Chapter 4

Results and Discussion

4.1 Chemical compositions of peel and flesh of Nam Dok Mai Si Thong mango

Chemical compositions of peel and flesh of Nam Dok Mai Si Thong mango in the first day of experiment were shown in Table 4.1.

Table 4.1 Chemical compositions of peel and flesh of Nam Dok Mai Si Thong mango.

Chemical composition (wet weight percentage)	Peel	Flesh
water content	71.51^{a}	82.54^{b}
Protein	1.13^{a}	0.60^{b}
Fat	0.18^{a}	0.07^{b}
Ash	1.03^{a}	0.32^{b}
Carbohydrate	26.14^{a}	16.46^{b}

[x]Different letters within treatment denote significant different by using DMRT at $p \leq 0.05$

In Table 4.1, the chemical compositions between the peel and flesh differed as evidence from the higher moisture content of the latter. This was due to the fact that mango flesh consisted of parenchyma cells whose vacuoles were relatively large with various chemicals in the solution form. The role of vacuole was to store various chemicals and maintain water balance in the cells. Thus the mango flesh had a higher moisture content than the peel. Because of the majority of cells found on the peel were epidermis with lipid compounds coating, the higher lipid contents in the peel was thus not unexpected (Techaphinyawat, 2001, Boonyakiat, 2001).

Each variety of mango had different chemical compositions such as Chok Anan contained higher moisture content, lipid, ash and carbohydrate than Nam Dok Mai Si Thong (Panuson, 2005). Besides variety, weather condition, preharvest management and cultivation area also played important factors (Whangchai, 2000; Ketsa, 1995).

When the comparison was made with other mango variety, Nam Dok Mai Si Thong had a similar chemical composition to Nang Klang Wan which was also consumed ripe (Table 4.2; Department of Industrial Promotion, 2001). Besides the chemical compositions mentioned previously, mango still provided other nutrition values that were necessary to the normal body function such as vitamin B, C and essential minerals. The comparison with foreign mango such as Haden variety indicated that ripe Thai mango had a higher nutrition value than the foreign one (Table 4.3).

Table 4.2 Chemical compositions of green and ripe mangoes of different variety.

Percentage	Ripe/green	Variety			
		Kaew	**Nang Klang Wan**	**Sam Phee**	**Talarb Nak**
Water content	Green	85.02	83.18	85.51	84.86
	Ripe	83.71	82.79	83.71	85.04
Fiber	Green	0.63	0.44	0.69	0.46
	Ripe	0.049	0.48	0.82	0.40
Protein	Green	0.47	0.77	0.82	0.58
	Ripe	0.52	0.71	0.55	0.44
Fat	Green	0.07	0.10	0.13	0.12
	Ripe	0.09	0.12	0.05	0.07
Ash	Green	0.31	0.49	0.48	0.24
	Ripe	0.30	0.31	0.39	0.19
Carbohydrate	Green	14.11	15.46	13.05	14.19
	Ripe	15.35	16.04	15.29	14.25
Degree Brix	Green	3.2	4.0	3.4	3.4
	Ripe	12.0	13.0	12.0	11.0
pH	Green	2.8	3.4	2.8	2.9
	Ripe	4.3	4.4	3.8	4.3

Source: The Department of Industrial Promotion, 2001

Table 4.3 Nutrition values of the mango flesh between Thai mango (the variety was not specified) and Haden per 100 g fresh weight.

Composition	Green mango*	Half ripe mango*	Ripe mango*	Haden variety**
Water content (g)	82.9	81.1	82.6	83.9
Protein (g)	0.6	0.4	0.6	0.3
Fat (g)	0.4	0.6	0.6	0.1
Carbohydrate (g)	15.3	17.5	15.9	15.0
Fiber (g)	0.4	0.2	0.5	0.5
Calcium (mg)	10.0	10.0	10.0	8.0
Phosphorus (mg)	15.0	15.0	15.0	10.0
Iron (mg)	0.2	0.3	0.3	0.2
Vitamin A (IU/g)	183	392	3133	3813
Vitamin B1	0.06	0.06	0.06	0.1
Vitamin B2	0.05	0.05	0.05	-
Niacin (mg)	0.6	0.6	0.6	0.3
Vitamin C (mg)	62	48	36	15.1
Energy (kCal/100 g)	60	69	62	55.71

Source: *The Department of Industrial Promotion, 2001, ** Wenkam, 1990

4.2 Thermal properties of Nam Dok Mai Si Thong Variety

The specific heat capacity, thermal conductivity, density and thermal diffusivity of the peel and flesh of Nam Dok Mai Si Thong mango variety was illustrated in Table 4.4.

4.2.1 Specific Heat Capacity

From Table 4.4, the peel and mango flesh had different specific heat capacity because of the difference in chemical compositions. Mango flesh had a higher water content that the peel which lead to the higher specific heat capacity. This result was in accordance to the report of Polley *et al.* (1980) who found that the specific heat capacity of apple was between 3.60-4.02 kJ/kg K when the moisture value was in the range of 75-85%. Additional confirmation was also made by Alvarodo (1991) who showed that the specific heat capacity of apple flesh was decreased from 3.64 to 2.68 kJ/kg K when the moisture content of the flesh dropped from 87 to 49.7%.

Table 4.4 Thermal properties of peel and mango flesh of Nam Dok Mai Si Thong variety at 25.0°C.

Thermal Properties	Peel	Mango flesh
Specific heat capacity (kJ/kg·K)	2.81 ± 0.23^{a}	3.43 ± 0.30^{b}
Thermal conductivity (W/m·K)	0.34 ± 0.07^{a}	0.35 ± 0.09^{a}
Density (kg/m^3)	1085.38 ± 11.27^{a}	1036.09 ± 13.57^{b}
Thermal diffusivity (m^2/s)	1.11×10^{-7a}	9.85×10^{-8b}

[x]Different letters within treatment denote significant different by using DMRT at $p \leq 0.05$

4.2.2 Thermal conductivity

The analysis of mango thermal conductivity was performed using the method described by (1998). Two sample sizes of different thickness were prepared. Because the thickness of the peel was only 0.8 mm, the experiment on the thick slab of 3.5 mm can only be carried out when the portion of the mango flesh attached to the peel was included. The thermal conductivity obtained was assumed to be the same as the thermal conductivity of the peel alone. The thermal conductivity of the peel and mango flesh at 25.0°C was shown in Table 4.4. Sweat (1974) reported that the thermal conductivity of fruits and vegetables with moisture content between 65-95% at the same temperature had a direct relationship with the moisturecontent. Further study on the influence of moisture on the thermal conductivity of various vegetables and fruits was shown in Table 4.5. Besides the effect moisture, temperature was considered to exert similar effect to the thermal conductivity as well (Table 4.6). Ramaswamy and Tung (1981) showed that the thermal conductivity of apple with moisture content of 85.8% increased with rising temperature.

Table 4.5 Effect of moisture on the variation of thermal conductivity of some fruits.

Fruit	Moisture (%)	Temperature (°C)	Thermal conductivity (W/m K)	References
Apple	87.2	28	0.559	Bhumbla *et al*., 1989
Red apple	84.9	28	0.531	Sweat, 1974
Strawberry	91.7	28	0.567	Bhumbla *et al*., 1989
Strawberry	88.3	28	0.462	Sweat, 1976
Strawberry cv. Tioga	87	28	0.5563	Delgano *et al*., 1997
Cherry	86.7	28	0.553	Bhumbla *et al*., 1989
Grape	84.7	28	0.548	Bhumbla *et al*., 1989

Table 4.6 Effect of temperature on the thermal conductivity of some vegetables and fruits.

Fruit	Moisture (%)	Temperature (°C)	Thermal Conductivity (W/m K)	Thermal Diffusivity (m/s^2)	References
Red apple	84.9	28	0.531	N/A	Sweat, 1974
Red apple	84.9	22.2	0.40	1.00×10^{-7}	
Green apple	87.8	40-50	0.40	N/A	Buhri and Singh, 1993
Banana	N/A	17	0.48	1.1×10^{-7}	Fantana *et al.*, 2001
Banana	N/A	20-27	0.481	$1.27 - 1.46 \times 10^{-7}$	Sweat, 1974
Carrot	N/A	18.8	0.540	1.3×10^{-7}	Fantana *et al.*, 2001
Carrot	N/A	20	0.571	1.40×10^{-7}	Gratzek *et al.*, 1980
Carrot	N/A	28	0.605	1.55×10^{-7}	Singh, 1982
Strawberry cv. Tioga	87	28.08	0.5563	N/A	Delgano *et al.*, 1997
Strawberry cv. Tioga	87	20.0	0.5201	N/A	Delgano *et al.*, 1997

4.2.3 Density

The density of the peel and mango flesh at 25.0°C was illustrated in Table 4.4. The difference in density was due to the structural characteristics of cellular tissues. The majority of the cells comprising the peel tissues were epidermis cells that aligned themselves tightly with minimal spacing between individual cells. This was in contrary to the parenchyma cells of the mango flesh with a relatively loose alignment. Such alignment allowed the air to fill in the space between the individual cells and thus lead to the lower density of the mango flesh relative to the peel.

4.2.4 Thermal Diffusivity

The thermal diffusivity of the mango flesh at 25.0°C was shown in Table 4.4 and could be calculated from Equation (4.1)

$$\alpha = \frac{k}{\rho C_p} \qquad (4.1)$$

From Equation (4.1), the factors affecting the thermal diffusivity were the specific heat capacity, thermal conductivity and density. Because all three parameters on the right hand side of Equation (4.1) of the peel and mango flesh were different, these would contribute to the different in thermal diffusivity between the two. The study of Wang *et al.* (2001) supported such observation and stated that each type of fruit had a different thermal diffusivity due to the variation in thermal conductivity, specific heat capacity and density. From the experimental results, the initial thermal diffusivity of peel and mango flesh were $0.985 - 1.11 \times 10^{-7}$ m^2/s respectively. When the comparison was made to the Rad variety, the thermal diffusivity of the mango flesh was $1.52 - 1.59 \times 10^{-7}$ m^2/s depending on the measuring temperature (Chowdary, 1981). The relatively lower value of thermal diffusivity of Nam Dok Mai mango flesh was due to the higher value of thermal conductivity (3.53 - 3.68 kJ/kg·K) and specific heat capacity (0.533 - 0.584 W/m K) of the Rad variety (Chowdary, 1981). The examples of thermal diffusivity of some fruits were given in Table 4.7.

Table 4.7 The thermal diffusivity of some vegetables and fruits.

Fruit	Temperature (°C)	Thermal Conductivity (W/m K)	Thermal Diffusivity (m^2/s)	References
Red apple	22.2	0.40	1.00×10^{-7}	Sweat, 1974
Red apple	N/a	0.513	1.70×10^{-7}	Ralman, 1995
Green apple	N/a	0.422	1.44×10^{-7}	Ralman, 1995
Banana	17	0.48	1.1×10^{-7}	Fantana *et al.*, 2001
Banana	20-27	0.481	$1.27\text{-}1.46 \times 10^{-7}$	Sweat, 1974
Carrot	18.8	0.540	1.3×10^{-7}	Fantana *et al.*, 2001
Carrot	20	0.571	1.40×10^{-7}	Gratzek *et al.*, 1980
Carrot	28	0.605	1.55×10^{-7}	Singh, 1982
Orange	N/a	0.580	1.54×10^{-7}	Ralman, 1995
Papaya	N/a	N/a	1.52×10^{-7}	Hayes and Young, 1989
Pear	N/a	0.595	1.61×10^{-7}	Ralman, 1995
Potato	N/a	0.560	1.45×10^{-7}	Ralman, 1995

4.3 The Comparison of Thermal Properties Obtained From the Experiment to the Calculated Values From the Chemical Compositions

4.3.1 The Comparison of the Specific Heat Capacity From the Experiment to the Calculated Values From the Chemical Compositions.

The specific heat capacity of the peel and mango flesh computed from Equation (2.2) to (2.9) as shown in section 2.7.2 was differed from the experimental values in Table 4.8 and 4.9 for the peel and mango flesh respectively.

Table 4.8 The comparison of specific heat capacity of Nam Dok Mai Si Thong peel at 25.0°C between the experiment and equation.

