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Research on Using Natural Coating Materials on the Storage Life of Mango Fruit cv. Nam Dok Mai and Technology Dissemination

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Abstract

This study was designed to assess the suitable type and concentration of 3 natural coating materials, namely, *Aloe vera* gel, chitosan and carnaubar wax, on postharvest storage life of mango (*Mangifera indica* L.) cv. Nam Dok Mai. The experiment was divided into 3 treatments to compare the 3 types of coating materials and each appropriate concentration, to find the appropriate combination treatment, and to evaluate the benefit of this technology. The objectives of this research were to compare different concentrations and study the type of natural coating materials. At 20 % *Aloe vera* jelly, 1 % chitosan and 4 % carnaubar wax gave the longest storage life with good quality at 12 days at a storage temperature of 25 °C and 75±5 % relative humidity ($p \leq 0.05$). Further investigation was done by using these optimal concentrations alone or in combination under 2 different conditions, 25 °C with 75±5 % relative humidity and 13 °C with 90±5 % relative humidity. It was found that coating with combination of 20 % *Aloe vera* jelly and 1 % chitosan gave the best result in alleviating the formation of brown spot and extended the storage life up to 12 days as well as slowing down the weight loss, changes in peel and pulp color, firmness, texture, quality such as concentrate by titratable acidity, total soluble solids and respiratory rate significantly compared to control and other treatment ($p \leq 0.05$). The use of the coating materials did not alter the quality of the fruit when ripe. Technology dissemination to farmers and exporters was performed by using the training manuals created by the author. The results of the pre-test and after training post-test showed that farmers and exporters increased their knowledge, attitudes, awareness and skills in the use of the natural coating materials for prolonging storage life of mangos.

Keywords: Natural coating materials, storage life, mango fruit cv. Nam Dok Mai, technology dissemination

Introduction

Mango (*Mangifera indica* Linn.) is a tropical fruit that has economic importance in Thailand and can be grown in all regions of the country. Mango is mainly for domestic consumption and the rest is exported. The export volume and value of mangoes from Thailand increased respectively from 41,463 tons (1,027 million baht) in 2011 compared to 24,112 tons in 2010 worth 695 million baht, representing a 47.77 % growth rate. [1] The important export markets are Japan, Europe and America. Because of the nutritional and sensory qualities mangoes have become a favorite fruit for foreigners with export varieties such as Nam Dok Mai, Tongdum, Nung Glang Wan, Koh Rong and Rad but the major problems of mango during storage and export are weight loss, ripening during transport, and formation of brown spots resulting in decreased value. Therefore, identifying suitable coating compositions is key to extending the storage life and reduce post-harvest deterioration which required efficient and safe methods of fruit coating. [2] This research aimed to reduce the loss of productivity, give added value, extended the shelf-life and propagate the information that will help the farmers to select an appropriate coating.

Materials and methods

Materials

Aloe vera was taken from a local farm, Bangkla, Chachoengsao Province; chitosan from Seafresh Company and carnaubar wax from Honghuad Company Limited.

Preparing mangoes

Mango (*Mangifera indica* L.) 115 days old after flowering in March 2011 weight 300 - 350 g were selected from Bangkla, Chachoengsao Province. All of them were disease-free, with no wounds on the skin and mature at the same stage selected by using water floating and putting in 2 % brine. The fruits then were washed and air dried.

Coating method

Coating materials were prepared and used immediately. The mango fruits were dipped in the different coating materials for 30 s, air dried and weighed afterward. Then serial numbers were written on each of the mangoes and stored at the specified temperature.

Methodology

This study is a Completely Randomized Design (CRD) as follows.

Experiment 1: To determine the type and concentration of the appropriate coating materials the mangoes were divided into 3 groups, the first group was uncoated (control) (A1), solvent (water) (A2), 10 % *Aloe vera* jelly (A3), 20 % *Aloe vera* jelly (A4) and 40 % *Aloe vera* jelly (A5). The second group was treated with a series of chitosan, composed of uncoated (series control) (C1), solvent (acetic acid 0.5 %) (C2), 0.5 % chitosan (C3), 1.0 % chitosan (C4) and 1.5 % chitosan (C5). The last group was pretreated with a sequence of carnaubar wax including uncoated (control) (W1), solvent (triethanolamine 10 %) (W2), 2 % carnaubar wax (W3), 4 % carnaubar wax (W4), and 6 % carnaubar wax (W5). Each condition was tested using 3 mango fruits. The storage experiment was carried out at 25 °C (relative humidity. 75±5 %). The mangoes were inspected every 2 days for a total of 6 times or 12 days.

Experiment 2: After identifying the appropriate concentration of natural coating materials in experiment 1, we then further evaluated the effectiveness of coating materials by using 8 different treatments which comprised of uncoated (control) (T1), *Aloe vera* jelly 20 % (T2), 1 % chitosan (T3), 4 % carnaubar wax(T4), 20 % *Aloe vera* jelly + 1 % chitosan (T5), 20 % *Aloe vera* jelly + 4 % carnaubar wax (T6), 1 % chitosan + 4 % carnaubar wax (T7), 20 % *Aloe vera* jelly + 1 % chitosan + 4 % carnaubar wax (T8) and all treatments were stored at 25 °C (relative humidity 75±5 %) and 13 °C (relative humidity 90±5 %) measured every 2 days at 25 °C and every 4 days at 13 °C. The mangoes were evaluated every 2 days for a total of six times or 12 days.

Experiment 3: Natural material coating technology was disseminated to the community (90 farmers and exporters) in a mango product optimization project held by the Provincial Agricultural Office, Land Development Office, Cooperative Auditing Office, and Cooperative office, Chachoengsao Province on 13 June 2012 at Grand Royal Hotel, Muang district, Chachoengsao Province by using a training manual created by the researcher. A selection of participants for the training was performed by using purposive sampling.

Qualitative analysis

Experiment 1: Disease and storage life were analyzed by determining the number of mangoes affected with anthracnose by browning score which could be seen on mango skin. A browning score greater than 30 % was considered expired storage. Weight loss, changes of peel color and pulp color, firmness, titratable acidity (TA), total soluble solid (TSS) were observed to assess the overall acceptance by 8 trained testers. A nine point hedonic scale was accepted in this experiment [3]. The additional measurement in experiment 2 apart from experiment 1 was scoring the yellow peel of mangoes (0 point = 0 %, no yellow on the mango skin, 1 point = 1 - 25 %, 2 points = 26 - 50 %, 3 points = 51 - 57 %, 4 points = 76 - 100 %). Measurement of mango respiration in a closed system was also performed. Percentage and analysis of variance were calculated by considering the differences in all experiment aspects. When the difference was statistically significant at the confidence level of 95 percent, Duncan's New Multiple Range Test then was performed and a quality index of mango fruit on overall linking of consumer was analyzed by Principal Component Analysis: PCA. In experiment 3, the average of pre- and post-test scores were analyzed by using t-test.

