagenmaier and Shaw, 1992). However, increasing wax concentrations had no additional effect on fruit height reduction during the storage. Fruit which stored at 5 °C retained it's height better than that stored at ambient temperature (Table 4.2 and 4.14). This was because low temperature maintained fruit freshness by reducing vapour pressure deficit between fruit and storage environment (Kays, 1998).

5.1.2 Respiration

The highest respiration rate was observed in uncoated fruit as compared with Teva wax coated fruits (Table 4.3). It was likely due to the shellac in Teva wax increased the diffusive resistance to oxygen and carbon dioxide movement into and out of the tissue (Kays, 1998) by altering the natural permeability of fruit skin to gases (Hagenmier, 2002). However, the respiration rates of mandarins were not significantly different between the uncoated or Rosy wax coated treatments (Table 4.15). It could be due to Rosy wax coating had high enough gas permeability for mandarin to respire as the same rate as that of uncoated fruit due to fine crack or lesion of coating on the fruit. This result was contrast with Perez-Gago et al. (2003) who found that edible coating of fruits could reduce respiration rate of the fruit. Rosy wax had no reduction effect on fruit respiration rate compared with the uncoated fruit as Teva wax did.

No significant result was observed on the concentration of applied wax on mandarin in both experiments. It might be due to fine crack or lesion or uneven coating. Therefore, high concentration of wax was not necessary to reduce respiration rate of mandarin in long term storage. In contrast, Ladaniya (2001) reported that reduced respiration rate depends on the solid in wax emulsion 'Mosambi' sweet orange fruit.

In this experiment, the respiration rate was measured at an ambient temperature, from one to three hours after transferred the fruits from the cold storage. This could be the reason why the fruit stored at 5 °C had higher respiration rate compared to those stored at ambient temperature in Teva wax experiment. It might be due to the sudden increased in the temperature during measuring the respiration rate at an ambient temperature. Kim (2002) mentioned that stress factors could alter the respiration rates of the fruit. In contrast, Murata (1997) who stated that respiration rate of oranges, grapefruits and lemons were increasing with the increasing of temperature._But, no significant differences in respiration rate were observed in fruits stored at ambient temperature or at 5 °C in Rosy wax experiment.

5.1.3 Glossiness

Citrus fruits could be improved in appearance by synthetic wax application (Thompson, 1996). The lowest glossiness was observed in uncoated fruits stored at ambient temperature in Teva wax experiment (Table 4.4). This was because removing and changing of natural wax in postharvest period in combination with faster natural wax changes at ambient temperature as compared with low temperature. In this study, wax coated mandarins had shown better appearance (glossiness) than uncoated one throughout the experiment (Table 4.5 and 4.17). It is likely due to the fact that wax coating not only maintained fruit freshness but also enhanced fruit glossiness. In addition, shellac in Teva wax provided a "fresh look" of the fruit for cosmetic purpose (Hagenmaier, 2000; Kaplan, 1986) and resin in Rosy wax coating had relatively higher gloss than the wax-based coating (Hagenmaier, 2002). Ladaniya (2001) found that waxed fruit with non diluted Sta-fresh (451) had higher score of appearance in 'Mosambi' sweet orange after 30 days as compared with non waxed fruit. Martinez-Romero et al. (2005) also mentioned that the highest score of visual aspect was found in the *Aloe*-treated sweet cherries fruit compared with the control after 16 days of cold storage plus 1 day at 20 °C. However, it was observed that fruit coated with Teva wax had better appearance than fruit coated with Rosy wax. It might be due to the shellac containing in Teva wax provide high-gross of the fruit.

The moderately glossiness in fruit was still achieved up to 28 days and 21 days in Teva and Rosy wax coatings. It indicated that Teva and Rosy waxes were the effective fruit glossiness agents for storing fruit. However, there was no significantly difference of glossiness observed within coating treatments during storage. This might be due to the panelists that did not detect glossiness differences within concentrations of wax. Therefore, high concentration of Teva or Rosy wax was not necessary to use for long term storage of mandarin. However, high concentration of Rosy wax coated fruits in ambient temperature storage still appeared the same glossiness as those stored in cold storage at day 21 (Table 4.16). Therefore, high concentration of wax was required to maintain the fruit glossiness in ambient temperature.

After storage for 28 days, the fruits stored at 5 °C maintained more glossiness as compared with the fruits stored at ambient temperature in this study. This is because low temperature caused slower natural wax changes compared to ambient temperature.

5.1.4 Off flavor

Coating fresh produce could change fruit flavor due to entrapment of volatiles or effect of volatile synthesis (Baldwin et al., 1995). Recommended concentration of Rosy wax had the highest off flavour development 14 days after storage (Table 4.18). However, in both experiments, off flavor development of coated and uncoated fruits were not different during storage period. This indicated that Teva and Rosy wax coating did not cause off flavor development on mandarin during storage. Laws and Prasad (1999) suggested that fruits with uniform peel characteristic might have less variable responses to surface coating.

In the same way, it was observed that any storage temperature did not develop off flavor during storage. By the end of the storage period, sensory panelists could not differentiate off flavor development within treatments while eating quality changes were observed in all treatments with increasing of the storage time. This result was contrast with the finding of Hagenmaier (2001), who reported that coated mandarin stored at 5 °C was rated most fresh than at 21 °C even though least permeable coating was used.