Specific heat capacity (kJ/kg·°C)								
Measured value	Values computed from the equation							
	(2.2)	(2.3)	(2.4)	(2.5)	(2.6)	(2.7)	(2.8)	(2.9)
2.8142	3.2319	3.3381	3.4151	3.3501	3.3955	3.3919	3.6025	3.7630
Difference (%)	12.92	15.70	17.59	16.00	17.12	17.03	21.88	25.21

Table 4.9 The comparison of specific heat capacity of Nam Dok Mai Si Thong flesh at 25.0°C between the experiment and equation.

Specific heat capacity (kJ/kg·°C)								
Measured value	**Values computed from the equation**							
	(2.2)	**(2.3)**	**(2.4)**	**(2.5)**	**(2.6)**	**(2.7)**	**(2.8)**	**(2.9)**
3.4269	3.6013	3.6679	3.7151	3.6706	3.7094	3.7150	3.6025	3.7630
Difference (%)	4.84	6.57	7.76	6.64	7.62	7.76	4.87	8.93

The specific heat capacity of Nam Dok Mai Si Thong peel obtained from the DSC was compared to the calculated values from Equation (2.2) – (2.9). The discrepancy was between 12.92 – 25.21% with the best prediction obtained from Equation (2.2) which employed the water ratio. In the case of mango flesh, the closest prediction was also attained from Equation (2.2) with the difference of only 4.84% followed by Equation (2.8) with 4.87%.

The discrepancies between the experiment and predicted values (Equation (2.2)-(2.9)) were relative small for the mango flesh. This might be due to the fact that these Equations were more suitable for the sample with high moisture content as evidence from the better prediction of specific heat capacity in the mango flesh with relative higher moisture content. This was in accordance with the value computed from Equation (2.8) which was the Equation obtained from the mango. The specific heat capacity of the mango flesh calculated from Equation (2.8) was differed from the actual value by only 4.87%.

4.3.2 The Comparison of the Thermal Conductivity From the Experiment to the Calculated Values From the Chemical Compositions.

The thermal conductivity of the peel and flesh of Nam Dok Mai Si Thong mango calculated from the equations were listed in Table 4.10 and 4.11.

Table 4.10 The comparison of thermal conductivity of Nam Dok Mai Si Thong peel at 25.0°C between the experiment and equation.

Thermal conductivity (W/m·K)								
Measured value	Values computed from the equation							
	(2.11)	(2.12)	(2.13)	(2.14)	(2.15)	(2.16)	(2.17)	(2.18)
0.3447	0.5031	0.4615	0.4960	0.4938	0.4835	0.4547	0.5005	0.4899
Difference (%)	31.49	25.30	30.50	30.19	28.71	24.20	31.13	29.63

Table 4.11 The comparison of thermal conductivity of Nam Dok Mai Si Thong mango flesh at 25.0°C between the experiment and equation.

Thermal conductivity (W/m·K)								
Measured value	**Values computed from the equation**							
	(2.11)	**(2.12)**	**(2.13)**	**(2.14)**	**(2.15)**	**(2.16)**	**(2.17)**	**(2.18)**
0.3519	0.5406	0.5240	0.5324	0.5400	0.5223	0.5172	0.5549	0.5546
Difference (%)	34.36	32.27	33.34	34.27	32.05	31.38	36.04	36.01

The thermal conductivity of Nam Dok Mai Si Thong peel obtained from DSC was compared to Equation (2.11) - (2.18). Equation (2.16) which utilized the water ratio provided the least discrepancy from the measured value. Similar result was also obtained with the mango flesh, in which Equation (2.16) gave 31.38% discrepancy. The next best prediction was Equation (2.15). The variation of thermal conductivity from the calculated value was due to the analytical procedure being employed because DSC measured heat transfer at the steady state which required a long analytical time. As a result, the moisture content (up to 5 – 11% of the initial weight) in some samples with the high ratio of surface area per weight, such as thick mango slab, might be lost when remained in the DSC for 5 – 20 min. Such drop in moisture content led to the slower rate of heat transfer in the sample and subsequently the lower thermal conductivity than the actual value. The comparison of different methodologies in the measurement of thermal conductivity of the mango flesh was made between DSC and line heat source probe. The latter method determined the thermal conductivity during unsteady state. The thermal conductivity evaluated from Nam Dok Mai Si Thong mango flesh from Amphur San Sai, Chiang Mai Province using the DSC (0.3722 W/m K) was lower than the line heat source probe (0.4662 W/mK). The measured value from the line heat source probe was still lower than the predicted value of

Equation (2.16) by 9.86%. Equations (2.11) to (2.18) were generally applied to the calculation of thermal conductivity in food whose chemical compositions differed greatly from the mango flesh. Hence the predicted thermal conductivity was higher than the actual value.

4.3.3 The Comparison of the Thermal Diffusivity From the Experiment to the Calculated Values From the Chemical Compositions

The thermal diffusivity of the peel and flesh of Nam Dok Mai Si Thong mango calculated from the Equations (2.21) – (2.23) were compared to the experimental values as shown in Table 4.12 and 4.13.

Table 4.12 The comparison of thermal diffusivity of Nam Dok Mai Si Thong peel at 25.0°C between the experiment and equation.

Thermal diffusivity (m^2/s)			
Measured Value	**Values computed from the equation**		
	(2.21)	**(2.22)**	**(2.23)**
1.11×10^{-7}	1.2686×10^{-7}	1.0407×10^{-7}	1.2684×10^{-7}
Difference (%)	12.50	6.66	12.49

Table 4.13 The comparison of thermal diffusivity of Nam Dok Mai Si Thong mango flesh at 25.0°C between the experiment and equation.

Thermal diffusivity (m^2/s)			
Measured Value	**Values computed from the equation**		
	(2.21)	**(2.22)**	**(2.23)**
9.85×10^{-8}	1.3516×10^{-7}	1.2011×10^{-7}	1.3317×10^{-7}
Difference (%)	27.12	17.99	26.03

The thermal diffusivity of peel and mango flesh calculated from Equation (4.1) applied the specific heat capacity, thermal conductivity and density of peel and mango flesh from the experimental measurements. The comparison between Equation (2.21) – (2.23) indicated that the calculated value from Equation (2.22) had the least discrepancy to the experimental result. However, the computed thermal diffusivity might be less than the actual value because of the predicted thermal conductivity was lower than what should have been. The loss of moisture during the measurement was contributed to this and eventually resulting in the wide gap between the predictive and experimental values.

4.4 The Application of Numerical Methodology in the Prediction of Temperature Changes Within Nam Dok Mai Si Thong During Thermal Processing

The predicted initial temperature at any specific location within the mango fruit was obtained solely from the measurements. Thermal processing began through heat transfer by a diffusive mean at a medium surface. The heat was transferred through the mango fruit by the process of thermal conduction that led to temperature changes within the fruit.

The preliminary investigation of temperature distribution within the mango fruit at a specific time interval was carried out under the assumptions provided in Chapter 3. The schematic diagram of a mango underwent temperature profile analysis by finite difference method was shown in Figure 4.1. The mango was considered to have a cylindrical shape with radius of r (m) and divided by radial direction into five sections. Each section has an equal spacing of Δr. The symbol m represented the specific location within the mango, m = 0 implied the position at the center of the seed core. The shaded area illustrated the seed with thickness measuring from the seed core center of Δr. Therefore m = 1 was the location at which the mango flesh was attached to the seed. The mango surface was located at m = 5. Thermal properties used in the prediction were derived from experimental results as reported previously in section 4.2.

Figure 4.1 Schematic cross-section diagram of the mango used in the investigation of temperature profiling by finite difference method.

4.4.1 The Storage at Low Temperature by Keeping the Mango Fruit in the Indicator (Air Temperature 13.0 ± 0.5°C)

The temperature controlled incubator had a forced convection circulation system. The speed and temperature of the air were controlled using a microprocessor. Air temperature was measured using a thermocouple which reported the constant value of 12.8°C throughout the experiment. The speed of air flow was averaged at 0.6 m/s with an initial fruit temperature of 27.19°C which was found to be constant throughout the whole fruit. Such observation was in accordance with the preliminary assumption. The average diameter, seed and peel thicknesses of the mango were 0.073, 14.665 × 10^{-3}, and 0.0008 m, respectively. The calculated heat transfer coefficient at this condition was 9.9110 × 10^{-8} W/m^2·°C (Appendix C1) with F_0 = ¼ and Δr =7.3325 × 10^{-3} m. The value of Δt was determined to be 135.62 s (Appendix C3). The heat generated from the fruit respiration had minimal effect to temperature-time profile and could be neglected completely (Piranchana, 2005). The heat transfer model at a specific location by finite difference method was later compared to the measured value as shown in Figure 4.2 to 4.4 (Detailed data was given in Appendix B1).

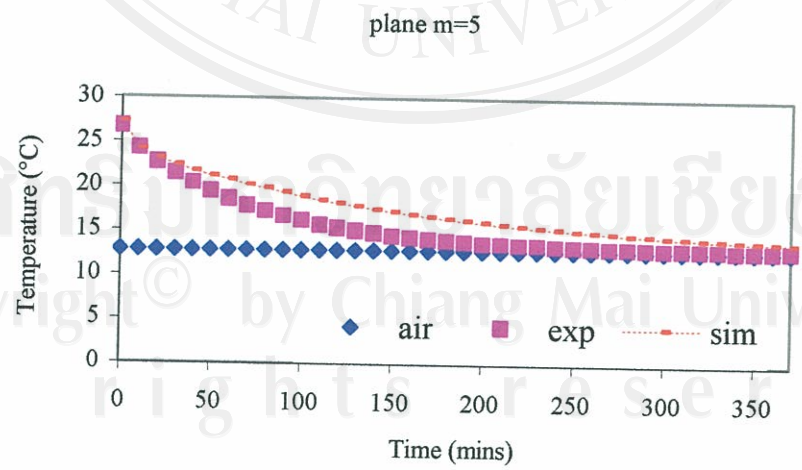

Figure 4.2 The comparison between the temperature obtained from the experiment (exp) and model (sim) at the surface (m = 5) of Nam Dok Mai Si Thong mango in the incubator (13.0 ± 0.5°C).

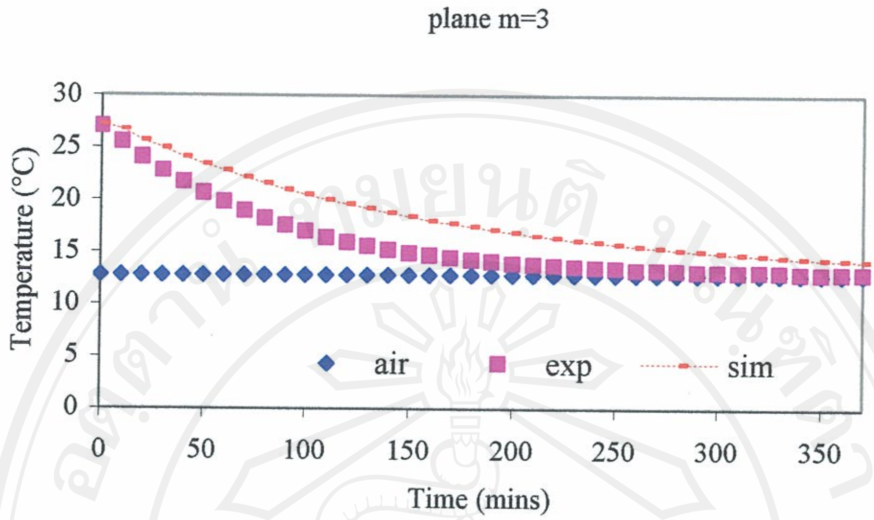

Figure 4.3 The comparison between the temperature obtained from the experiment (exp) and model (sim) at the center of Nam Dok Mai Si Thong mango flesh in the incubator (13.0 $\pm$ 0.5°C).