Results and discussion

Experiment 1: Appropriate type and concentration of the coating materials

The disease, and storage life of mangoes in all series of experiments showed that the brown spot was found in mangoes coated with A4, C4 and W4 later than the other groups stored for 12 days (**Table 1**), indicating that the coating was a slow ripening agent as the unripe fruits are more disease resistant compared to the ripe fruit. [4] This might be due to the antibacterial activity of *Aloe vera* gel [5] or the antifungal properties of chitosan. [6] Carnaubar wax (4 %) gave the best result. The possible explanation maybe that too low a concentration was not enough for antibacterial activity and too high a concentration could inhibit anaerobic respiration thus increase susceptibility to the disease. Moreover, the coating limits the exchange of O_2 and increases CO_2, consequently slowing down the metabolism by inhibition of ethylene [7] resulting in a delay of mangoes ripening, destruction of mangoes by pathogens and making the storage life longer [8-10].

Table 1 Percentage of disease affected mangoes coating with various materials and stored at 25 °C (relative humidity 75±5 %).

Treatment	% Disease day 12	Treatment	% Disease day 12	Treatment	% Disease day 12
A1	70	C1	60	W1	60
A2	70	C2	60	W2	60
A3	60	C3	60	W3	40
A4	30	C4	30	W4	30
A5	50	C5	30	W5	50

Weight loss of mangoes in all treatments were time dependently increased. Mangoes coated with A4, C4 and W4 were found to lose weight less than the others, the A4 and C4 group that showed the minimal weight loss was only 5.23 and 4.94 % respectively on day 6 of storage while the W4 group had the minimal weight loss at 9.24 % on day 8 compared to the control group ($p \leq 0.05$) (**Table 2**). Transpiration of mangoes depend on the specific properties of coating materials which the replace natural wax and closed the opening pores. The limitation of gases diffusion resulted in a decreased respiratory rate and decreased mango weight loss [11,12]. Weight loss is directly related to the concentration of the coating materials, low concentrations gave less transpiration and gas exchange whereas high concentrations will limit gas exchange and decrease the tissue O_2 supply [7] resulting in changes in the smell and flavor of the mangoes.

The firmness of mangoes in all treatments decreased throughout the storage time. Mangoes coated with A4, C4 and W4 were found to decelerate this process significantly compared to the control ($p \leq 0.05$) with a firmness of 15.92, 23.93 kg/cm^2 for A4 and C4 group respectively on day 6 while a maximum firmness for the W4 group was 15.37kg/cm^2 on day 8 of storage (**Table 2**). The firmness of the fruits naturally decreased gradually when they ripened because pectin causes tight bonds in raw fruit changed to a smaller size and more water soluble resulting in loss of cell adhesion. The firmness was decreased when coated because of a limitation in O_2 diffusion resulting in a decrease in ethylene [7], because O_2 is involved in the process ethylene production and through activating enzymes is involved in cell wall degradation of the fruit resulting in soft tissue [13]. This makes the coating beneficial in decelerating firmness loss [14].

Titratable acidity (TA), and total soluble solids (TSS) of fruit in every series of experiments tended to vary inversely. While the amount of TA in all mangoes decreased, the TSS in the fruits increased through the harvest period. This means that when the storage period of mangoes was longer, ripe mangoes taste sweeter but less sour. Mangoes coated with A4, C4 and W4 were the best groups that could prevent the decline of TA and increase TSS, especially mangoes coated with A4 and C4 on day 6 of storage with a maximum amount of TA at 1.19 and 1.25 %, respectively, but the lowest amount of TSS at 21.57 and 17.94 % respectively. In addition, mangoes coated with W4 at day 8 of storage was shown to have 1.09 % of TA and 24.89 % of TSS which were significantly different compared to the control and other treatments ($p \leq 0.05$) (**Table 2**). This implied that the coating could delay the amount of TA and TSS in the fruit because the coating maintains a state of adaptation resulting in an increase of CO_2 which inhibits activity of ethylene thus delays ripening, and slow changes in the amount of TA in the vacuole. Most of the acids found in the fruit were citric acid and malic acid [15]. Moreover, coating could delay the decomposition of starch into sugar (glucose, fructose and sucrose), which was the majority composition of TSS [5]. This is consistent with the report of Luengwilai *et al*. that an increase in the amount of TSS in ripe fruit had a direct relationship with the decomposition of starch [16].

Table 2 Weight loss, firmness, TA and TSS of Nam Dok Mai mangoes with different coating materials and stored at 25 °C (relative humidity 75±5 %).

Treatment	Weight loss (%)	Firmness (kg/cm^2)	TA (%)	TSS (%)
	day 6	day 6	day 6	day 6
A1	8.12±0.94 ^{a}	14.10±0.27 ^{b}	0.69 ±0.16 ^{c}	26.83±0.53 ^{a}
A2	7.82±0.96 ^{a}	14.12±0.33 ^{b}	0.64 ±0.14 ^{c}	22.63±0.68 ^{c}
A3	7.10±0.95 ^{a}	14.88±0.82 ^{b}	1.00 ±0.17 ^{ab}	23.82±0.59 ^{b}
A4	5.23±0.93 ^{b}	15.92±0.51 ^{a}	1.19 ±0.25 ^{a}	21.57±0.62 ^{c}
A5	7.05±0.94 ^{a}	14.50±0.31 ^{b}	0.75 ±0.14 ^{bc}	24.55±0.50 ^{b}
C1	7.25±0.80 ^{a}	12.53±0.91 ^{e}	0.67 ±0.14 ^{c}	27.11±0.92 ^{a}
C2	6.79±0.77 ^{a}	13.57±0.94 ^{d}	0.95 ±0.11 ^{bc}	25.88±0.94 ^{a}
C3	6.31±0.92 ^{a}	16.26±0.93 ^{c}	1.11 ±0.19 ^{a}	20.40±0.95 ^{b}
C4	4.94±0.62 ^{b}	23.93±1.04 ^{a}	1.25 ±0.10 ^{ab}	17.94±1.06 ^{c}
C5	6.93±0.60 ^{a}	19.19±0.93 ^{b}	1.08 ±0.13 ^{ab}	20.07±0.96 ^{b}
	day 8	day 8	day 8	day 8
W1	10.60±0.92 ^{a}	12.43±0.92 ^{b}	0.37±0.16 ^{b}	33.46±0.93 ^{a}
W2	9.96±1.06 ^{ab}	12.61±0.93 ^{b}	0.68±0.28 ^{ab}	27.96±1.03 ^{b}
W3	9.63±0.95 ^{ab}	12.50±0.92 ^{b}	0.80±0.21 ^{ab}	28.86±0.96 ^{b}
W4	9.24±0.92 ^{b}	15.37±0.92 ^{a}	1.09±0.29 ^{a}	24.89±0.92 ^{c}
W5	9.55±0.90 ^{ab}	12.79±0.93 ^{b}	0.78±0.21 ^{ab}	28.79±0.92 ^{b}

Numbers followed by a letter in the column represent a statistical significance of the mean comparison according to Duncan's New Multiple Range Test ($p \leq 0.05$).