5.1.5 Shelf life

The wax coated mandarins were observed to have longer shelf life than the uncoated fruits did (Table 4.7 and 4.19). This may be due to the advantages of waxing on inhibiting water loss. This finding was supported by Quezada Gallo et al. (2003) who reported that the coated Mexican guava had at least 3 days longer shelf life than the uncoated fruit at 25 °C and 50-70 % RH. The combination advantages of wax coating and low temperature storage was observed in Rosy wax experiment. It was observed that the longest shelf life (74 days) was observed in fruits coated with over recommended concentration of Rosy wax at 5 °C, whereas, uncoated fruit stored at ambient temperature showed the shortest shelf life (9 days) among all treatments combinations (Table 4.19). Therefore, Rosy wax was effectively extended the shelf life of mandarin at an low temperature storage.

The shelf life of all the coated fruits was not statistically different at ambient temperature in both experiments. Therefore, high concentration of Teva or Rosy wax was not necessary to use in ambient storage. However, the storage life of the fruits depended on the concentration of Rosy wax in cold storage while those of Teva wax did not. Therefore, higher concentration of wax should be used to get longer fruit shelf life in cold storage even it did not effect on fruit glossiness.

Temperature management was the most effective tool for extending the storage life of fresh horticultural commodities (Kim, 2002). In this study, it was observed that low temperature storage efficiently extended shelf life of mandarin longer than those stored at ambient temperature (Table 4.7 and 4.19). This indicated that low temperature could increase the storage life of the mandarins by slowing down their metabolic process. Similarly, Jobling (2008) reported that shelf life of stone fruit could be extended by storing at 0 °C compared to 3 or 5 °C. It was observed that shelf life extension was correlated with fruit weight loss, fruit height reduction and appearance in this study.

5.1.6 TSS/TA ratio

There was no statistically difference in TSS/TA ratio in all treatments up to 28 and 21 day for Teva and Rosy wax, respectively. In Rosy wax experiment, the lowest and the highest TSS/TA ratio was found in uncoated fruit and over recommended concentration of wax coated fruits among all treatment combinations after storage for 28 days (Table 4.21). It might be due to the wax coated fruit could delay the biochemical changes of the fruit as compared with uncoated fruit. At the end of storage period, slightly increase in TSS/TA ratio was observed in both experiments. This was due to the decreasing in organic acids of the fruits by utilizing as respiratory substrates and as carbon skeleton for the synthesis of new compound for color development (Kays, 1998) or increasing sugar content due to conversion of acid to total sugars in fruits after harvest and during storage. On the other hand, it might be due to the reduction of fresh weight loss increased along with the storage time. Sandhu et al. (2004) mentioned that organic acids were used in the enzymatic reactions of respiration in Pear cv. Punjab Beauty.

5.1.7 pH

Wax coating did not affect pH of fruit throughout the storage (Table 4.9 and 4.22). However, pH of fruits at 5°C (4.00) was statically higher than that of ambient temperature storage (3.83) on day 7 of storage in Teva wax experiment (Table 4.9). In contrast, the fruit stored at ambient temperature had higher pH than fruits stored at 5 °C on day 14 and day 21 in Rosy wax experiment (Table 4.22). Te change of pH could be due to TSS values increased whereas TA decreased with increase in storage time. However, the pH of mandarin fruit juice was not different at any storage temperature during 28 days storage in both experiments. Similarly, Bringas-Taddei et al. (2005) reported that pH, TSS, and TA of 'Kent' mango were not significantly different among fruit coating with calcium, wax and combination of both stored at 10 °C for 30 days and transferred to 20 °C for 12 days.

5.1.8 Peel color

Color of fruit could be altered when a blight luster such as wax is added to the surface (Kays, 1998). In this study, no significantly difference was observed in peel color a*, b* and L* values of mandarins in any wax coated treatments during storage. In contrast, Hernandez-Munoz et al. (2005) reported that chitosan coatings were capable of delaying external color changes in strawberries. However, the changes of peel color a* from negative to positive value showed green to light yellow during storage in both experiment (Appendix 8 and 9). Therefore, the color of wax coated fruits were greener than uncoated fruit even though no significant results were observed on peel color a*, b* and L*. It indicated that coating delay the color development of the mandarin.

The changes of a* values were obviously found in mandarins stored at ambient temperature rather than those observed at 5 °C in both experiment. This is because storage temperature and duration of storage affect on the color development of fruit (Ladaniya, 2008). Similarly, the changes of specific pigment of many tissues arc temperature dependent (Kays, 1998). Hernandez-Munoz et al. (2005) reported that external color between coated and uncoated samples during storage at 20 °C were more acute than cold stored strawberries.

It was found that significant higher peel color b* was observed in fruits stored at 5 °C than that of fruits stored at ambient temperature at day 28. It indicated that the fruit storage at cold storage maintained green color more than ambient temperature. In both experiment, no significant difference was observed in changes of L* values of mandarins in both wax coating and storage temperature.

5.1.9 Ethylene production

In this study, ethylene production was measured only in Rosy wax experiment. Fruit coating with Rosy wax and low temperature storage did not affect ethylene production of mandarin. This could be because mandarin is a non climacteric fruit which does not exhibit remarkable change in ethylene production (Ladaniya, 2008). Although peel color development was observed in all treatments during storage (Appendix 9), it is only decomposition of chlorophyll and it was not correlated with the fruit ripening process related with ethylene production.