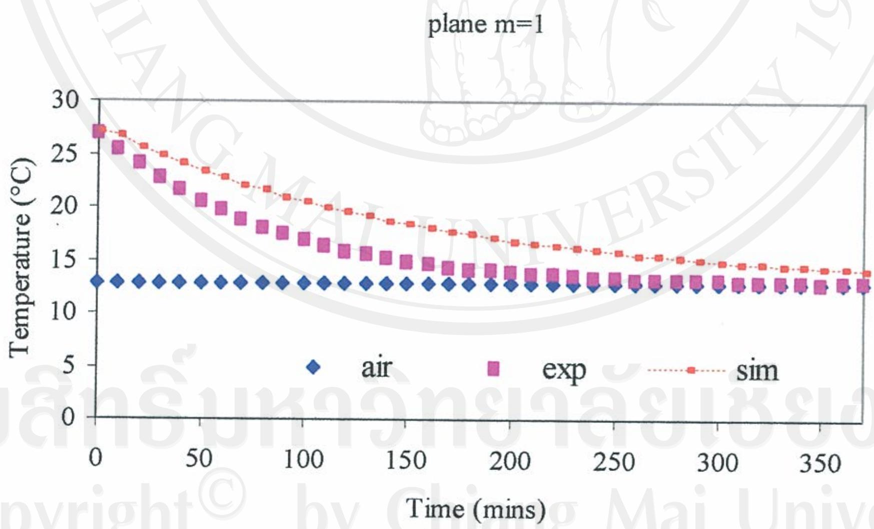

Figure 4.4 The comparison between the temperature obtained from the experiment (exp) and model (sim) at the position of Nam Dok Mai Si Thong mango flesh attached to the seed (m = 1) in the incubator (13.0 $\pm$ 0.5°C).

The accuracy of mathematical model was evaluated from root mean square error (*RMSE*) as shown in Equation (3.21). At m = 1, the location where the mango flesh attached to the seed, the temperature discrepancy measured in the term of *RMSE* was 6.98°C while at the center of the mango flesh (m = 3) this figure was 6.91°C. The smallest *RMSE* value of 4.02°C was detected at the surface of mango (m = 5). The highest discrepancy at the surface of mango was strongly pronounced during the first two hours after which the decline in discrepancy was observed. At 370 min, the discrepancy was less than 2°C.

An important criterion to be considered during the temperature drop of the mango was mainly focused at the center of the fruit. In this case, the model was used in the prediction at the location m = 1. The result suggested that at 300 min the discrepancy of predicted and measured temperatures was between 1.30 - 1.96 °C which was still within the acceptable boundary. Thus the heat transfer model developed in this study could be applied in the monitoring of internal temperature changes under low temperature condition. The principle described here might be used in the calculation of the time required during precooling of the products.

4.4.2 The Heating with Warm Water by Immersing Mango in the Temperature Controlled Water Bath (48.0 ± 0.5°C)

The effect of elevating the temperature inside the mango fruit was studied by immersing the mango in the temperature controlled water bath of 48.4°C which was assumed to be constant throughout the experiment. The initial temperature of the whole mango was 25.08°C.

The result indicated that the temperature at the surface of mango rose rapidly and level off to the water bath temperature in less than 5 min as shown in Figure 4.6. This was a result of high convective heat transfer coefficient of water. Therefore in order to model the internal temperature profile within the mango fruit, the surface temperature was assumed to be equivalent to that of warm water. The finite difference method was used in the development of heat transfer model at a specific location of mango fruit. The comparison was then made to the measured value as shown in Figure 4.5-4.7 (Data was given in Appendix B2)

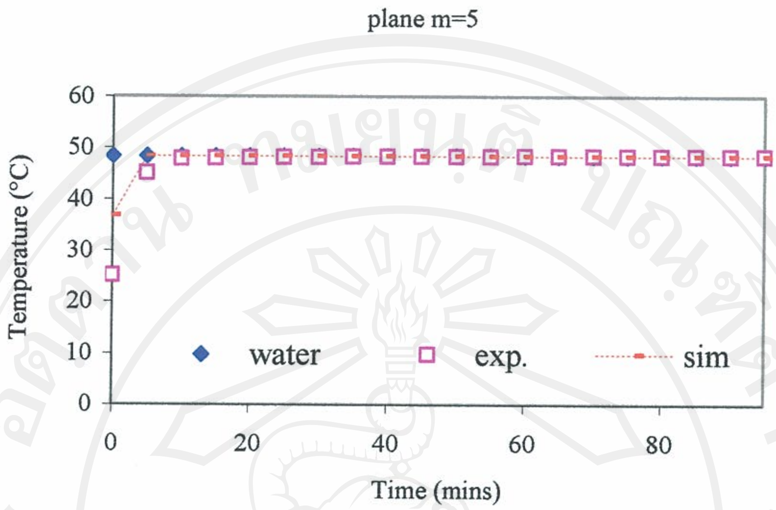

Figure 4.5 Comparison of temperature profile at the surface of Nam Dok Mai Si Thong between the experiment (exp) and predicted value from the model (sim) in the temperature controlled water bath at 48.4 ± 0.5°C.

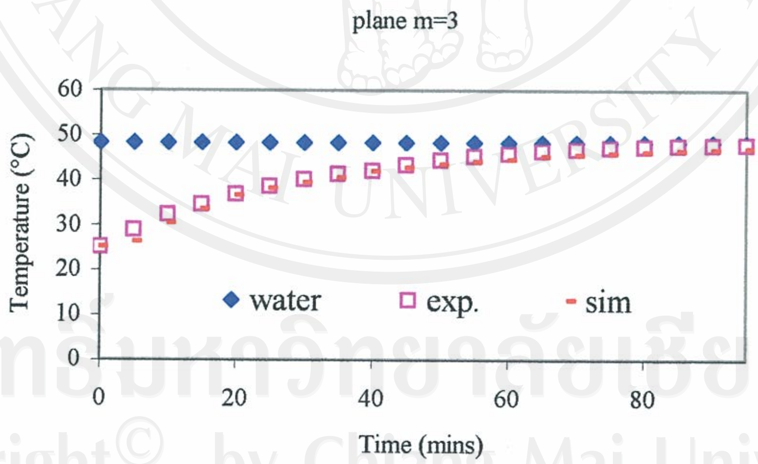

Figure 4.6 Comparison of temperature profile at the center of Nam Dok Mai Si Thong flesh (m = 3) between the experiment (exp) and predicted value from the model (sim) in the temperature controlled water bath at 48.4 ± 0.5°C.

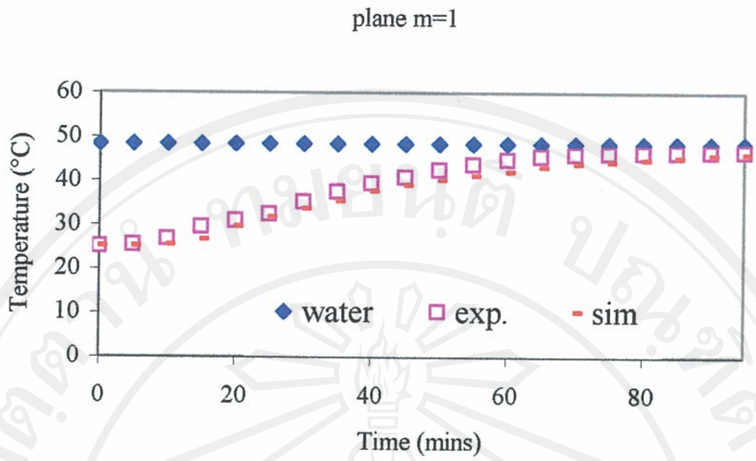

Figure 4.7 The comparison between the temperature obtained from the experiment (exp) and model (sim) at the position of Nam Dok Mai Si Thong mango flesh attached to the seed (m = 1) in the temperature controlled incubator (48.4 ± 0.5°C).

When the consideration was made to *RMSE* value at the position of mango flesh attached to the seed (m = 1) beneath the mango surface for $4\Delta r$, there existed the discrepancy of 1.81°C. This was compared to the position $2\Delta r$ ($m = 3$) with the difference of 1.14°C. It should be noted that the temperature discrepancy at $m = 3$ was higher at the beginning but gradually subsiding with time.

As mentioned previously, the important criterion utilized in the current study was the temperature at the center of the fruit. The experimental result at m = 1 pointed out that the time lapse of 85 min was required in order to increase the temperature from 25.08 to 46.5°C. This was compared to the predicted value of 45.25°C which differed from the actual temperature by merely 1.25°C. In fact, the predicted time would have been 100 min if the temperature at the center of mango increased to 46.52°C. As evidence from this result, the heat transfer model could be applied in the prediction of temperature profile inside the fruit product.

From Figure 4.2 – 4.4 and 4.5 – 4.7, the characteristics of heat transfer obtained from the model were actually lower than the real situation. Such discrepancy might have been resulted from the initial assumption that restricted the shape of mango to a cylinder with the radius measured from the thickest part of the slab. The one dimensional analysis in the radial direction might contribute directly to the rate of heat transfer. Further model complexity such as the smaller size of the anterior and posterior ends of the fruit as well as the transfer of heat that could have been occurred either in the radial or axial positions might be included, both of which might have elevated the rate of heat transfer.

4.5 Determination of the Relationship Between the Chilling Injury and Thermal Properties of Nam Dok Mai Si Thong Mango During the Storage at 5 and 13°C.

The measurement of chilling injury found in the mango was based on chilling index or chilling score, leakage of electrolytes, color changing of the peel and respiratory rate.

4.5.1 Chilling Index

4.5.1.1 Storage of mango at 5°C

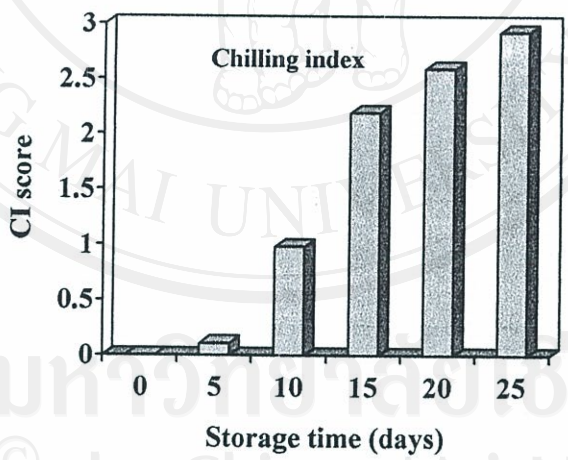

Figure 4.8 Chilling index score of the mango kept at 5°C.

In this study the score of chilling index was given by examining the external appearance only without further consideration into chilling injury that occurred with the mango flesh.

Figure 4.8 illustrated the chilling index at the peel of the mango being kept at 5°C. It was found that mango started to show the symptom of chilling injury at the peel on the fifth day of storage with the score of 0.11. The symptom included the occurrence of brown small spots. A closer investigation under stereomicroscope revealed that at the beginning surface underneath the peel became watery within a confined area. The watery portion of the fruit gradually expanded with storage time as shown in Figure 4.9. The score of chilling index was thus increased with the storage time at this temperature. At the end of 25 days storage period, the chilling index score reached the peak of 2.92 with more than 20% of observable injury. However, such chilling injury of the mango kept at 5°C was only happened to the peel without noticeable effect to the mango flesh. Such observation was in accordance with the study on Chok Anan mango by Vasanasong (1998), Kuakunkho (2005) and Katawatcharakul (2000) who found that the chilling injury of the mango fruit kept at 3 and 5°C only took place at the peel. The watery peel gradually expanded to the larger area when the fruit was kept for a long period of time. There was also a noticeable effect of darkening color of the peel. The result was also confirmed by the experiment on other mango varieties of Pair and Taimour (Aziz *et al.*, 1976), Alphonso (Thomas and Oke, 1983). This watery symptom was the effect of membrane deformation which was the first event that plant responded to the storage temperature below the critical level. It was an immediate response when the plant first contacted the low temperature and led to the abnormal function of the internal biochemical pathways. For example, the physical phase changes of saturated fatty acid which was the component of membrane from fluid-like to the liquid-crystalline phase (Marangoni et al., 1996; Wang, 1990; Moris, 1982, Lyon, 1973). Such changes caused the degrading operation of the membranes and making them lose the ability in controlling the permeability of various substances. Murata *et al.* (1994) reported the decrease in double bond of the unsaturated fat which was the component of phopholipid and eventually resulted in the gel-like cell membrane. Raison and Orr (1986) discovered that 4% of phospholipids in the cell membrane of the plant Olender, which was subjected to chilling previously, also underwent phase change from the liquid to semi-liquid phase. The deformation of the membrane induced the latter event which was the effect from the first event that had already caused damages to the cells or tissues.