Changes in mangoes peel color and pulp color in all experiments increased according to the L*, a* and b* of mangoes peel color increased while the L* of mangoes pulp color decreased, but the a* and b* of the pulp color increased when stored for a longer time. Changes in L*, a*, and b* in the non-coated group were higher than the coated groups. Mangoes of the A4, C4 and W4 groups gave the best result in slowing the changes of L*, a* and b* of the peel and pulp color. On day 6, mangoes coated with A4 and C4 had the lowest values of L*, a* and b* with L* = 63 and 61.08, a* = −10.56 and −10.88, b* = 27.43 and 26.90, respectively. While the highest L* = 74.12 and 73.53 respectively, but a* = −3.45 and -3.28 respectively, b * = 34.45 and 34.82 respectively. Mangoes coated with W4 has lowest value of L*, a* and b* with L* = 62.61, a* = −10.32 and b* = 26.42. While the L* value was 72.21 but the lowest a* and b* values were −2.38 and 36.58 respectively. Overall, there were significant differences between L*, a* and b* values of peel and pulp color of mangoes on day 6 and 8 ($p \leq 0.05$) (**Table 3**). This indicated that coating with natural materials could delay color changes from green to yellow. This was because of an increase synthesis of carotenoids during the ripening of fruit and the decomposition of chlorophyll by ethylene [13] and the enzyme chlorophyllase activity [17,18]. The coating materials could restrict O_2 exchange and increase CO_2 production and inhibit ethylene activity which is fruit ripening hormone [19,20].

Table 3 L*, a* and b* values of the peel color and pulp color of Nam Dok Mai mangoes when coated with different materials and then stored at 25 °C (relative humidity 75±5 %).

Treatment	Peel color			Pulp color		
	L*	a*	b*	L*	a*	b*
	day 6	day 6	day 6	day 6	day 6	day 6
A1	72.02±1.67 ^{a}	-9.35±0.35 ^{ab}	30.43±0.97 ^{a}	70.75±1.16 ^{b}	-2.14±0.26 ^{a}	36.14±0.48 ^{a}
A2	70.00±1.03 ^{a}	-9.12±0.45 ^{a}	30.22±0.51 ^{a}	71.34±0.85 ^{b}	-2.44±0.33 ^{a}	36.31±0.37 ^{a}
A3	66.41±1.05 ^{b}	-10.00±0.45 ^{bc}	27.80±0.93 ^{b}	72.49±0.84 ^{ab}	-3.33±0.33 ^{b}	35.49±0.47 ^{a}
A4	63.00±1.75 ^{c}	-10.56±0.21 ^{c}	27.43±0.96 ^{b}	74.12±0.59 ^{a}	-3.45±0.49 ^{b}	34.45±0.45 ^{b}
A5	66.48±1.08 ^{b}	-10.02±0.32 ^{bc}	29.21±0.72 ^{ab}	72.62±0.72 ^{ab}	-2.91±0.47 ^{ab}	35.57±0.55 ^{a}
C1	70.41±0.95 ^{a}	-9.47±0.41 ^{a}	30.67±0.42 ^{a}	70.97±1.07 ^{c}	-2.27±0.30 ^{a}	37.86±0.95 ^{a}
C2	67.09±0.97 ^{b}	-10.12±0.41 ^{b}	28.81±0.41 ^{b}	70.97±1.03 ^{c}	-2.35±0.33 ^{a}	36.32±0.94 ^{b}
C3	64.51±0.89 ^{b}	-10.15±0.47 ^{b}	28.35±0.45 ^{b}	72.50±0.95 ^{ab}	-2.72±0.34 ^{ab}	35.91±0.97 ^{b}
C4	61.08±0.97 ^{d}	-10.88±0.39 ^{c}	26.90±0.84 ^{c}	73.53±1.02 ^{a}	-3.28±0.33 ^{b}	34.82±0.94 ^{c}
C5	64.09±0.61 ^{c}	-10.11±0.22 ^{b}	28.84±0.45 ^{b}	72.45±0.86 ^{ab}	-2.67±0.29 ^{a}	36.82±0.94 ^{b}
	day 8	day 8	day 8	day 8	day 8	day 8
W1	67.86±0.92 ^{a}	-9.10±0.36 ^{a}	32.29±0.92 ^{a}	67.11±0.92 ^{c}	-1.64±0.31 ^{a}	39.71±0.96 ^{a}
W2	65.28±0.95 ^{b}	-9.40±0.35 ^{ab}	27.37±0.90 ^{bc}	67.81±0.92 ^{c}	-1.89±0.37 ^{ab}	37.74±0.92 ^{bc}
W3	64.18±0.92 ^{c}	-9.59±0.28 ^{ab}	27.84±0.92 ^{bc}	70.57±0.91 ^{ab}	-2.04±0.31 ^{abc}	38.08±0.93 ^{b}
W4	62.61±0.93 ^{d}	-10.32±0.34 ^{c}	26.42±0.92 ^{c}	72.21±0.92 ^{a}	-2.38±0.35 ^{c}	36.58±0.93 ^{c}
W5	64.12±0.92 ^{c}	-9.83±0.27 ^{bc}	28.26±0.92 ^{b}	70.01±1.03 ^{b}	-2.19±0.17 ^{bc}	38.41±0.93 ^{ab}

Numbers followed by a letter in the column represent a statistical significance of the mean comparison according to Duncan's New Multiple Range Test ($p \leq 0.05$).

Overall acceptance of mangoes in all treatments showed an increasing tendency along with the storage life and decreased again when the mangoes came to deterioration stage. Mangoes coated with A4, C4 and W4 was effective in helping to maintain the best quality, especially mangoes coated with A4 and C4 on day 6 of storage and mangoes coated with W4 at day 8 of storage. Overall the acceptance score did not significantly differ from the control group ($p > 0.05$) (**Table 4**). We found that on the 10th day of storage, mangoes in groups A4, C4 and W4 had an overall acceptance score at 7.96, 7.50 and 7.60, respectively (**Table 4**). The concentration of the coating materials also affects the quality of the fruit [8], with a low concentration of materials or too thin a coating allowing transpiration and more O_2 exchange while a high concentration or too thick a coating causing materials to waste due to a lack of O_2 thus causing an accumulation of acetaldehyde and ethanol by anaerobic respiration causing a fermented smell and taste disorders [21]. This was not acceptable to the taste which is consistent with the report of Kaswija *et al*. that the factors that affect the inclination of consumers to mangoes was the texture [22].