5.1.10 Disease incidence

Stem end rot caused by *Diaporthe citri* were observed in only in Rosy wax coated fruit stored at ambient temperature on day 12th of storage. It might be high moisture content inside the wax coated fruit favor the disease development when stored at ambient temperature. Therefore, uncoated fruit stored at ambient temperature did not showed any disease incidence during storage. The uncoated fruit lost water quickly from fruit peel. Therefore, the dry fruit skin could not contribute to low/no disease development. Ladaniya (2008) reported that perforations are necessary to regulate water vapor transmission to the desired level to reduce of relative humidity. On the other hand, dry peel in uncoated fruit caused less favorable condition for pathogen activity for disease development than fresh peel did. Murata (1997) also reported that temperature and humidity in storage also influence the development of decay of the fruit. He stated that stem end rot is a major disease in citrus in warm humid region. Fruit stored at 5°C did not show any disease symptom during storage. This result, similar work with Murata (1997), suggested that low temperature (4-5 °C) and low humidity (80-88 % RH) could help to reduce the occurrence of stem end rot.

The overall result suggested that both Teva and Rosy waxes gave positive result on shelf life extension by reducing fruit weight loss, improving fruit glossiness, reducing fruit height reduction, According to this study, it was observed that the recommended concentration of Teva wax and Rosy wax were appropriate to extend shelf life of mandarin stored at ambient temperature as well as cold storage. However, the over recommended concentration of Rosy wax on mandarin could extend the shelf life almost 10 days in combination with cold storage (5 °C).

Chapter 6

Conclusion

Wax coating can prevent shrinkage resulting from water loss. Another practice is cold storage with the appropriate temperature for keeping quality and storage life.

Wax coating on mandarin slow down the weight loss percentage, fruit height reduction, respiration rate, glossiness, shelf life and peel color a*. In Teva wax experiment, the highest weight loss percentage was observed in uncoated fruits when stored at ambient temperature. However, no combination result of wax coating and storage temperature was observed in Rosy wax experiment. On the other hand, the lowest fruit height loss was observed in Rosy wax coated fruit as compared with uncoated fruit.

In Teva wax experiment, high respiratory rate was detected in uncoated fruit at day 28 while little variation of respiration rates occurred between concentrations of applied wax. However, Rosy wax did not affect on respiration rate of mandarin at day 28. In addition, increasing of wax concentration in coating emulsion did not only enhance water vapour resistant but also improved glossiness of the fruit. However, no difference in glossiness of the fruits among coating treatments was observed at the end of the storage period. Wax coating had beneficial effect on the shelf life of mandarin at least 10 days as compared with uncoating. Wax coating had little effect on slowing down the external color change, especially peel color a*. However, coating with different concentrations had no effect on off flavor, TSS/TA ratio, pH, peel color a*, b* and L*.

Significant effects of storage temperature were observed on the parameters such as percentage of weight loss, fruit height, respiration rate, glossiness and shelf life of fruit. Regardless of waxing, lower percentage of weight loss in mandarin occurred at 5 °C over the storage period while weight loss of fruits changed extremely fast at ambient temperature. In the same way, fruit height reduction was slow in fruits stored at 5 °C as compared with ambient temperature. Low temperature storage maintained the glossiness of fruit at the end of storage period. Shelf life of the fruits decreased considerably with the increased storage temperature. In this study, mandarin stored at 5 °C had shelf life 7 times longer than that of fruit at ambient temperature. Nevertheless, TSS/TA ratio, pH, peel color changes did not show any response with low temperature during storage. Panelists evaluated that coating application led to a slightly decrease in mandarin's eating quality either stored at 5 °C or ambient temperature. This result showed that low temperature had no effect on maintaining eating quality of mandarin after storage for 28 days as excepted. Although coating with Teva wax did not show any disease incidence during storage, Rosy wax coated fruits showed stem end rot on 12 days after storage. It was observed that coating mandarin with recommended concentration of wax can be extending the shelf life of mandarin up to 2 to 3 weeks at ambient temperature. The combination of wax coating with recommended concentration of wax and cold storage could extend mandarin shelf life up to 2 months.

The overall result suggested that the potential of Teva and Rosy waxes provides positive results on shelf life extension of mandarin by maintaining fruit fresh weight, glossiness and flavor quality of the fruit. Although this commercial coating could be a good option to increase shelf life of 'Sai Nam Paung' mandarin, low temperature is still necessary to store mandarin for 1 month without changing appearance and sensory quality. This study recommended that storage temperature of 5 °C gave the best storage life of mandarin in combination with wax coating can be used successfully for long term storage of 'Sai Nam Paung' mandarin.