The observable effect included the brown coloring of the mango peel being stored at 5°C for the period of 5 days.

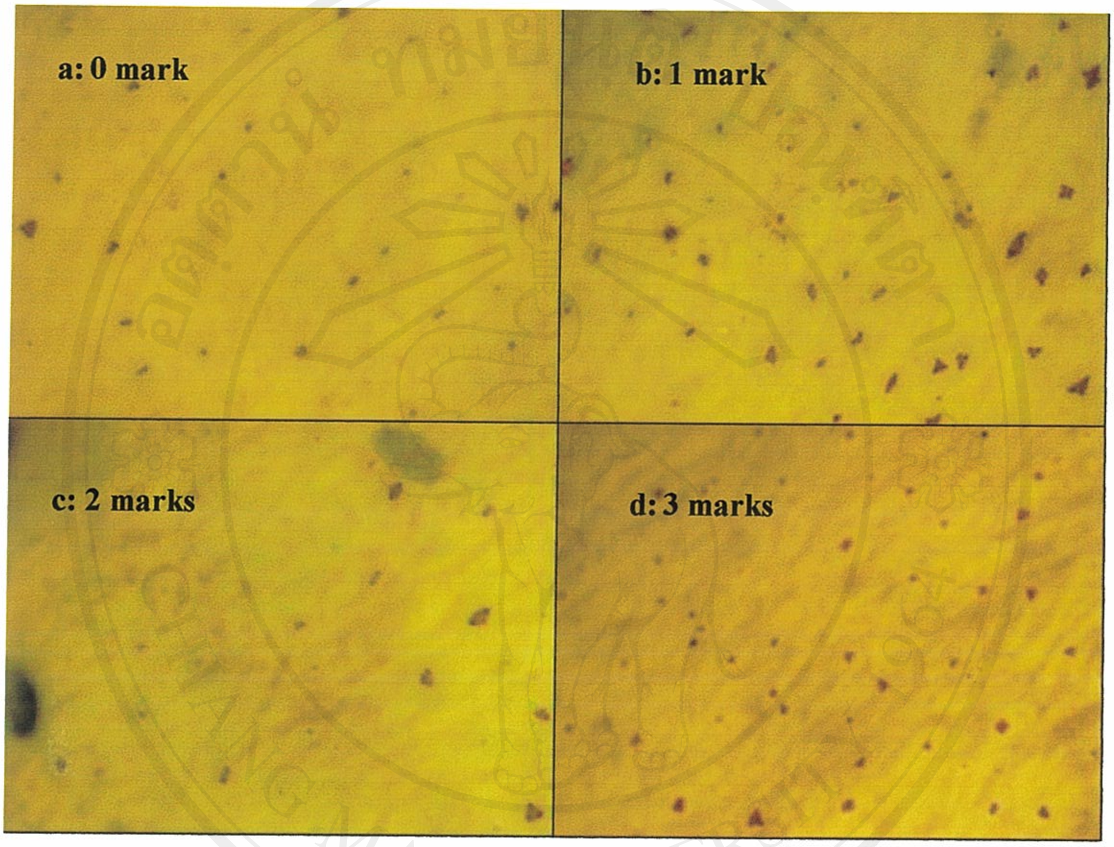

Figure 4.9 The characteristics of chilling injury observed in Nam Dok Mai Si Thong mango that was stored at 5°C (1.5× magnification).

4.5.1.2 Storage of mango at 13°C

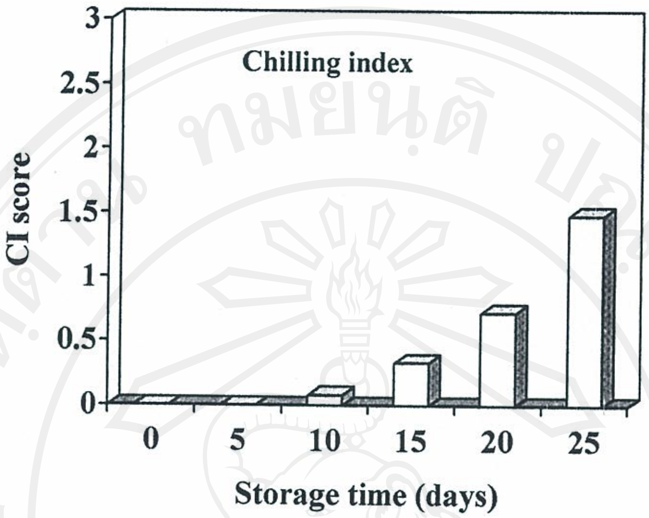

Figure 4.10 Chilling index score of the mango kept at 13°C.

The storage of mango at 13°C also generated the chilling injury effect to the mango being kept at 5°C. The symptom began at day 10 of the storage period with a relatively mild symptom with the score of 0.8 (Figure 4.10) then the score increased with storage time. However, the increasing rate of injury was less than the mangoes being kept at 5°C. The pronounced effect of chilling injury became apparent on day 20 of the storage period with the score of 0.72. The score on day 25 was 1.48 which was less than that at 5°C by about 50%. The observed chilling injury at the peel at 13°C was similar to 5°C. The small browning spot at the peel began to emerge with watery effect underneath which was gradually expanded to other area with long storage time.

The chilling injury symptom of the mango at 13°C was the result of cell membrane degradation caused by long storage period at low temperature. This was not the same as the mangoes being stored at 5°C whose membranes underwent phase change from fluid to liquid-crystalline phase. Ratue *et al.* (2006) reported the chilling injury of Berangan banana being maintained at 15°C that the evidence of increasing damage could be observed from the level of peel browning associated with ripening process. This was considered to constitute a portion of cell senescence process. The increased proportion of unsaturated fatty acid in the phospholipids enhanced the fluid-like properties of the cell membrane which was considered to be different from the cell membrane degradation that stemmed from chilling injury in which the cell membrane underwent phase change from fluid to semi-solid.

4.5.1.3 The storage of mango at 25°C

There was no evidence of chilling injury for the mango being stored at 25°C. The mango underwent natural ripening process with short storage period.

4.5.2 Electrolyte leakage value of electrolyte in the mango peel

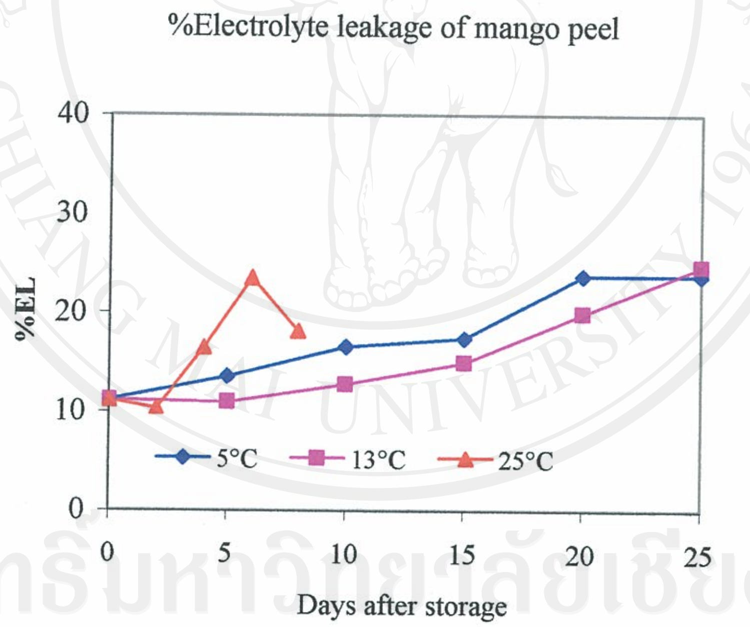

Figure 4.11 Profile of the electrolyte leakage value at the mango peel of Nam Dok Mai Si Thong mango being kept at 5, 13, and 25°C.

4.5.2.1 Storage at 5°C

From Fig. 4.11, the extent of electrolyte leakage at the peel increased with the storage time at all storage temperatures. The electrolyte leakage from the mango being kept at 5°C was found to increase from the first day of storage from an initial value of 11.15 to 23.77% on the 25th day. In fact, the electrolyte leakage increased with the chilling injury symptom (Fig. 4.12). Low temperature storage resulted in the enhanced production of free radicals, especially a reactive oxygen type such as superoxide ($O_2^{\bullet}$), hydrogen peroxide (H_2O_2) and hydroxyl radicals ($^{\bullet}OH$). These radicals were able to degrade saturated fatty acids which constituted various cell membranes through lipid oxidation. The degradation of saturated fatty acids caused the destabilization of the cells membrane and allowed various ions such as amino acids, sugars, and pigments to move freely through the cells that eventually led to the imbalance of chemicals both inside and outside of cells (Shewfelt and Rosario, 2000; Murata, 1990). The subsequent enzyme-substrate interaction could generate further abnormality symptom which was the characteristic of plant chilling injury, for example, the accumulation of chloroginic acid or phenol compounds which could be oxidized by PPO (polyphenoloxidase) enzyme into brown color of quinones (Ketsa and Chirdtragool, 2001) that was noticetable at the peel (McCollum and McDonald, 1991).

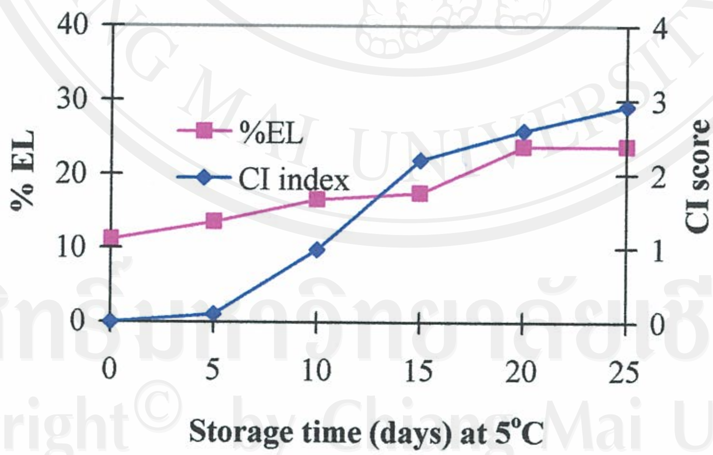

Figure 4.12 The relationship between the leakage of electrolyte from the peel of Nam Dok Mai Si Thong mango and the chilling index score when the mango was kept at 5°C.

The increase of electrolyte leakage when the products suffered chilling injury was the result of low temperature that had been observed with various fruits such as tomato (King and Ludford, 1983), papaya (Chan *et al.*, 1985), orange and lemon (McCollum and McDonald, 1991), Chok Anan mango (Kuakhuntod, 2005 and Vasanasong, 1998) and Berangan banana (Ratule *et al.*, 2006). However, this trend was not observed in some fruits being kept in certain conditions. The electrolyte leakage in the peel of Berangan mango at 10°C was found to decrease even though the chilling injury had already occurred (Ratule *et al.*, 2006). The woolliness of fruit (Furmanski and Bueschner, 1979) was the result of ligation between the methyl group in pectin compounds and calcium ions which eventually resulted in the decrease of charge leakage from the cells.

4.5.2.2 Storage at 13°C

From Fig. 4.11, the electrolyte leakage from the mango being kept at 13°C was found to increase from the first day of storage from an initial value of 11.15 to 24.7% on the 25th day. The ripening process started from the first day of storage when the peel color changed from green-yellow to completely yellow on the 25th day of storage. The respiratory rate of the fruit was also heightened from the 10th day with the highest level on the 20th day at this storage temperature. This result was in accordance with the storage of Nam Dok Mai #4 at 13 and 25°C at which the electrolyte leakage increased with storage time and ripening stage of the fruits (Angsooksiri and Kanlayanarat, 2003; Whangchai, 2000). Patterson et al. (1979) and Whitlow *et al.* (1992) elaborated that electrolyte leakage was the measurement of charged compounds presence in the cells, for example, potassium with the positively charged. Because such leakage was the evidence of fallen capability in preventing or allowing certain compounds to permeate the cell membrane and could be used as an indicator for senescence or deteriorating signs of the cells. The loss in capability of differentiating chemicals permeating through the cell membrane depended on the ripening stage and degradation level of the fruits (Brady, 1987; Wang, 1990; Zsom *et al*, 2003). Lester and Stein (1993) stated that ripening process caused the change in soluble solid content and cell wall components. Such changes contributed to the increased leakage of chemicals from the cells and were the main cause of ever increasing leakage of electrolyte throughout storage period.