Table 4 The overall acceptance of Nam Dok Mai mangoes when coated with different materials and then stored at 25 °C (relative humidity 75±5 %).

Overall acceptance (score) of mangoes when coated with different storage time (day)								
Treatment	**day 6**	**day 10**	**Treatment**	**day 6**	**day 10**	**Treatment**	**day 8**	**day 10**
A1	7.97±1.05 a	ND	C1	7.80±0.77 a	ND	W1	7.30±0.80 a	ND
A2	5.66±1.14 b	ND	C2	4.15±0.89 c	ND	W2	6.37±0.84 ab	ND
A3	4.96±0.98 b	ND	C3	6.34±0.89 ab	ND	W3	5.41±0.97 b	6.01±1.05
A4	7.57±0.88 a	7.96±1.32	C4	7.17±0.87 a	7.50±1.41	W4	7.43±0.84 a	7.60±1.62
A5	5.32±0.92 b	7.77±1.06	C5	4.90±0.94 bc	6.23±1.82	W5	6.34±0.94 ab	5.40±1.71

Numbers followed by a letter in the column represent a statistical significance of the mean comparison according to Duncan's New Multiple Range Test ($p \leq 0.05$).

Experiment 2: The results of each type of coating materials on postharvest quality

We found that storing mangoes at 25 °C (relative humidity 75±5 %) caused more disease (brown spots) than keeping groups at 13 °C (relative humidity 90±5 %). Mangoes coated with T5 could slow down the disease with storage life of 12 days at 25 °C and 28 days at 13 °C (**Table 5**). This indicated that the temperature was the most important factor, high temperatures catalyzed and sped up the ripening rate, respiratory rate, and caused damage easily [17]. It has been reported that *Aloe Vera* jelly helps to decelerate the disease in mangoes [23], to protect mangoes against pathogens and increase storage life. In addition, it may be the result of a combination with chitosan which could stimulate phytoalexin anti-fungal [5,24] and also inhibit deep skin cracks from incisional wounds [20], resulting in inhibition of fungal growth in mangoes.

Table 5 Disease of Nam Dok Mai Mangoes when coated with different materials and stored at 25 °C (relative humidity 75±5 %) and 13 °C (relative humidity 90±5 %).

Treatment	**Disease (%) of mangoes when coated with different storage time (day)**	
	25 °C (day 12)	**13 °C (day 28)**
T1	70	70
T2	30	40
T3	30	40
T4	30	40
T5	30	30
T6	60	50
T7	60	50
T8	40	50

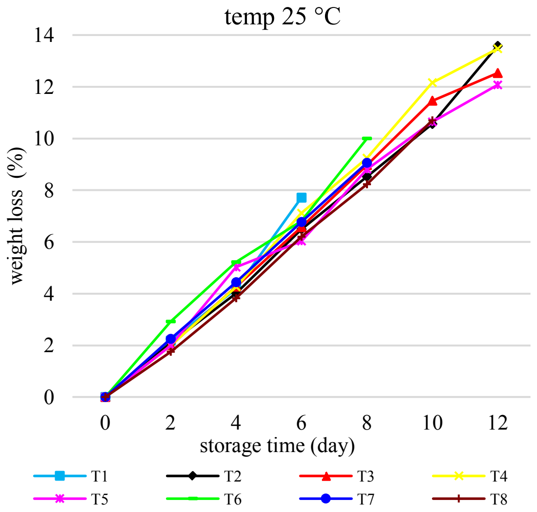
Weight losses of mangoes in all treatments were raised and have similar values when stored longer. Mangoes stored at 25 °C have more weight loss than the fruits stored at 13 °C as shown in **Figures 1a** and **1b**. Mangoes coated with T5 gave the best result in slowing weight loss, especially on day 6 of storage at 25 °C with weight loss less than 6.03 %, and on the 20th day of storage at 13 °C with weight loss less than 6.70 %, which were less than the weight loss in non-coated and other treatments ($p \leq 0.05$) (**Table 6**). Because weight loss of the fruit is mostly due to water loss and at 25 °C the relative humidity was lower than at 13 °C, consequently the difference in the relative humidity and vapor pressure between the water inside the mango and the surrounding air in 25 °C group is more than at 13 °C, resulting in moving of water from inside mangoes to the air faster. Therefore, the mangoes stored at 25 °C lost more weight than fruits stored at 13 °C [25,26].

The firmness of mangoes in all treatments decreased when stored longer. Mangoes stored at 25 °C ripened more quickly and the firmness was lower than those stored at 13 °C as shown in **Figures 1c** and **1d**. Mangoes in T5 showed the greatest slowing of loss of firmness; especially on day 6 of storage at 25 °C with a firmness of 20.22 kg/cm^2 and on the 20th day at 13 °C a firmness of 14.39 kg/cm^2 compared to the control ($p \leq 0.05$) (**Table 6**). Because the insoluble pectin was in the form of protopectin the fruit was not yet ripe. When the fruit began to ripen, insoluble pectin was reduced while a soluble form of pectin, galacturonic acid, increased. There were 2 types of enzyme pectin methylesterase (pectinesterase) and polygalacturonase [27] that caused the unsterification reaction which separate-CH_3 groups and depolymerization reaction which shorten the length of the polymers. High temperature was the main factor for those enzymes activation thus inducing softness of ripe fruit.

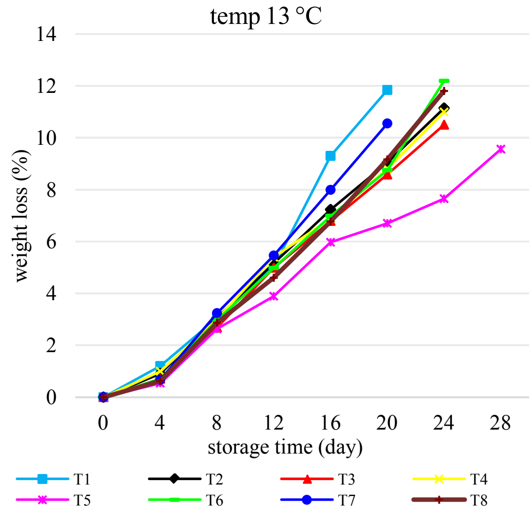
TA and TSS content of fruit in all treatments showed an opposite trend, the amount of TSS increased while the amount of TA decreased. Mangoes stored at 25 °C has lower TA but higher TSS than those kept at 13 °C as shown in **Figures 1e - 1h**. Mangoes coated with T5 could slow down the decrease of TA and delay an increase of TSS more than the other groups, especially on day 6 of storage at 25 °C with TA about 1.32 %, and TSS at 20.37 %, whereas the amount of TA was 0.88 % and TSS was 26.81 % on day 20 of storage at 13 °C ($p \leq 0.05$) (**Table 6**). Because higher temperatures stimulate breathing and metabolism of plants thus the disintegration of the TA, the substrate of breathing, increased at higher temperatures [17,28]. Higher temperatures can also stimulate the change of starch into sugar which was the largest component of TSS that increased. Coating could slow down breathing resulting in a delayed decrease of TA [19,20] and TSS increased slowly especially at low temperature [29].