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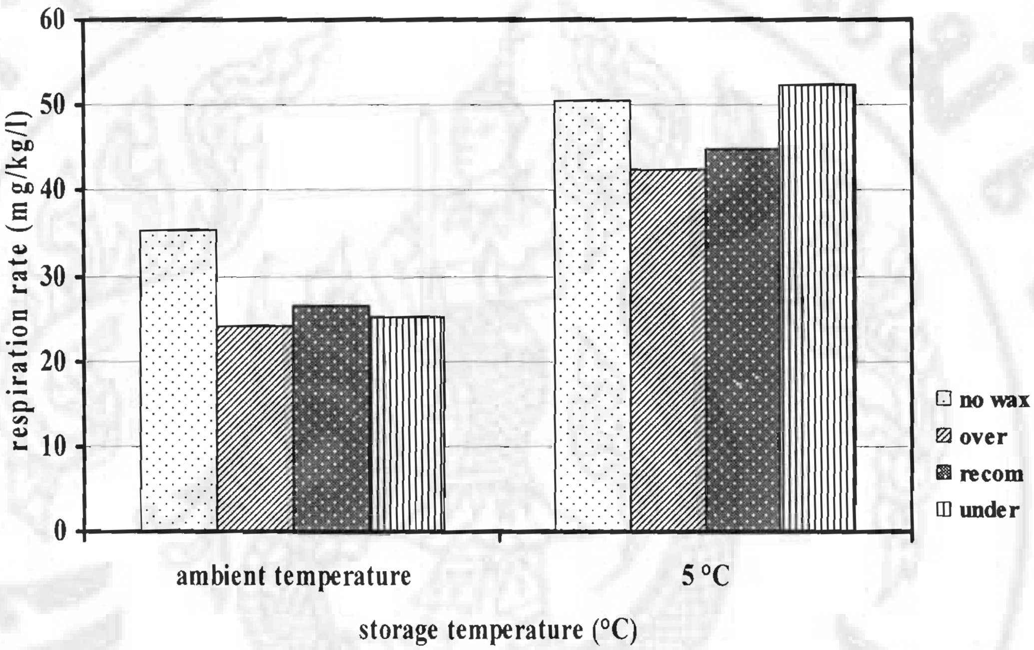
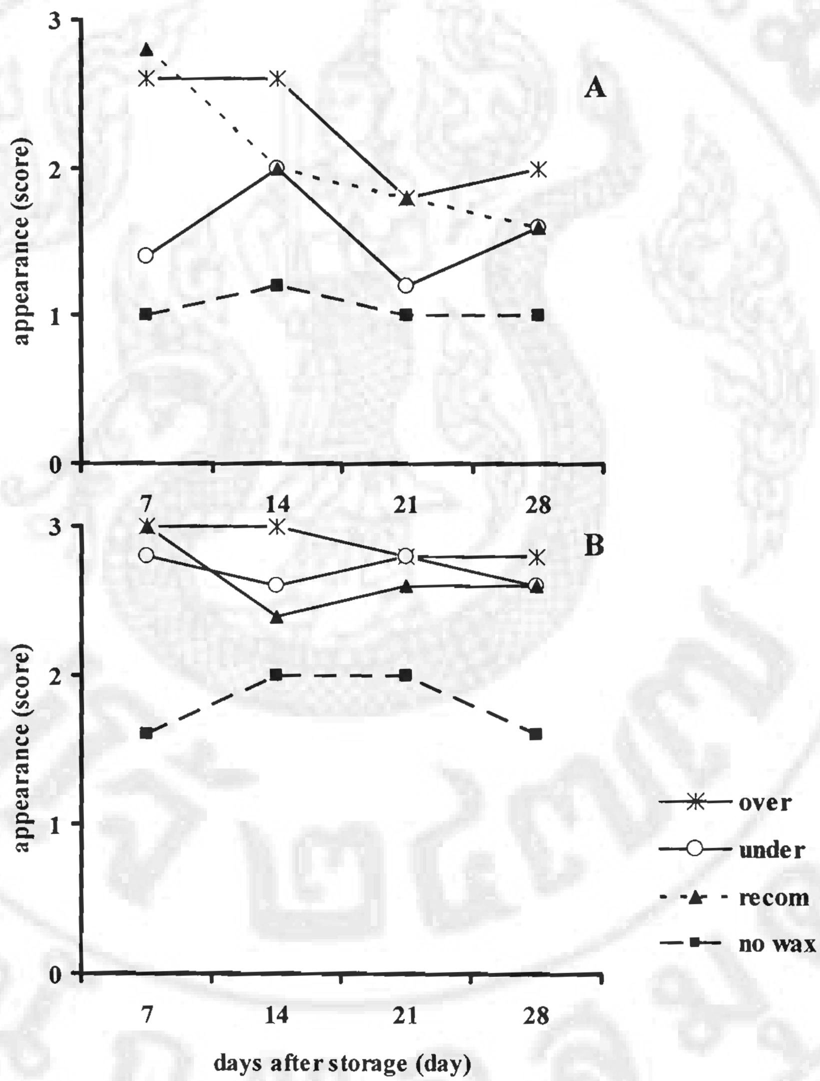
Appendices