The consideration of relationship between the electrolyte leakage and the chilling injury at storage temperature of 13°C indicated that the leakage level of electrolyte elevated with chilling injury (Fig. 4.13). However, the chilling injury at this temperature was the result of cell membrane degradation due to ripening process that was different from the chilling injury at 5°C. Similar result was reported by Ratue *et al*. (2006) who found the increased severity of Berangan banana chilling injury at 15°C as evident from the browning level of the peel that varied with ripening stage of the fruits. Ripening process is one part of the senescence process of the cells with an increased proportion of unsaturated fat in phospholipids. Such elevation affected the property of cell membrane by transforming it to fluid-like structure. This was not the same as cell membrane degradation from chilling injury at which the phase of cell membrane was altered from liquid to semi-solid phase.

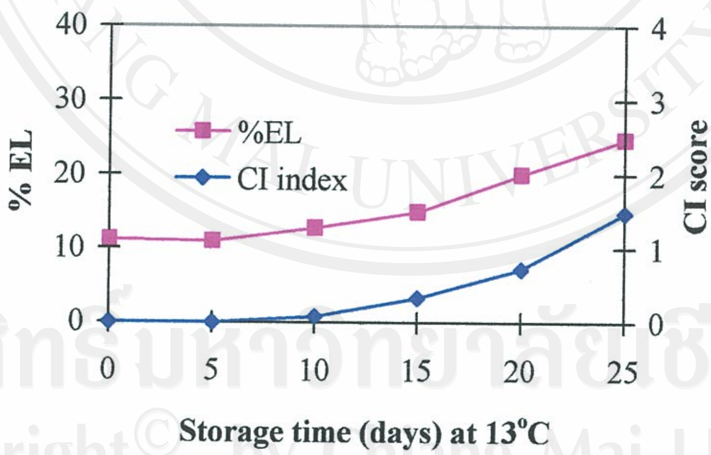

Figure 4.13 The relationship between electrolyte leakage of Nam Dok Mai Si Thong peel and the chilling index score of electrolyte at 13°C.

4.5.2.3 Storage at 25°C

The electrolyte leakage of the peel at 25°C increased with storage time as observed at 5 and 13°C, however, the rate of leakage was faster. The faster rate could be seen in the first day with leakage percentage of 11.15 which was later increased to 23.53% in the 6th day of storage. The increase of electrolyte leakage of the peel at this temperature was the result of ripening process as observed in the storage temperature of 13°C. However, the storage of mango at 25°C had developed into ripening process faster than the storage period of 13°C. The mango fruit being kept at 25°C developed color change at a greater level than at 13°C as observed from b* value representing yellow color (+ b*). The mango at 25°C had an elevated b* level from the first day of 37.17 to 41.47 on the 8th day while the peel being stored at 13°C had an elevated b* value of 40.94 in the 25th day of storage. The respiratory rate was also considered as it was another indicator of ripening process. The rise in respiratory rate of mango being maintained at 25°C began on the 2nd day of storage until the highest level was reached on the 8th day. Hence the increase in electrolyte leakage at the peel of Nam Dok Mai Si Thong peel at 25°C was the main result of ripening process.

4.5.3 The Change of the Peel Color

The changes of peel color of the mango at 5, 13 and 25°C could be measured in term of L*, a*, b*, C* and hue angle as follows;

4.5.3.1 The L*-value profile of Nam Dok Mai Si Thong peel

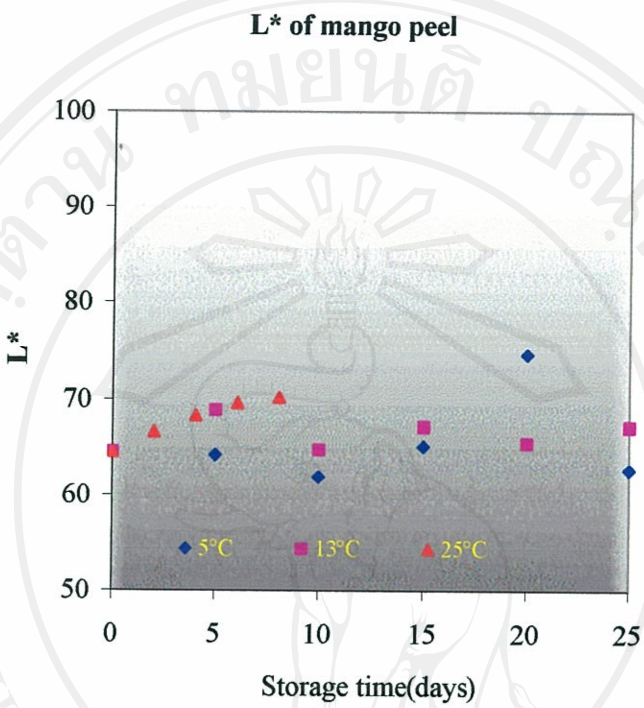

Figure 4.14 The profile of luminosity of the mango peel stored at 5, 13 and 25°C.

Figure 4.14 illustrated the L*-value profile of mango peel maintained at 5, 13 and 25°C. The L* value of mango kept at 5°C decreased with storage time as evident from the decrease in L* value of 64.56 on the first day of storage to 62.53 on the 25th day which represented the drop of -2.03. This was an indication that the peel of mango being kept at this temperature became darkened. Further consideration by taking chilling injury effect into account, L* value began to drop during the increase chilling injury effect at the peel (Figure 4.15) as visibly observed by the watery effect. The symptom began with the small spot and gradually expanded to wider area with storage time. The color of the peel became darkened or had changed to an increasing appearance of brown color. The browning of the peel was due to the diminished capability of the cell membrane in controlling of substance permeability effect which was another clear indication of cell membrane degradation. Such deterioration would eventually lead to the imbalance of substances inside and outside of cells. Further evidence included the increased leakage of electrolyte with storage time or severity of the chilling injury (Figure 4.11 and 4.12). There also existed a relationship between the decrease of L* value at the peel with the increased electrolyte leakage at the same region due to the occurrence of chilling injury (Figure 4.16).

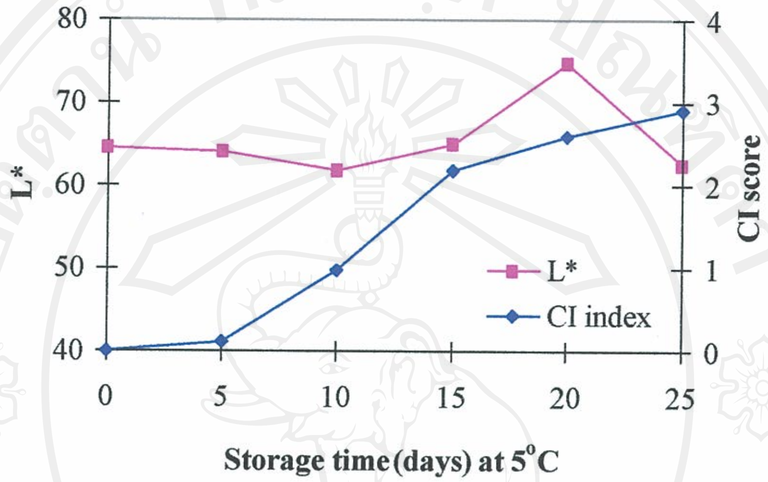

Figure 4.15 The relationship between the chilling index score and L*-value of Nam Dok Mai Si Thong peel being kept at 5°C.

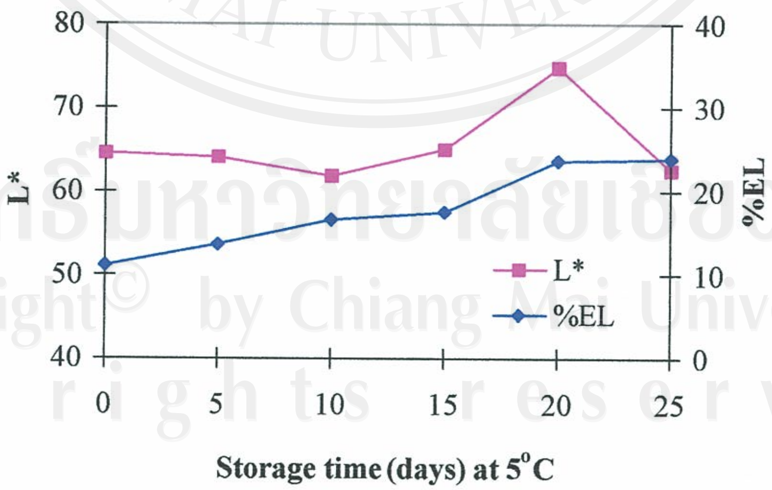

Figure 4.16 The relationship between L*-value and electrolyte leakage of the Nam Dok Mai Si Thong peel kept at 5°C.

When the plant was subjected to low temperature but still above the freezing point, the plant tissues would respond by enhancing the activity of PAL (Phenylanine ammonia lyase) and PPO (Friend and Rhodes, 1981; Kahl, 1987; Hassan and Pantastico, 1990; Stewart *et al.*, 2001; Vela *et al.*, 2003 and Crisosto and Labantoh, 2002). The production of phenol compounds in plants was related to PAL and PPO enzymes. PAL facilitated the synthesis of phenol compounds while PPO catalyzed the formation of browning agents such as quinones from the phenols. Ketsa and Chirdtragool (2001) reported that Nam Dok Mai Si Thong peel being stored at 4°C had an elevated level of PAL activity in all cases being investigated which was in contrast to the lowering level of phenol compounds in the peel. This was due to the effect of PPO enzyme that utilized phenol compounds in the formation of browning agent such that the chilling injury effect was evident. Furthermore, the lightness of the peel stored at 5°C measured from L* value also dropped from the initial value of 64.56 to 62.57 on the 25^{th} day of storage (Fig. 4.15).

The L* value of peel being stored at 13 and 25°C increased with the storage time. The luminosity and rate of luminosity change of peel kept at 25°C was higher than at 13°C. On the first day of storage, L* value was elevated from 64.56 to 70.09 (+ 5.53) and 67.1 (+2.54) on the 8^{th} and 25^{th} day of storage at 25 and 13°C respectively. The slower rate of luminosity change for the peel being stored at 13°C was the result of low temperature storage which decelerated various metabolic processes. The color development of the peel at 13°C was thus slower. This observation was confirmed by Srivichien (2006) who found that L* value of Nam Dok Mai Si Thong peel maintained at 13°C was gradually increased in parallel with the ripening process. In addition, browning effect at the peel was considered to be the same as the chilling injury of the peel being kept at 5°C together with an expansion in browning area as the storage time increased (Figure 4.17). Browning at the mango peel after storage at 13°C was the result of cells degradation due to ripening process. At this stage cell membrane gradually lost the capability in controlling the type of permeates passing through and led to electrolyte and chemical leakages such as phenol compounds, which in turn elevated the concentration of K^+ and browning agent due to further oxidation reaction catalyzed by PAL. This observation was therefore in accordance with Figure 4.18 which suggested that the peel kept at 13°C had an increase in electrolyte leakage while the decrease in luminosity or darkening of the peel was observed for the storage at a lower temperature of 5°C.

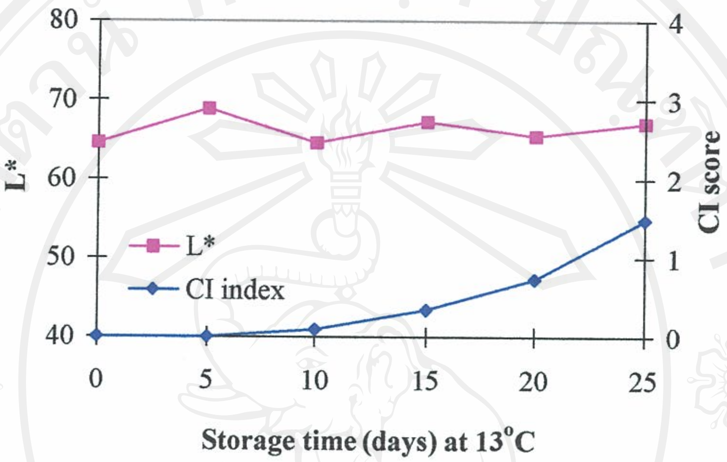

Figure 4.17 The relationship between the chilling index score and L*-value of Nam Dok Mai Si Thong peel being stored at 13°C.