It was shown that changes in peel and pulp color of the mangoes stored at 25 °C were more rapid than those stored at 13 °C. Mangoes coated with T5 can slow the change of L*, a* and b* of mangoes peel color compared to the control and other groups ($p \leq 0.05$), especially on day 6 of storage at 25 °C with the L*, a* and b* at 62.58, −10.59 and 27.18, respectively. The highest L* was 74.48 but the lowest a* and b* were −3.01 and 36.04, respectively. Moreover, on the 20th day of storage at 13 °C, the L*, a* and b* of the mangoes peel color were 63.40, −9.81 and 29.25, respectively, with the highest L* value of 72.67 and the lowest a* and b* values of −2.46 and 36.57 respectively (**Table 7**). Researchers have found that higher temperatures can accelerate the synthesis of carotenoids by the enzyme phosphatase and increase the decomposition of chlorophyll by chlorophyllase enzymes [27,30].

We also showed that the respiratory rate of the fruit in all treatments rose during the early phase and decreased in the late phase when the mango came into the deterioration stage. Mangoes stored at 25 °C had a higher respiratory rate than those stored at 13 °C as seen in **Figures 1i** and **1j**. Mangoes coated with T5 were the most effective in slowing down the respiratory rate compared to the control ($p \leq 0.05$) (**Table 8**). On day 6, mangoes coated with T5 and stored at 25 °C had a minimal respiratory rate of 89.66 mg.CO_2/kg.hr and on the 20th day of storage at 13 °C had a minimal respiratory rate of 28.65 mg.CO_2/kg.hr because mango is a climacteric fruit in which the respiration rate increases when ripe [31]. Fruit respiration is a process controlled by several enzymes, thus storage at low temperatures was an effective method to decelerate biochemical processes and extend the storage life of fruit. Because the coating is made of semipermeable films on the fruit skin this resulted in a modified atmosphere by reducing the respiratory rate and slowed down the physical and chemical changes [32,33].


temp 25 °C
weight loss (%)
0
2
4
6
8
10
12
14
storage time (day)
T1
T2
T3
T4
T5
T6
T7
T8

(a)


temp 13 °C
weight loss (%)
0
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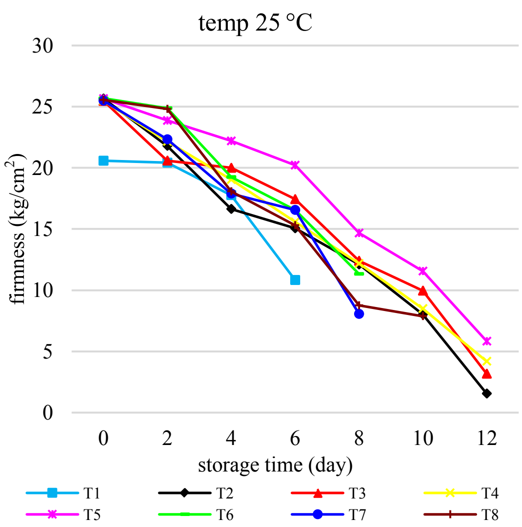
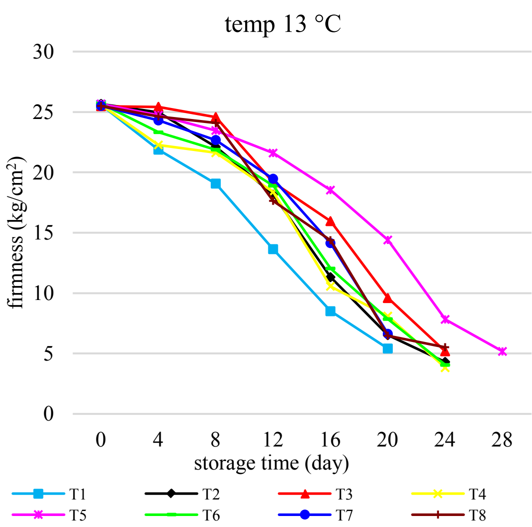
28
storage time (day)
T1
T2
T3
T4
T5
T6
T7
T8

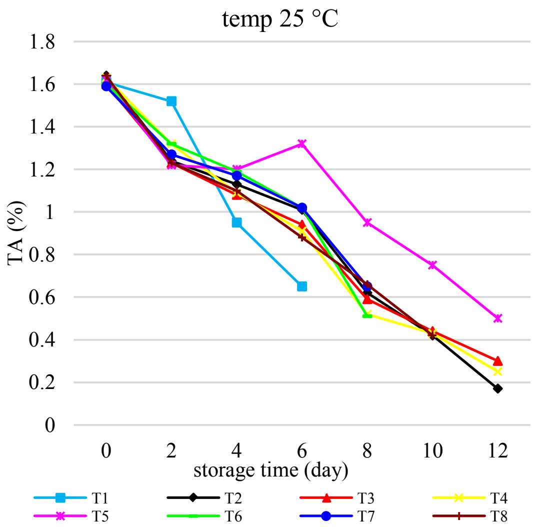
(b)


temp 25 °C
firmness (kg/cm2)
0
5
10
15
20
25
30
storage time (day)
T1
T2
T3
T4
T5
T6
T7
T8

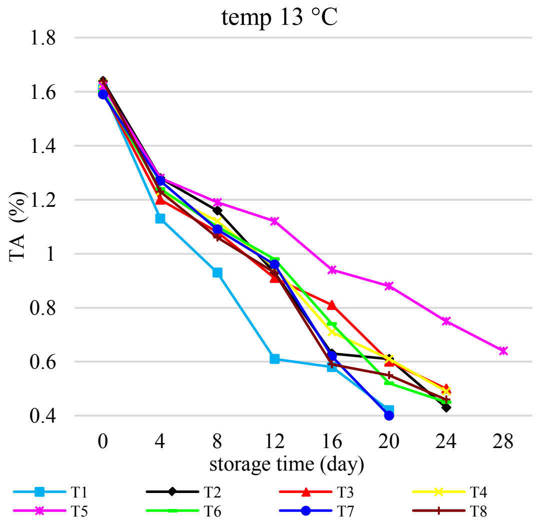
(c)


temp 13 °C
firmness (kg/cm2)
0
5
10
15
20
25
30
storage time (day)
T1
T2
T3
T4
T5
T6
T7
T8