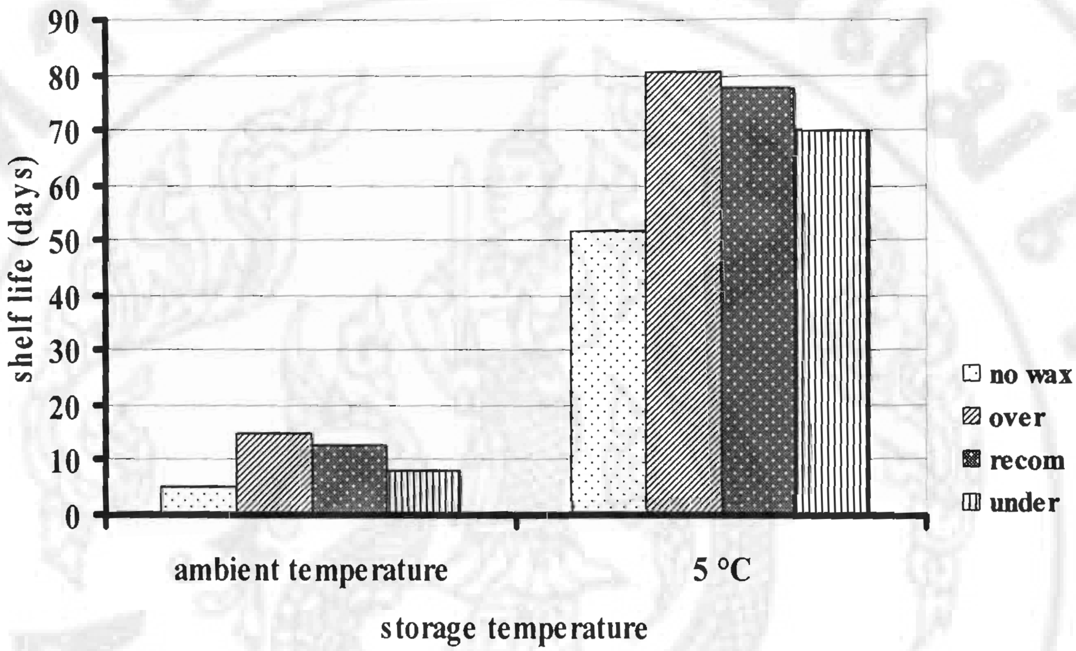
Appendix 1 Effect of Teva wax at different concentration (500kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on respiration rate of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) at day 28.



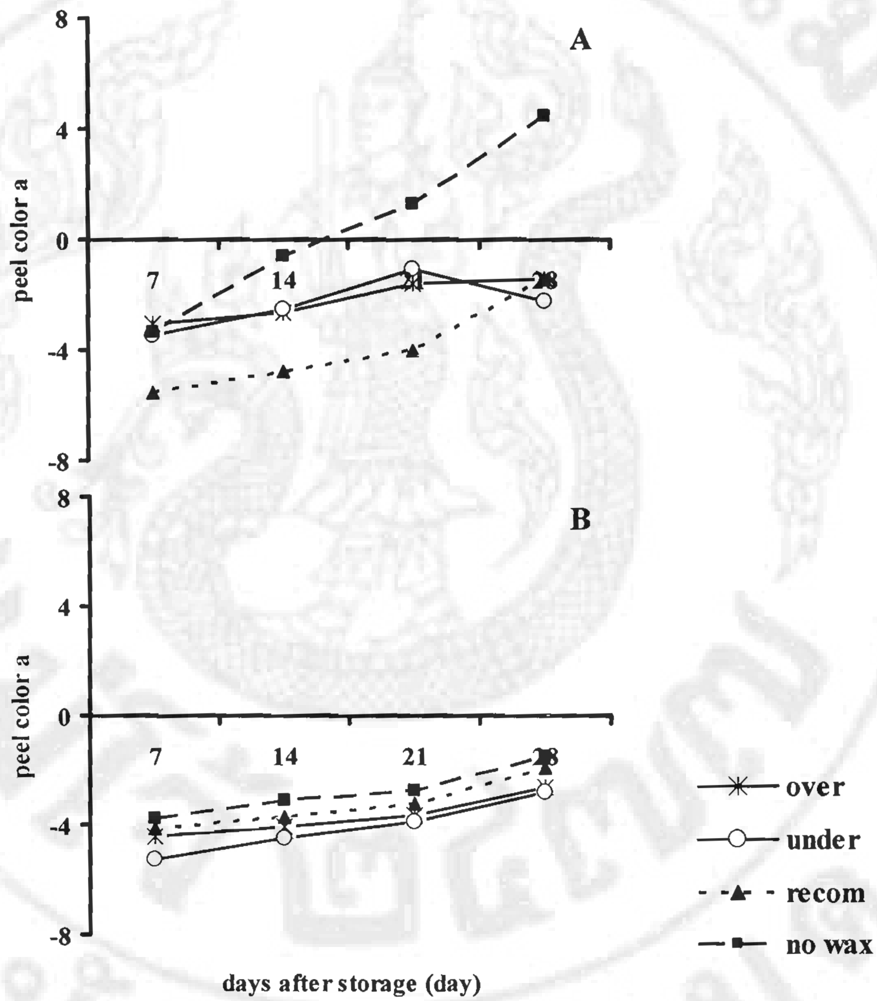
Appendix 2 Effect of Teva wax at different concentration (500kg/l, 1000 kg/l, 1500 kg/l and Uncoated) on glossiness of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco cv.) stored at ambient temperature (28 °C) (A) and cold storage (5 °C) (B).