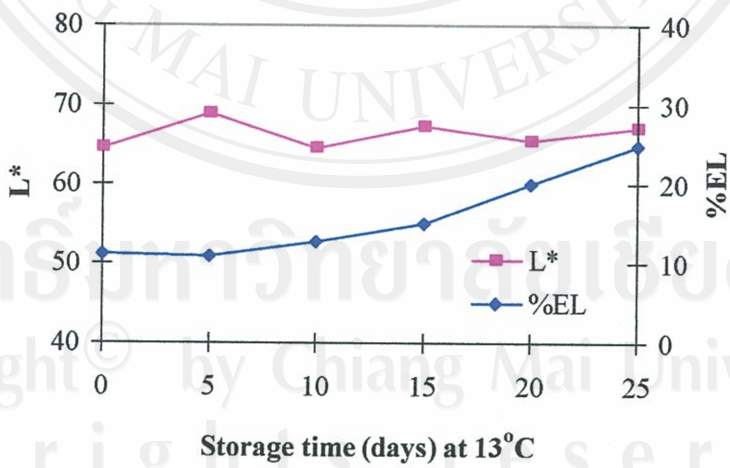

Figure 4.18 The relationship between the percentage of electrolyte leakage and L*-value of Nam Dok Mai Si Thong peel being stored at 13°C.

4.5.3.2 The change of a* of Nam Dok Mai Si Thong peel

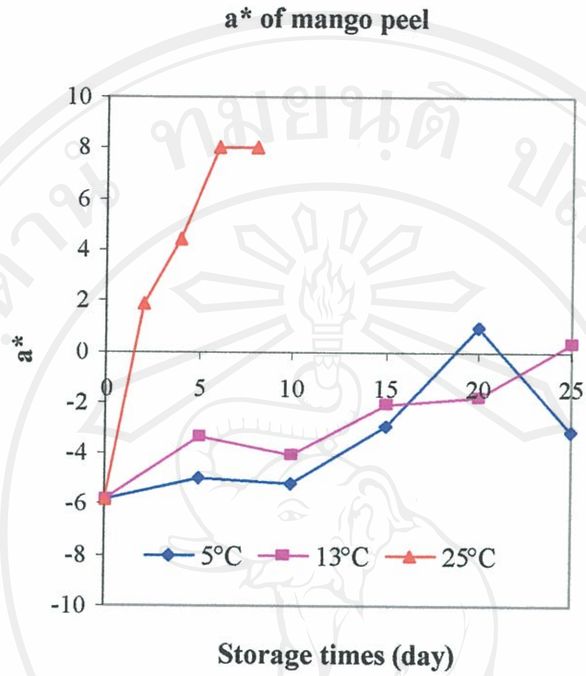

Figure 4.19 The profile of a* value of Nam Dok Mai Si Thong peel being kept in the incubator at 5, 13 and 25°C.

Figure 4.19 illustrated the profile of a* value that indicated the greenness (-a) and redness (+a) of the peel being kept at 5, 13 and 25°C. The rate of a* elevation when the peel was kept at 25°C was faster than at 13 and 5°C. Such rise was the clear indication that the peel was less green and the storage at high temperature would decrease the greenness at a faster rate than at low temperature. Initial a* value of the peel was -5.85 and would gradually rise to 8, 0.29 and –3.11 respectively on the 8^{th} and 25^{th} day of storage at 25, 13 and 5 °C. The decrease of greenness was the result of chlorophyll degradation occurred during the ripening process of mango fruit. Chlorophyllase enzyme was responsible for this catalytic reaction of chlorophyll at high temperature (Will et al., 1981; Ketsa et al., 1999). Therefore the greenness mango kept at 25°C would drop faster than at 13°C due to development into ripening process while the storage at 5°C still exhibited green color.

4.5.3.3 The change of b* value of Nam Dok Mai Si Thong peel

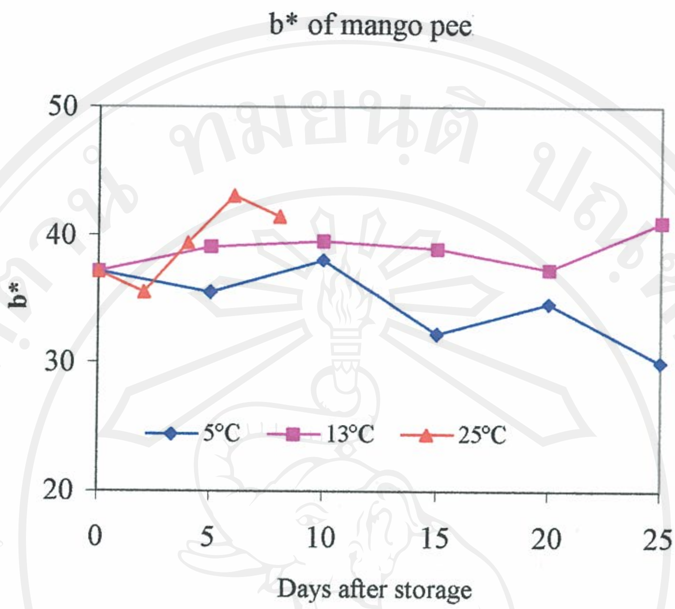

Figure 4.20 The profile of b* value of Nam Dok Mai Si Thong peel being kept in the incubator at 5, 13 and 25°C.

Figure 4.20 illustrated the profile of b* value which represented yellowness (+b) and blueness (-b) of the peel during storage at 5, 13 and 25°C. The b* value of the mango being kept at 13 and 25°C was found to increase with the storage time. The b* value in the first day of 37.13 was elevated to 40.94 and 41.47 on the 25th and 8th day of storage at 13 and 25°C respectively. The development of peel into yellow color at 25°C was both greater in extent and faster in rate than 13°C. Color development of the peel from green to yellow was a sign that indicated development into ripening process. The storage of mango at 5°C proved that there existed a tendency b* value reduction when the mango was stored for a long period of time. The decline from the original value of 37.13 to 30.03 was evident in the 25th day of storage. The color change of the mango peel was related to carotenoid synthesis catalyzed by phosphatase that operated at moderate temperature. Therefore the peel being maintained at 25°C was able to develop into yellow color faster than at 13°C. This was in contrary to the storage at 5°C where the enzyme was inhibited and thus further increase in yellow color of the peel was not observed.

For the storage at 5°C, only the chilling injury was evident while the development of yellow color or development into ripening process (Fig. 4.21) was not observed at the peel. The effect of chilling injury could be easily observed by the watery effect underneath the peel by starting of with the small spots followed by a gradual expansion upon storage for long period of time with darkened skin color. It was thus concluded that the chilling injury at the peel was the response to the storage at temperature below critical level and corresponded to the rise of electrolyte leakage at the peel (Fig. 4.22).

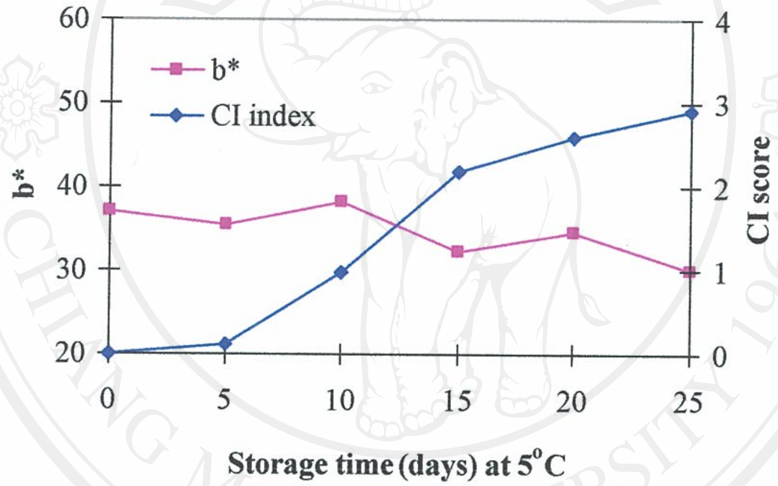

Figure 4.21 The relationship between the chilling index score and b*-value of Nam Dok Mai Si Thong peel being stored at 5°C.

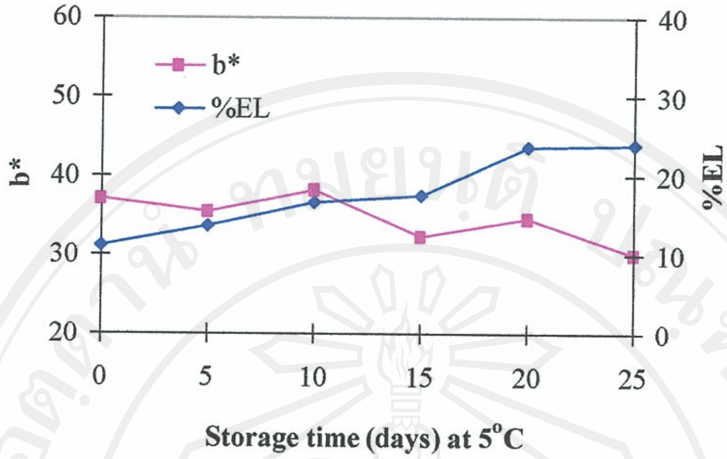

Figure 4.22 The relationship between the percentage of electrolyte leakage and b*-value of Nam Dok Mai Si Thong peel being stored at 5°C.

The relationship between the profile of b* value and the chilling injury of the peel at 13°C was opposite to that of 5°C. The peel stored at 13°C had developed yellow color as could be seen from the rising of b* during storage (Fig. 4.23) which was the clear indication that the mango stored at this temperature would develop ripening process. The associated chilling injury of the peel was thus the result of natural cells degradation and was in accordance with the increase of electrolyte leakage at the peel as shown in Fig. 4.24.

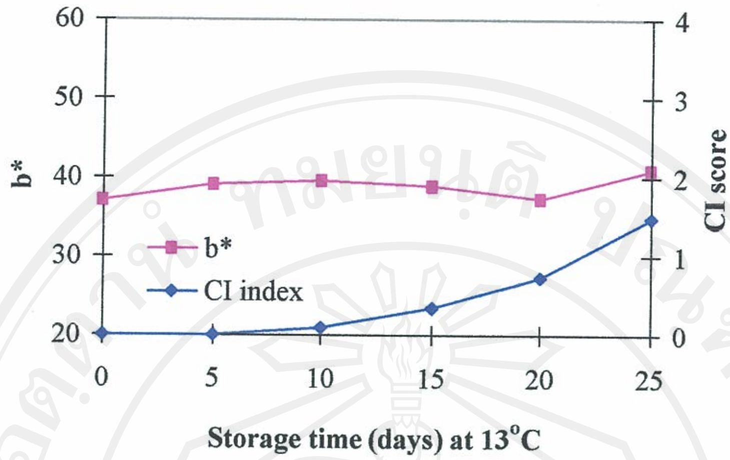

Figure 4.23 The relationship between the chilling index score and b* value of Nam Dok Mai Si Thong peel maintained at 13°C.

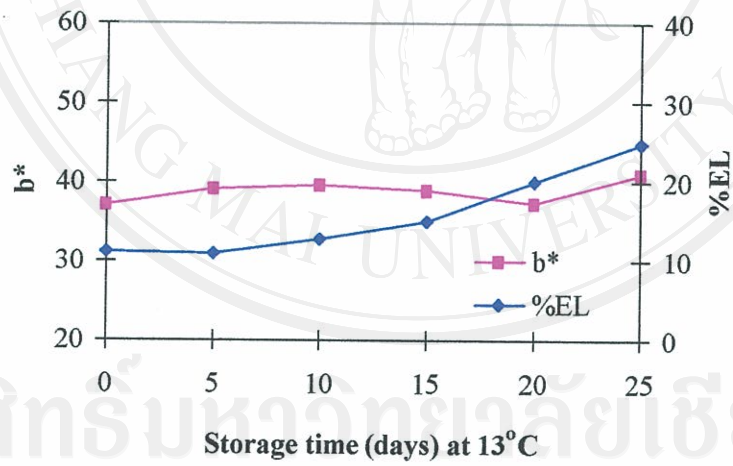

Figure 4.24 The relationship between the electrolyte leakage and b* value of Nam Dok Mai Si Thong peel maintained at 13°C.