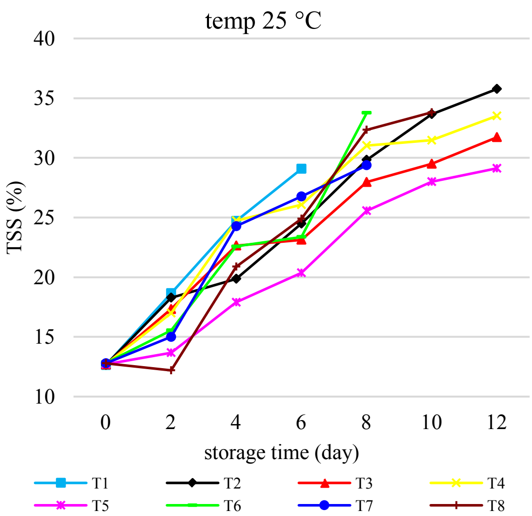
(d)


temp 25 °C
TA (%)
storage time (day)
T1 T2 T3 T4 T5 T6 T7 T8

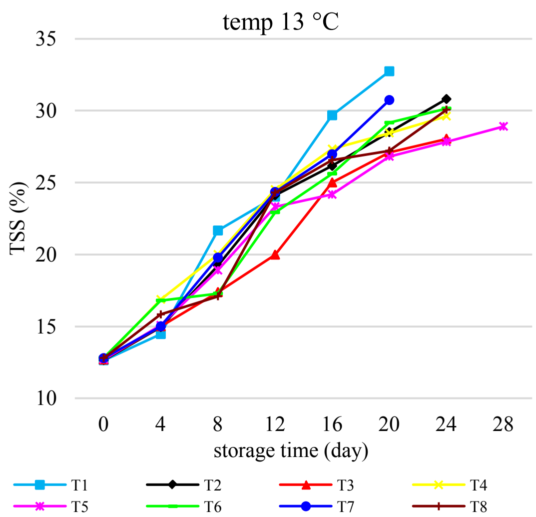
(e)


temp 13 °C
TA (%)
storage time (day)
T1 T2 T3 T4 T5 T6 T7 T8

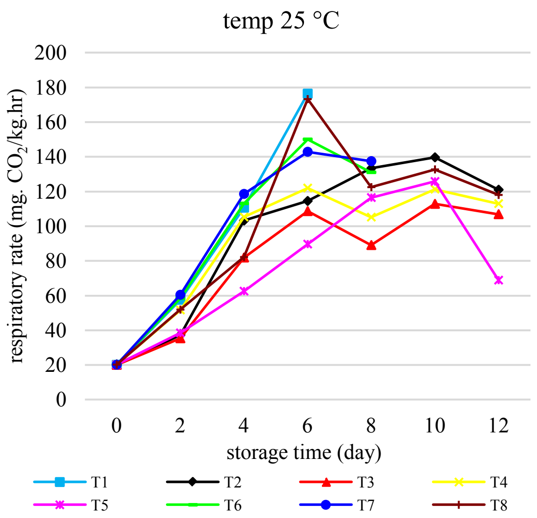
(f)


temp 25 °C
TSS (%)
storage time (day)
T1 T2 T3 T4 T5 T6 T7 T8

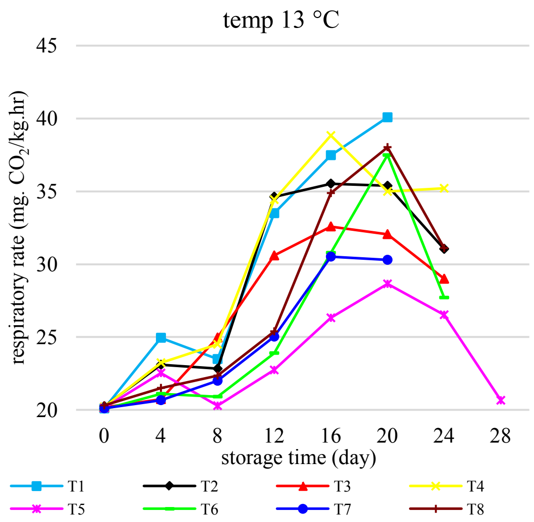
(g)


temp 13 °C
TSS (%)
storage time (day)
T1 T2 T3 T4 T5 T6 T7 T8

(h)



(i)



(j)

Figure 1 Weight loss (a) and (b), firmness (c) and (d), TA (e) and (f), TSS (g) and (h) and respiratory rate (i) and (j) of Nam Dok Mai mango when coated with the different materials and stored at 25 °C (relative humidity 75±5 %) and 13 °C (relative humidity 90±5 %).

Table 6 Weight loss, texture (firmness), titratable acid (TA) and total soluble solids (TSS) of Nam Dok Mai mango when coated with different materials and stored at 25 °C (relative humidity 75±5 %) and 13 °C (relative humidity 90±5 %).

Treatment	Storage at 25 °C (Relative humidity 75±5 %)			
	Weight loss (%)	Firmness (kg/cm^2)	TA (%)	TSS (%)
	day 6	day 6	day 6	day 6
T1	7.64 ±1.18^{a}	10.83±1.07^{e}	0.65 ±0.76^{c}	29.08 ±1.15^{a}
T2	6.49 ±0.93^{bc}	15.06 ±1.07^{d}	1.01 ±0.76^{ab}	24.49 ±0.95^{cde}
T3	6.57 ±1.31^{bc}	17.44 ±1.37^{b}	0.94 ±0.53^{bc}	23.14 ±1.08^{e}
T4	7.11 ±1.05^{ab}	15.58 ±0.87^{cd}	0.91 ±0.88^{bc}	26.07 ±0.98^{bc}
T5	6.03 ±1.25^{c}	20.22 ±0.89^{a}	1.32 ±0.51^{a}	20.37 ±0.96^{f}
T6	6.81 ±0.75^{abc}	16.55 ±1.20^{bc}	1.02 ±0.64^{ab}	23.38 ±1.08^{de}
T7	6.76 ±1.03^{abc}	16.56 ±1.27^{bc}	1.02 ±0.39^{ab}	26.76 ±1.24^{b}
T8	6.19 ±1.42^{bc}	15.31 ±0.80^{d}	0.88 ±0.37^{bc}	24.90 ±0.91^{cd}
Treatment	Storage at 13 °C (Relative humidity 90±5 %)			
	Weight loss (%)	Firmness (kg/cm^2)	TA (%)	TSS (%)
	day 20	day 20	day 20	day 20
T1	11.84 ±0.93^{a}	5.40 ±1.09^{d}	0.42 ±0.50^{b}	32.73 ±1.03^{a}
T2	9.04 ±0.95^{bc}	6.51 ±1.45^{cd}	0.61 ±0.39^{b}	28.50 ±1.16^{c}
T3	8.58 ±0.93^{c}	9.58 ±1.11^{b}	0.60 ±0.55^{b}	27.09 ±1.15^{d}
T4	8.81 ±1.03^{bc}	8.09 ±1.43^{bc}	0.61 ±0.49^{b}	28.44 ±0.90^{c}
T5	6.70 ±0.98^{d}	14.39 ±1.15^{a}	0.88 ±0.42^{a}	26.81 ±1.24^{d}
T6	8.75 ±0.94^{bc}	7.84 ±1.18^{c}	0.52 ±0.64^{b}	29.16 ±1.00^{c}
T7	10.55 ±0.93^{ab}	6.62 ±1.35^{cd}	0.40 ±0.46^{b}	30.73 ±1.23^{b}
T8	9.16 ±0.95^{bc}	6.46 ±1.74^{cd}	0.55 ±0.51^{b}	27.21 ±0.90^{d}