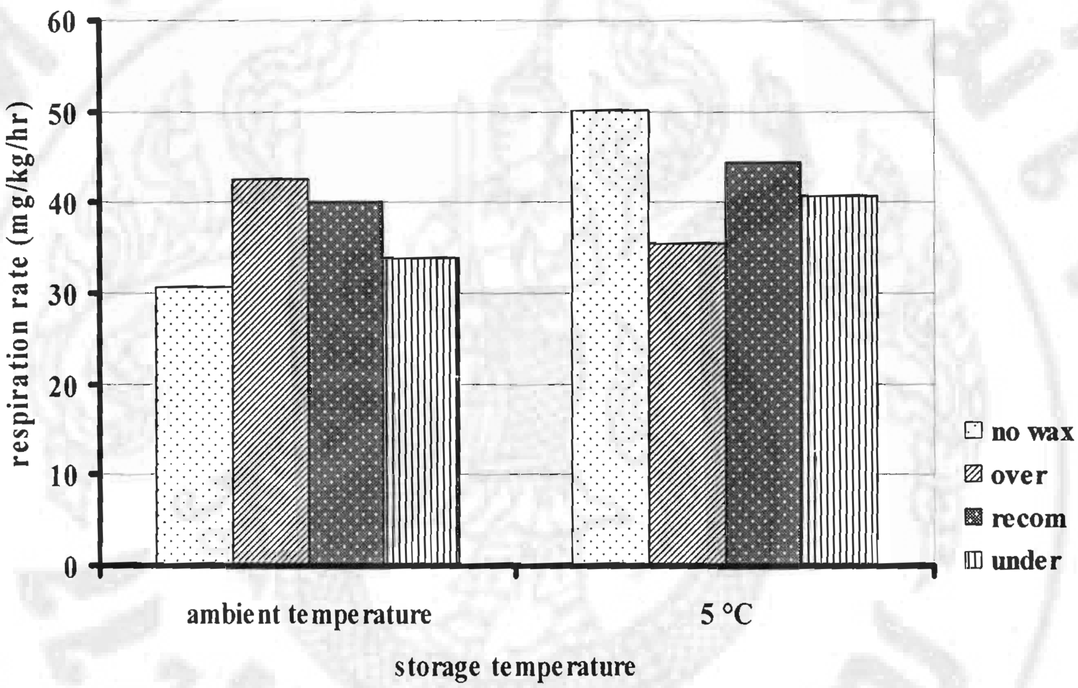
Appendix 3 Effect of Teva wax at different concentration (500kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on shelf life of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco).



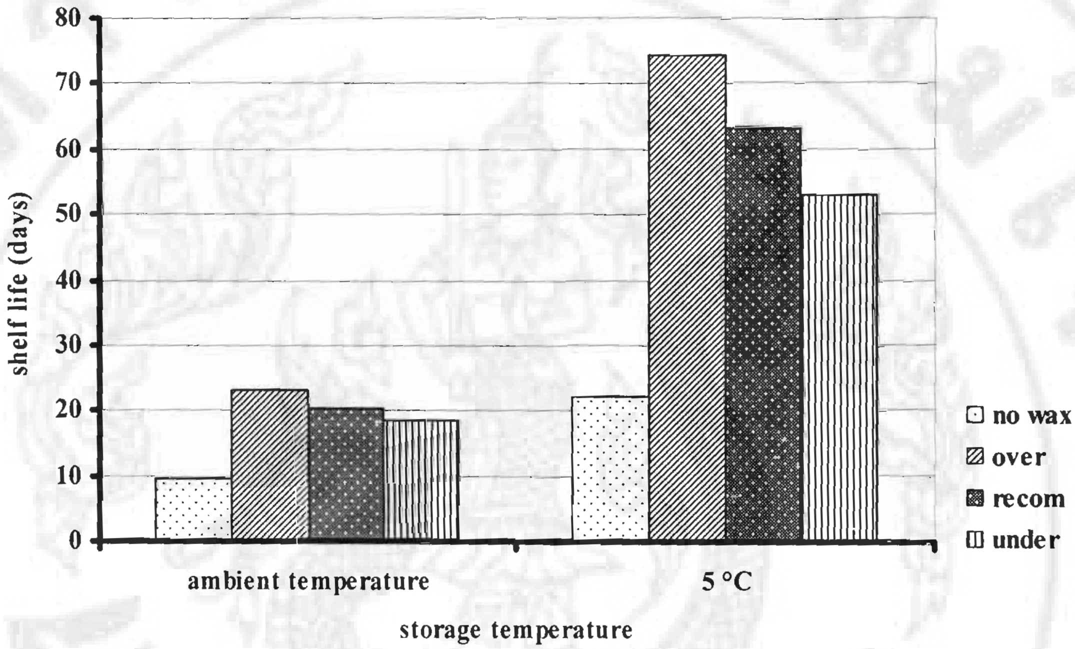
Appendix 4 Effect of Teva wax at different concentration (500kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C (A) and 5 °C (B) on peel color a* of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) for 28 days of storage.