4.5.3.4 The change in Chroma (C*) value of Nam Dok Mai Si Thong peel

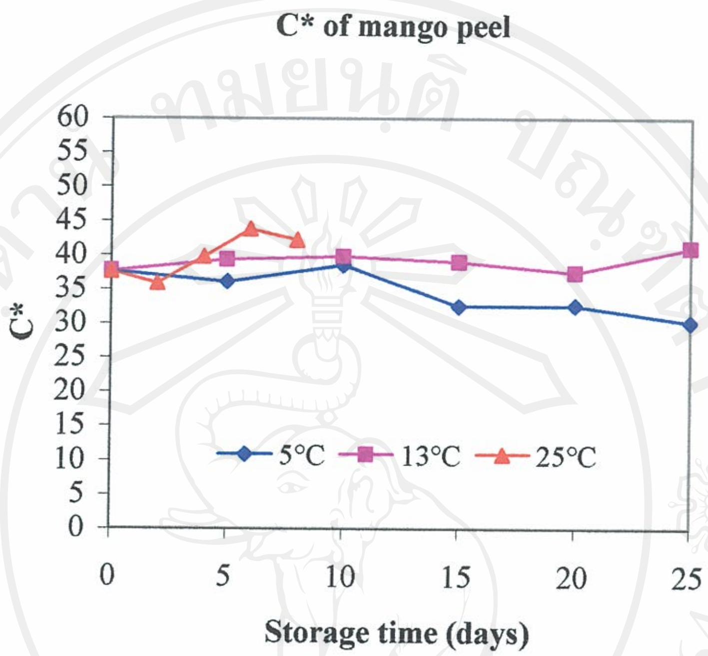

Figure 4.25 The profile of chroma (C*) value for Nam Dok Mai Si Thong peel maintained in the incubator at 5, 13 and 25°C.

The chroma value (C*) of the peel stored at 13 and 25°C increased with storage time. The peel of the mango kept at 25°C had the higher chroma value than that at 13°C. At the first day of storage, the chroma value was 37.65. During the course of storage, the chroma value had increased to 42.25 (+4.65) and 41.04 (+3.39) on the 8^{th} and 25^{th} day for 25 and 13°C, respectively as shown in Fig. 4.25. In the other words, the mango peel had the increase in the brightness value which corresponded to the rise in L* and b* of the peel being kept at 13 and 25°C. Whereas the storage at 5°C indicated that the chroma of the peel decreased with storage time as evident from the dropping of initial chroma value of 37.65 on the first day to 30.23 (-7.42) on the 25^{th} day and hence resulted in dullness of the peel as shown in Fig. 4.25. Such decrease in chroma value was stemmed from chilling injury as confirmed by the decrease of L* (representing lightness or luminosity) and b*.

4.5.3.5 The change in hue angle value of Nam Dok Mai Si Thong peel

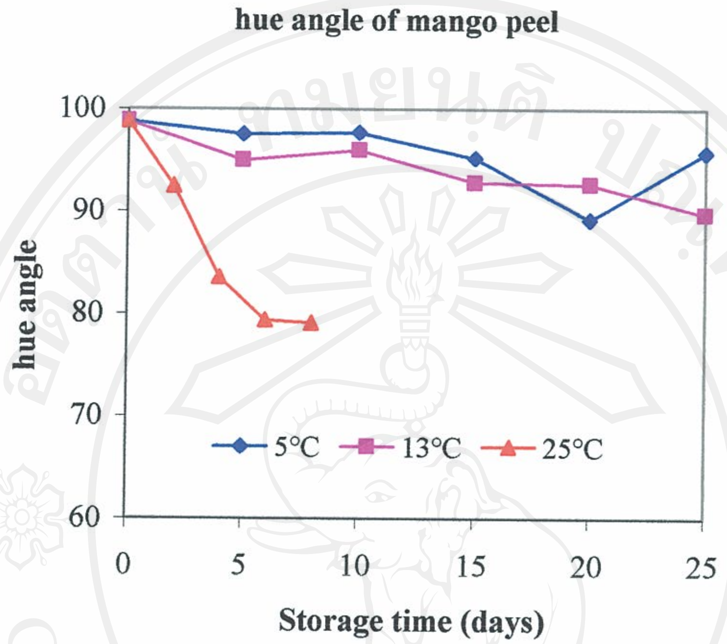

Figure 4.26 The hue angle profile of Nam Dok Mai Si Thong peel being kept in the incubator at 5, 13 and 25°C.

Fig. 4.26 described the change in hue angle value or actual color of the mango peel being kept at 5, 13 and 25°C which was found to decrease with storage period. The change in peel color being kept at 13 and 5°C was slower than at 25°C. The initial hue angle color of the peel was 98.8 or yellowish-green color was decreased to 79.11, 89.76 and 95.78 when kept for 8 and 25 days at 25, 13 and 5°C, respectively. At the end of storage period at 25 and 13°C, the peel color was altered from yellowish-green color (h° = 90-135 °) to yellow (h° = 45-90°) whereas the original color of the peel being stored at 5°C was still remained (Fig. 4.27 A-C).

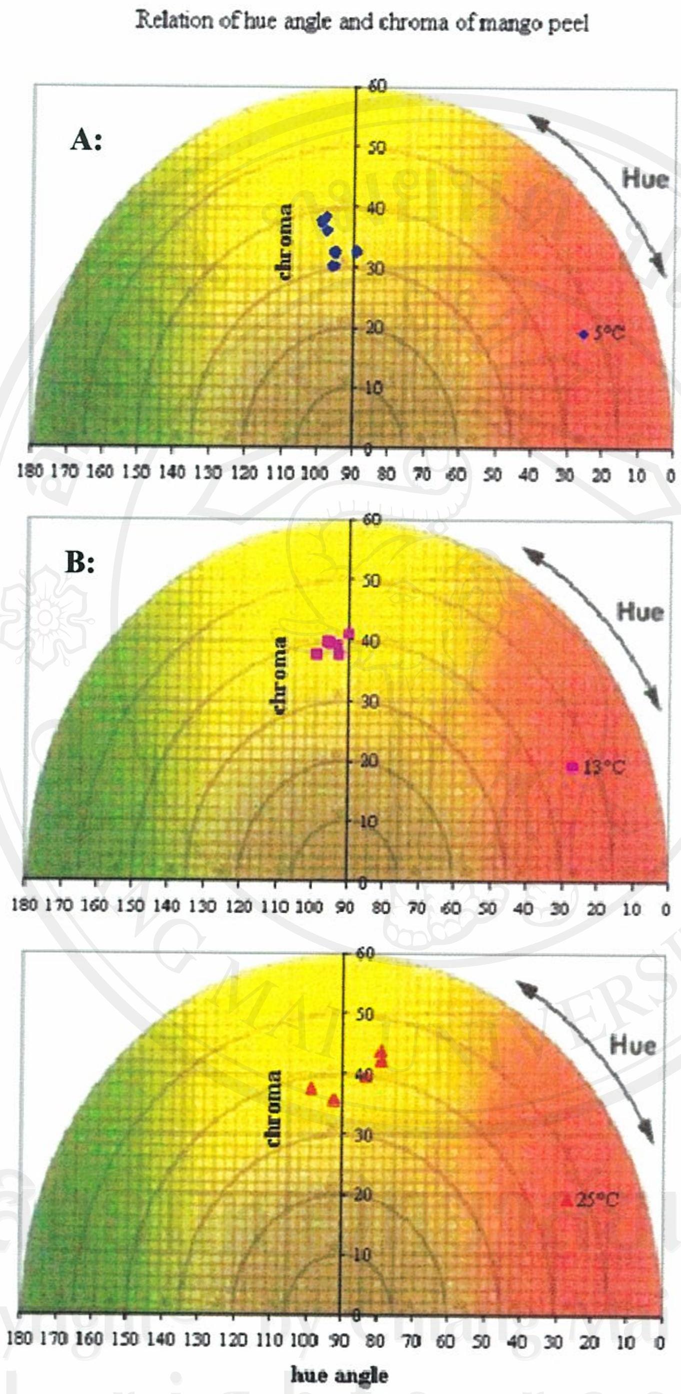

Figure 4.27 The color change of Nam Dok Mai Si Thong peel being kept at A:5°C, B:13°C. and C:25°C.

The color change of the peel from yellowish-green to yellow occurred during ripening or storage period. The storage at 25°C produced a faster color change to yellow than that at 13°C. This was in contrary to the storage at 5°C which was lower than the critical temperature. The color development of peel at this temperature was inhibited with chilling injury that emerged in the form of browning effect to the peel. The study by Charles and Tung (1973) supported this finding; the peel of Volery banana kept at low temperature had developed yellowish color in a lesser extent than storage at a higher temperature. Similar result was observed in mango of Chok Anan variety (Intalook, 2005), Maha Chanok variety (Andkard, 2004), Nang Klang Wan variety (Katawatcharkul, 2000), Kensington variety (Mclauchlan and Well, 1996) and Tommy Atkins variety (Moore, 2003) all of which being maintained at low temperature (5-13°C). The development of the peel to yellowish color of these fruits were faster when kept at a higher temperature (25°C) due to the accelerated activities of chlorophyllase and peroxidase whose major roles were to degrade the chlorophyll and optimal operating temperature was nearer to the room temperature (Will *et al*., 1981; Ketsa et al., 1999; Martinez et al., 2001). The results presented by Andkard (2004) also supported this by showing that the storage of Maha Chanok mango variety at 25°C influenced the faster decrease in chlorophyll a and b contents than at 13°C. In addition, higher temperature also promoted the synthesis of carotenoids (Gross, 1987) by induction of phosphatase activity which played a major role in the carotenoid biosynthesis (Vazque-Salinas and Lakshminarayana, 1985). Similar observations were reported for Kensington (Chaplin *et al*., 1991), Julie (Sankat *et al*., 1993), Manila (Hidalgo *et al*., 1996) and Tommy atkin varieties (Moore, 2003). This was in accordance with the experiment results which stated the correlation between storage temperature and b* value. The peel being kept at 25°C had the increased rate of transition into yellowish color than at 13°C. The change of surface color being maintained at 25°C was the result of ripening process. While the peel being stored at 5°C had a slower rate of color development due to the inhibiting effect or slowing down of the related enzyme to produce a color change at low temperature. It was thus not unexpected that the yellowish color development of the peel would be slower than that at 13 and 25°C. However, the storage at this temperature would produce a chilling injury at the peel as observed in other studies with Chok Anan (Kuakhuntod, 2005) and Tommy atkins (Mohammed and Brecht, 2000) mango varieties as well as Berangan banana whose browning effect at the peel was strongly pronounced at the storage temperature of 5°C.

4.5.4 Respiratory rate

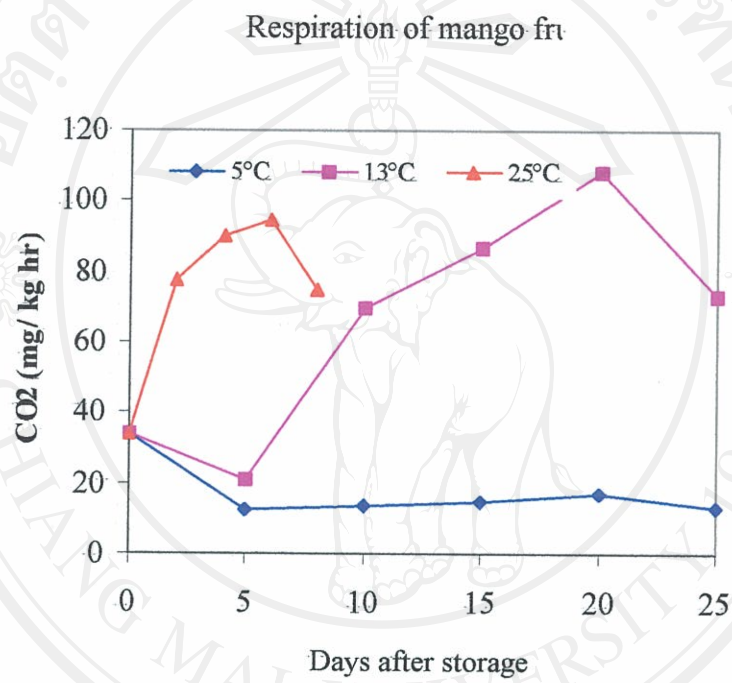

Figure 4.28 The respiratory rate of Nam Dok Mai Si Thong mango being kept in the incubator at 5, 13 and 25°C.