Numbers followed by a letter in the column represent a statistical significance of the mean comparison according to Duncan's New Multiple Range Test ($p \leq 0.05$).

Table 7 L*, a* and b* values of the peel and pulp color of Nam Dok Mai mango when coated with the different materials and stored at 25 °C (relative humidity 75±5 %) and 13 °C (relative humidity 90±5 %).

Treatment	Storage at 25 °C (Relative humidity 75±5 %)					
	Peel color			Pulp color		
	L*	a*	b*	L*	a*	b*
	day 6	day 6	day 6	day 6	day 6	day 6
T1	70.94±1.06^{a}	-9.06±0.45^{a}	30.20±0.66^{a}	70.81±0.93^{d}	-1.90±0.66^{a}	38.64±0.82^{a}
T2	67.74±0.76^{bc}	-9.45±0.41^{ab}	29.01±0.36^{ab}	73.53±1.43^{abc}	-2.24±0.36^{abc}	37.44±0.69^{ab}
T3	66.52±0.82^{d}	-10.19±0.32^{cd}	28.82±0.33^{ab}	73.01±1.33^{abcd}	-2.80±0.33^{cd}	38.18±0.76^{ab}
T4	66.79±0.95^{cd}	-9.77±0.34^{bc}	29.05±0.65^{ab}	72.82±1.26^{abcd}	-2.64±0.65^{bcd}	37.23±0.56^{bc}
T5	62.58±0.56^{f}	-10.59±0.41^{d}	27.18±0.41^{c}	74.48±1.08^{a}	-3.01±0.41^{d}	36.04±0.73^{c}
T6	64.70±0.87^{e}	-10.12±0.63^{bcd}	28.53±0.31^{b}	74.01±1.09^{ab}	-2.62±0.31^{bcd}	37.02±0.48^{bc}
T7	68.23±0.88^{b}	-9.95±0.54^{bcd}	29.30±0.48^{ab}	71.32±0.99^{cd}	-2.67±0.48^{bcd}	37.93±0.91^{ab}
T8	65.96±0.64^{d}	-9.66±0.34^{abc}	28.90±0.24^{ab}	71.77±1.07^{bcd}	-2.15±0.24^{ab}	37.51±0.57^{ab}
Treatment	Storage at 13 °C (Relative humidity 90±5%)					
	Peel color			Pulp color		
	L*	a*	b*	L*	a*	b*
	day 20	day 20	day 20	day 20	day 20	day 20
T1	73.59±1.09^{a}	-8.88±0.40^{a}	33.79±0.63^{a}	67.53±1.31^{d}	-0.97±0.32^{a}	39.59±0.86^{a}
T2	70.52±1.03^{b}	-9.39±0.65^{abc}	29.97±0.86^{cd}	70.98±1.00^{b}	-1.61±0.36^{ab}	37.76±0.73^{bc}
T3	65.05±1.20^{e}	-9.63±0.45^{bc}	31.19±0.89^{bc}	70.77±0.98^{b}	-1.96±0.51^{bc}	37.29±0.92^{bc}
T4	66.86±0.92^{d}	-9.58±0.31^{abc}	30.09±0.97^{cd}	69.73±1.05^{bc}	-1.75±0.43^{b}	38.52±0.87^{ab}
T5	63.40±1.13^{f}	-9.81±0.63^{c}	29.25±1.08^{d}	72.67±1.42^{a}	-2.46±0.42^{c}	36.57±0.77^{c}
T6	70.52±1.08^{b}	-9.61±0.59^{bc}	32.83±1.01^{ab}	68.91±1.25^{cd}	-1.39±0.56^{ab}	38.72±0.97^{ab}
T7	67.80±1.31^{cd}	-9.00±0.53^{ab}	30.61±0.98^{cd}	68.51±0.99^{cd}	-2.01±0.35^{bc}	37.84±0.84^{bc}
T8	68.55±1.11^{c}	-9.71±0.45^{bc}	30.95±0.91^{cd}	68.51±1.32^{cd}	-1.43±0.11^{ab}	38.63±1.00^{ab}

Numbers followed by a letter in the column represent a statistical significance of the mean comparison according to Duncan's New Multiple Range Test ($p \leq 0.05$).

Overall acceptance of any mangoes series of experiments:

The result showed that the acceptance score was higher when stored longer at both storage temperatures. Mangoes stored at 25 °C had an overall acceptance that was higher than that stored at 13 °C, especially on day 6 of storage at 25 °C and on day 20 of storage at a 13 °C where it was found that mangoes coated with all coating materials and at all concentrations had no different acceptance scores compared to the control ($p > 0.05$) (**Table 8**). All different concentrations of T5 coated mangoes preserved the quality of the fruit better than other coatings with a score of 7.50 on day 10 storage at 25 °C and 6.62 on day 28 storage at 13 °C. This could be explained by the increase in temperature which accelerates the maturing of mangoes or changes in starch to sugar, production of scent and flavor resulting in an increase in the acceptance score when stored at 25 °C compared to those stored at 13 °C. As a result, the mangoes stored at 13 °C took longer to mature but this did not impact the quality of the mango fruit and the skin turned yellow as normal by day 10 of storage at 25 °C and day 28 of storage at 13 °C with a peel color score of 3.20 and 3.60 respectively (**Table 9**), so the coating helps extend the storage life [8,34,35].

Table 8 Respiratory rate, peel color score and overall acceptance score of Nam Dok Mai mango when coated with different materials and stored at 25 °C (relative humidity 75±5 %) and 13 °C (relative humidity 90±5 %).