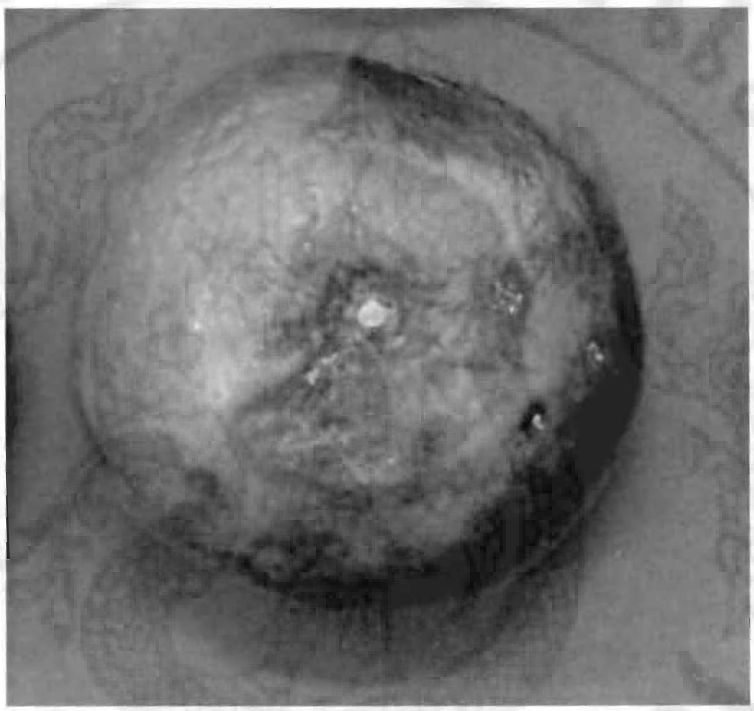
Appendix 5 Effect of Rosy wax at different concentration (500kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on respiration rate of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) at day 28.



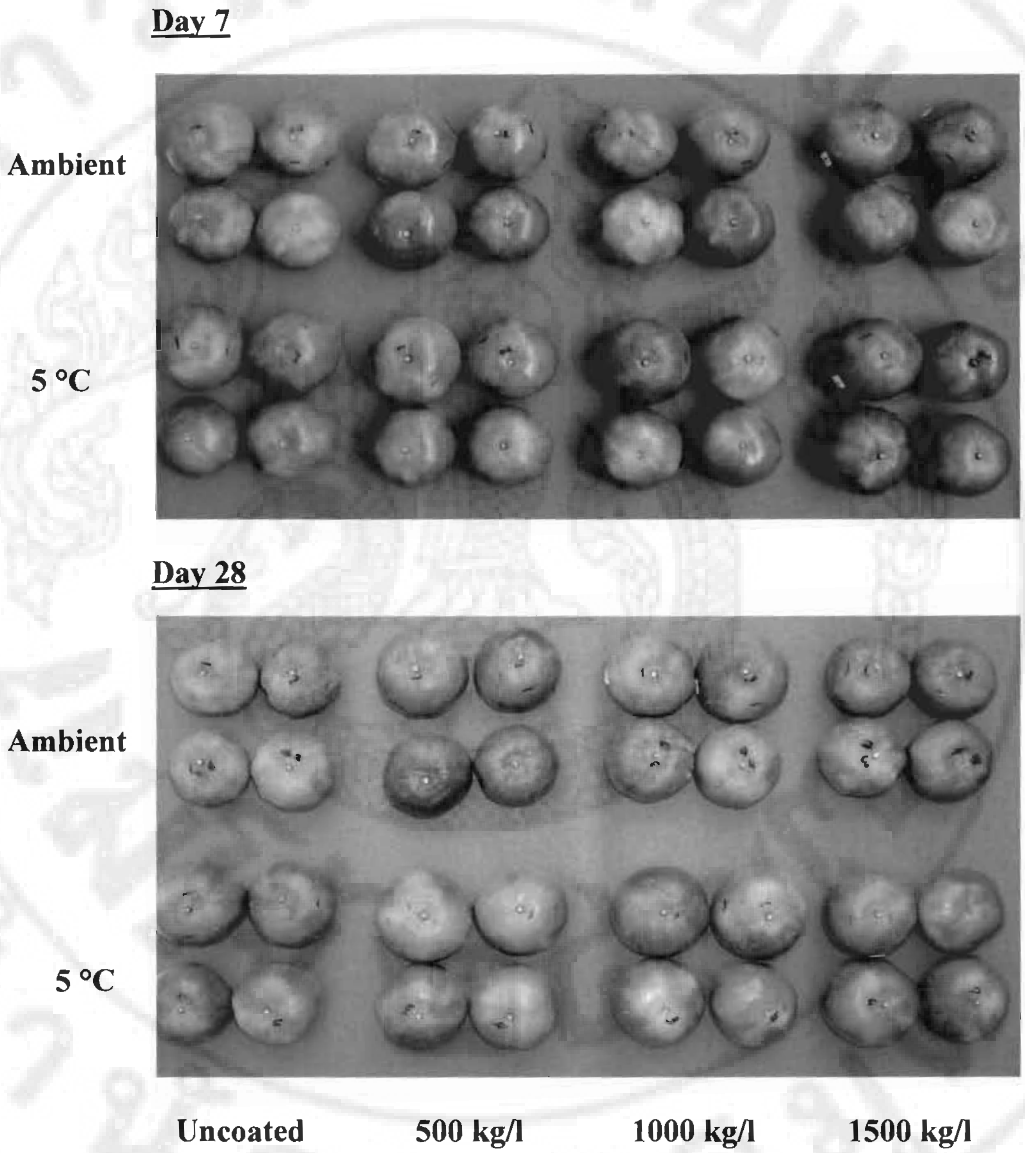
Appendix 6 Effect of Rosy wax at different concentration of wax (500kg/l, 1000 kg/l, 1500 kg/l and Uncoated) and storage temperature (28 °C and 5 °C) on shelf life of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco).