TRT	Respiratory rate ($mg.CO_2$/ kg.hr)		Peel color changes score				Acceptance score			
	25 °C	13 °C	25 °C		13 °C		25 °C		13 °C	
	(day 6)	(day 20)	(day 6)	(day 10)	(day 20)	(day 28)	(day 6)	(day 10)	(day 20)	(day 28)
T1	176.38±2.02 ^{a}	40.08±0.98 ^{a}	3.20±0.43^{b}	ND	3.30±0.76^{a}	ND	4.91±0.66	ND	7.44±0.39	ND
T2	114.52±2.98 ^{c}	35.38±0.87^{c}	2.80±0.41^{b}	3.54±0.43	2.45±0.57^{abc}	ND	6.75±0.50	6.37±0.63	6.23±0.44	5.50±0.52
T3	108.67±1.56 ^{c}	32.06±0.96^{d}	1.05±0.61^{cd}	2.20±0.64	1.45±0.52^{cd}	ND	5.78±0.49	6.87±0.69	6.34±0.64	5.62±0.61
T4	121.99±1.87 ^{c}	34.99±0.79 ^{c}	1.25±0.52^{cd}	3.23±0.65	1.90±0.73^{bcd}	ND	6.33±0.46	6.87±0.71	7.34±0.58	5.12±0.55
T5	89.66±2.23 ^{d}	28.65±0.94^{f}	1.85±0.54^{d}	3.20±0.45	1.00±0.64^{d}	3.6±0.41	4.52±0.39	7.50±0.58	7.23±0.59	6.62±0.49
T6	150.06±2.41 ^{b}	37.49±0.98^{b}	3.65±0.55^{ab}	ND	2.45±0.40^{abc}	ND	5.08±0.32	ND	7.23±0.70	ND
T7	142.87±2.44 ^{b}	30.30±0.85^{e}	4.00±0.45^{a}	ND	2.80±0.63^{ab}	ND	6.53±0.44	ND	7.45±0.49	ND
T8	173.22±2.59 ^{a}	38.03±0.82^{b}	1.80±0.56^{c}	ND	2.15±0.76^{abc}	ND	6.85±0.51	7.36±0.72	6.45±0.57	ND

Numbers followed by a letter in the column represent a statistical significance of the mean comparison according to Duncan's New Multiple Range Test ($p \leq 0.05$).

Principal Component Analysis; PCA could classify 2 groups of Principal Component (temp 25 °C and temp 13 °C) and can explain the variable 47.04 % (F1 29.62 and F3 17.43 %). The liking of quality indexes at 25 °C showed that the odor was closest to the directive of overall liking (same as 13 °C), texture and flavor respectively. Another quality indexes of liking at 13 °C were pulp color, texture and flavor respectively (**Figure 2**).

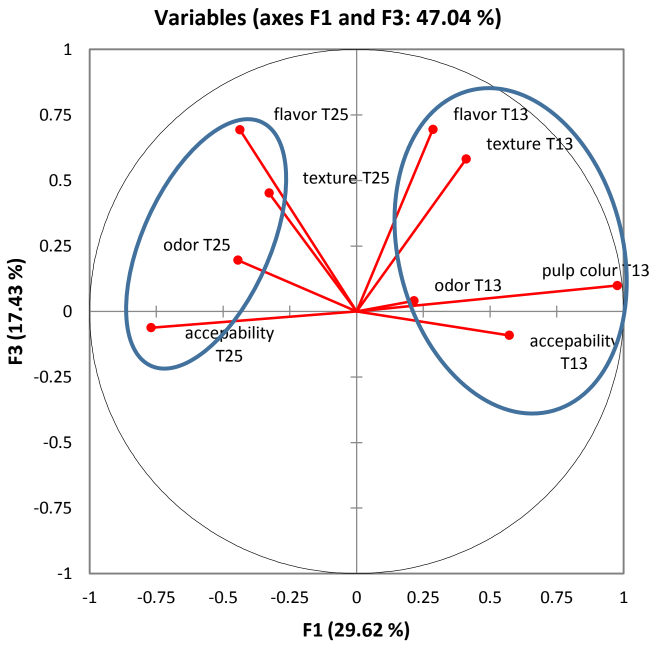


Figure 2 Correlation of principal component analysis at 25 °C and 13 °C.

Experiment 3: Results of the coating technology propagation.

The analyzes of the achievement, cognitive skills, awareness and attitudes before and after training from the training manual created by the researcher showed that after training the score was higher than the pre-test score. When analyzed by using a t-test we found that the post-test score was significantly higher than the pre-test score ($p \leq 0.05$) (**Table 9**). This indicated that training helps farmers and exporters to improve cognitive skills and attitudes. We delivered what we found to farmers and exporters by reading, lectures and practice and learn from scenarios and real situations and discussion. The participants cooperated in the implementation of activities as well as taking pleasure in learning as shown in **Figure 3**: a) the technology dissemination activities, opened by the governor, b) many games were integrated with the training, c) group discussion between farmers and exporters after training and watching a video, d) showing the use of natural coating materials by the experts, e) the farmers practicing after training and, f) discussion and conclusion among the experts, the farmers, and the exporters. The training budget was not much and did not take much time. Moreover, the trainees could use the knowledge immediately after training [36,37]. In addition, the training manuals helped farmers and exporters to be aware of the problem after the harvest, skills in the use of natural coatings, attitudes and enthusiasm to cooperate in solving and preventing problems, confidence in using natural coatings and reducing the yield loss. This will lead to an increase in value and prolong the storage life of mangoes.

Table 9 Comparison of the achievement, cognitive skills, awareness and attitudes before and after training.

Training interval	***n***	$\overline{X}$	***S.D.***	***t-test***	***P-value***
Before training	90	3.93	0.69	55.315*	0.001
After training	90	7.97	0.45		

*means a significant difference ($p \leq 0.05$).

(a) (b) (c) (d) (e) (f)

Figure 3 The participants cooperate in the implementation of activities as well as pleasure to learn.

Conclusions

Coating of Nam Dok Mai mangoes with 3 types of coating materials at different concentrations and temperature storage at 25 °C (relative humidity 75±5 %) indicated that A4, C4 and W4 could slow down the disease and prolong storage life for 12 days, delayed weight loss, changed the peel color, pulp color, texture and firmness and changed the chemical composition such as TA and TSS significantly compared to the uncoated (control), and other treatments ($p \leq 0.05$). Mangoes coated with T5 and stored at 25 °C were the best conditions to slow the disease found in mangoes by prolonging the storage period to 12 days, slow weight loss, changes in peel color and pulp color, firmness, TA, TSS and respiratory rate significantly compared to uncoated (control) and other treatments ($p \leq 0.05$). The same result could be found in mangoes coated with T5 and stored at 13 °C prolonging the storage life at 28 days. The acceptance score was not different from the control ($p > 0.05$) and the use of natural coating materials had no negative impacts on the quality of the mangoes when ripe. The propagation of technology to farmers and exporters using the training manuals created by testing before and after training showed that farmers and exporters developed skills, knowledge, awareness and attitudes in the use of natural coating significantly ($p \leq 0.05$).

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