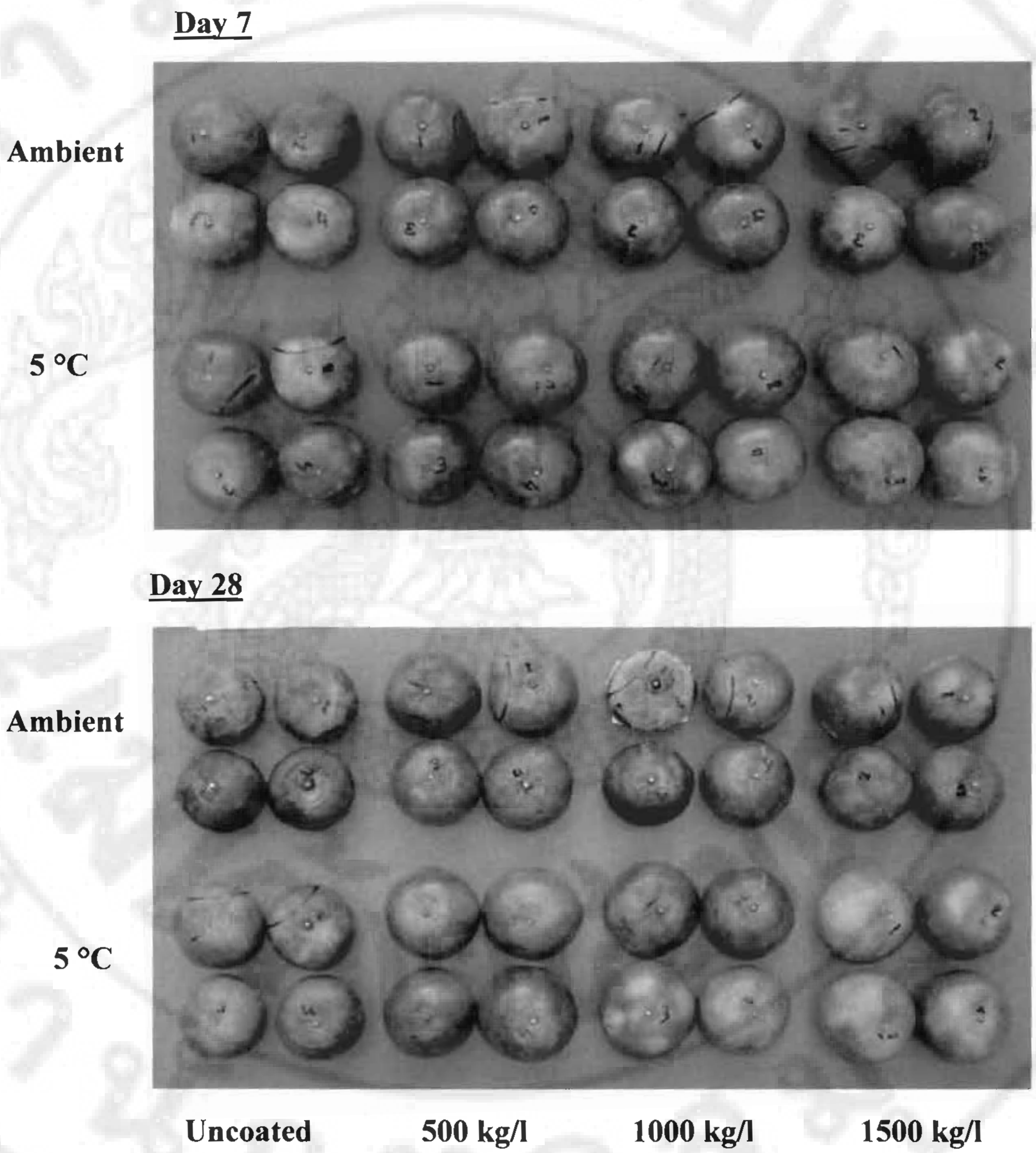
Appendix 7 Stem end rot disease symptom of Rosy wax coated 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) stored at ambient temperature after storage for 12 days.



Appendix 8 Peel color changes of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) coated with Teva wax stored at ambient temperature and cold storage after storage for 7 days and 28 days.



Appendix 9 Peel color changes of 'Sai Nam Paung' mandarin (*Citrus reticulata* Blanco) coated with Rosy wax stored at ambient temperature and cold storage after storage for 7 days and 28 days.



Appendix 10

Abstract of presented paper (oral presentation) in 7th National Horticultural Congress held on 27-29 May, 2008 at Naresuan University; Phitsanulok (Thailand).

Effect of Wax Coating on the Postharvest Quality of 'Sai Nam Paung' Mandarin Orange (*Citrus reticulata* Blanco)

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***Key word*:** wax coating, cold storage, mandarin orange

Abstract: Shrivelling of the peel is a key factor for the commercial decline of orange. The application of food grade wax not only reduces water loss from the fruit but also improves the appearance of the fruit. Low temperature storage is the most effective method to maintain quality and extend shelf life of the fruit. Postharvest quality of mandarin orange (*Citrus reticulata* Blanco cv. 'Sai Nam Paung') was studied in relation to teva wax (18% food grade shellac, polyethylene) coating and cold storage for 1 month. We found that teva wax coating is significantly difference from no wax (control) in % weight loss, shelf life and glossiness of the fruit. However, the glossiness of all wax coated fruits are not significantly difference at day 21 and 28. Moreover, the combination of wax coating and cold storage is significantly difference from that in room temperature storage for % weight loss, shelf life and no chilling injury appearance during 1 month of storage. There are no significantly changes in TSS/ TA ratio during storage.