4.5.4.1 The storage at 5°C

Figure 4.28 illustrated the respiratory rate of mango stored at 5, 13, and 25°C. The respiratory rate of the mango fruit kept at 5°C was dropped from the initial value of 34 mg CO_2 /kg.h to 12.69 mg CO_2 /kg.h after 5 days of storage. It should be noted that the measurement of initial respiration of mango was performed when the temperature of the fruit was between 25-27°C. Further measurement of the respiratory rate of the mango at 5°C indicated a slight value increase but was not significant at confidential interval of 95% or the respiratory rate of mango stored at this temperature was relatively constant.

4.5.4.2 The storage at 13°C

The mango being kept at 13°C had a slow rate of respiration during the first five days whereas the temperature was dropped from 25-27 to 13°C. The respiration rate was increased afterwards and reached the maximum value of 108.1 mg CO_2/kg.h in the 20th day of storage and dropped to 73.15 mg CO_2/kg.h on the 25th day. The mango kept at 13°C underwent the ripen process since the fifth day of storage, become pre-climacteric and had developed into a complete ripen stage on the 20th day of storage. After the maximum respiratory rate of 108.1 mg CO_2/kg.h (climacteric) was attained, the respiratory rate had dropped which was the indication of cell senescence with the respiratory rate of 73.15 mg CO_2/kg.h. This was in accordance with the alteration in physical characteristics of mango fruit by color changing of the pericarp from greenish-yellow to yellow as evident from the elevation of L*, a*, b* and C* values which corresponded to the rise in yellowness.

4.5.4.3 The storage at 25°C

The mango stored at 25°C had a similar respiratory rate as the mango being kept at 13°C except that the former entered the ripening process faster due to the effect of high temperature (Kay and Paull, 2004). The elevated level of respiratory rate was evident from the 2nd day of storage and reached the maximum (94.7 mg CO_2/kg.h) when the storage time of six days had passed. The rate of respiration was later dropped to 74.53 mg CO_2/kg.h on the 8th day (Fig. 4.13) which was in agreement with the study on Chok Anan (Intalook, 2005; Vasanasong, 1998) and Maha Chanok (Andkard, 2004) mango varieties that had been maintained at 25°C. The increase in respiration rate at this temperature was also faster than the storage at 13°C which indicated the benefit of low temperature storage at which enzyme activity related to the respiratory process was slowed down and thus resulted in the lower rate of respiration (Siripanich, 2001; Pantastico, 1975).

The storage of mango at 5°C aided the deceleration of metabolic changes that occurred during the ripening process of the mango fruit with better result than the storage at 13 and 25°C. However, there might be the appearance of chilling injury on the pericarp after ten days of storage (CI score of 0.98). The storage of mango at the higher temperature or application intermittent warming before the symptom occurred may prolong the storage time as evident from the study of Vasanasong (1998) who proved that Chok Anan mango might be kept in the intermittent warming conditions to alleviate the chilling injury effect. In addition, this method of storage could be applied to a wide variety of plant such as zucchini (Kramer and Wang, 1989), citrus (Davis and Hofmanm, 1973), peach, nectarine (Anderson and Penney, 1975), lemon (Cohen *et al.*, 1983) as well as cucumber (Cabrera and Salveit, 1990). The storage of mango fruit at 13°C slowed down the ripening process by shifting the maximum respiratory rate from day 6th for the storage at 25°C to day 20th of storage.

4.5.5 The change in physical and chemical characteristics of mango flesh

4.5.5.1. The change of mango flesh color

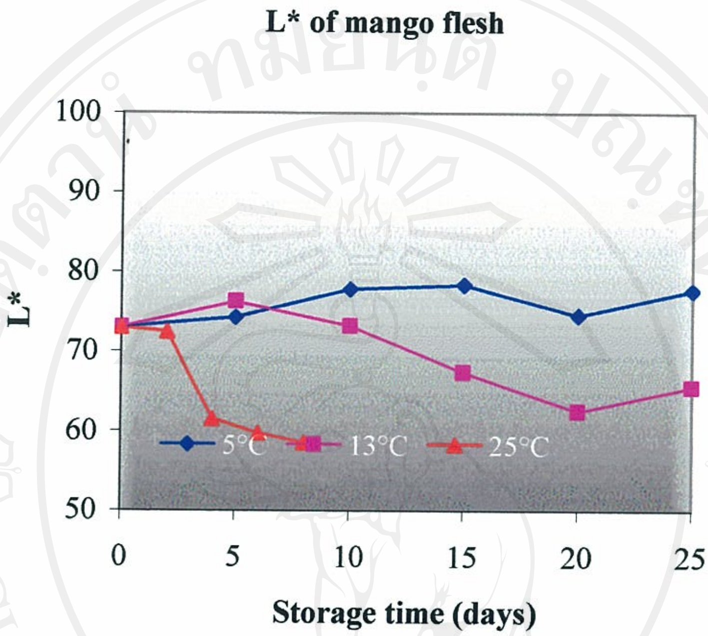

Figure 4.29 The change of L*-value of Nam Dok Mai Si Thong mango flesh stored in a temperature controlled incubator at 5, 13 and 25°C.

4.5.5.1.1 The change of L* value of mango flesh

Fig. 4.29 showed the L*-value profile of Nam Dok Mai Si Thong maintained at 5, 13 and 25°C. The L*-value of mango flesh stored at 13 and 25°C decreased with storage time. The latter condition of storage had the lower rate of decreasing in L* value than the mango flesh being stored at 13°C. The L* value decreased from 72.98 on the first day of storage to 61.51 (-11.47) and 65.53 (-7.45) in the 8th and 25th day of storage at 25 and 13°C, respectively. The decrease of the difference in L* value between the 8th and 25th day to the first day was the indication of darkening color of mango flesh resulting from the ripening process which lead to yellowish color of mango. The slow rate of decreasing in L* value at 13°C than at 25°C was the result of low temperature storage that decelerated the change in various processes such as color change. The color change in L* value was thus lower than at

25°C (Siripanich, 2002). For the mango flesh stored at 5°C, L* value increased with storage time from the initial value of 72.98 on the first day to 77.69 on the 25th day of storage which indicated the elevation of + 4.71.

4.5.5.1.2 The change in a* value of mango flesh

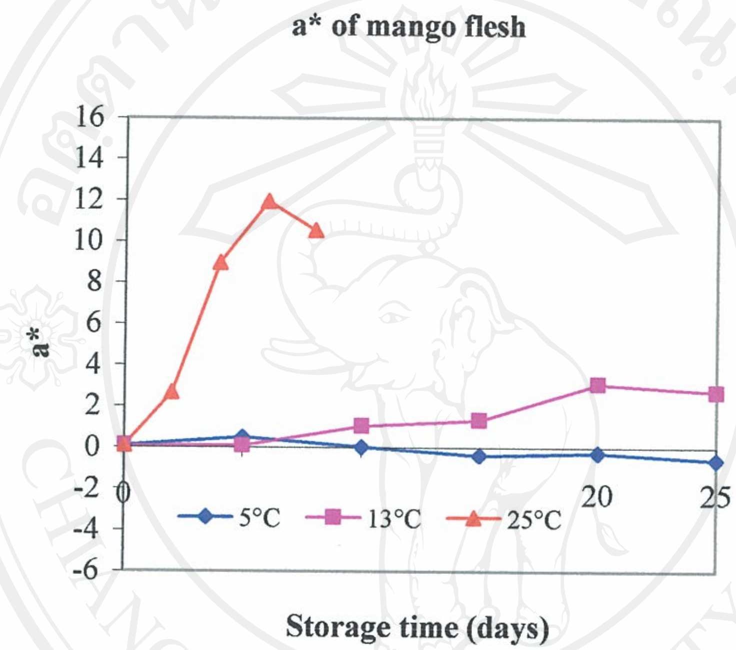

Figure 4.30 The change in a* value of Nam Dok Mai Si Thong mango flesh being stored at 5, 13 and 25°C in the incubator.

Figure 4.30 showed the profile of a* value of mango flesh being kept at 5, 13 and 25°C. It could be observed from the general trend that a* value of mango flesh increased with storage temperature of 13 and 25°C from 0.093 on the first day to 2.72 and 10.55 on the 25th and 8th day of storage. The increase of a* value suggested the enhancement of red color in the mango flesh. The storage at high temperature encouraged development of red color in the mango flesh faster than at low temperature. This was the result of activated ripening process as evidence from the rise in respiratory rate on the second and 10th day of storage at 25 and 13°C respectively (Fig. 4.28). In addition, chlorophyllase was able to degrade chlorophyll efficiently at high temperature (Will et al., 1981; Ketsa et al., 1999).

The a* value of the mango flesh stored at 5°C decreased with storage time from the initial value of 0.093 on the first day to -0.6 on the 25th day of storage. Such decrease in a* value was the indication that the storage at this temperature delayed color development in the ripening process of mango flesh. This also corresponded to the lower and constant respiratory rate of the mango being kept at this temperature throughout the storage period (Fig. 4.28). It was thus concluded that the storage at low temperature resulted in the inhibition of mango ripening process.

4.5.5.1.3 The change in b* value of mango flesh

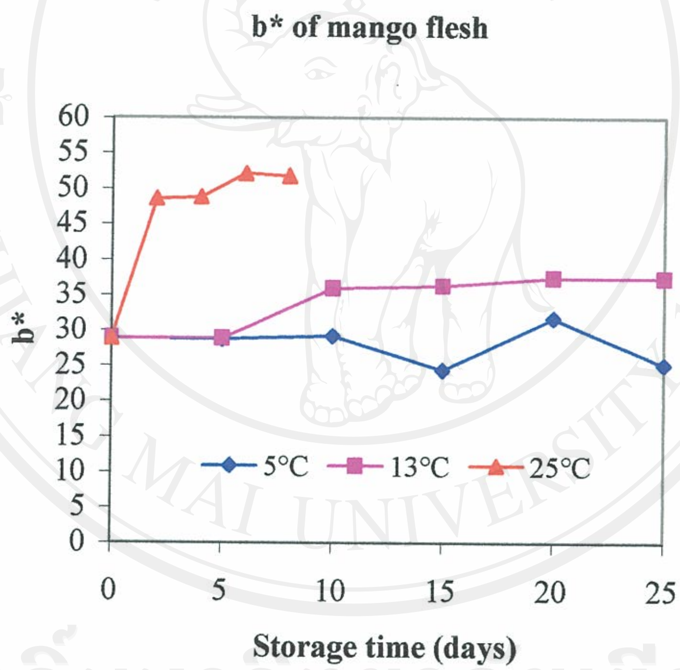

Figure 4.31 The profile of b* value of Nam Dok Mai Si Thong mango flesh stored in the incubator at 5, 13 and 25°C.

Fig. 4.31 illustrated the b* value profile of the mango flesh stored at 5, 13 and 25°C. The change in b* value was considered to be in a similar pattern as the change in a* value. The mango fruit stored at the temperature of 13 and 25°C had the enhanced b* value with storage time from the initial value of 28.94 to 37.42 and 51.82 on the 25th and 8th day of storage at 13 and 25°C. Mango flesh stored at 25°C was able to develop into yellow color in a greater extent and faster rate than the mango being maintained at 13°C. This was in contrary to the mango being stored at 5°C where b* value decreased with storage time from 28.94 in the first day to 25.16 in the 25^{th} day of storage (Fig. 4.31). The decrease in b* value was the result of inhibition on the activity of enzyme phosphatase which was responsible for the synthesis of carotenoid. It was evidence that low temperature was not suitable for the operation of this enzyme (Thomas, 1975).

4.5.5.1.4 The change in C* value of mango flesh

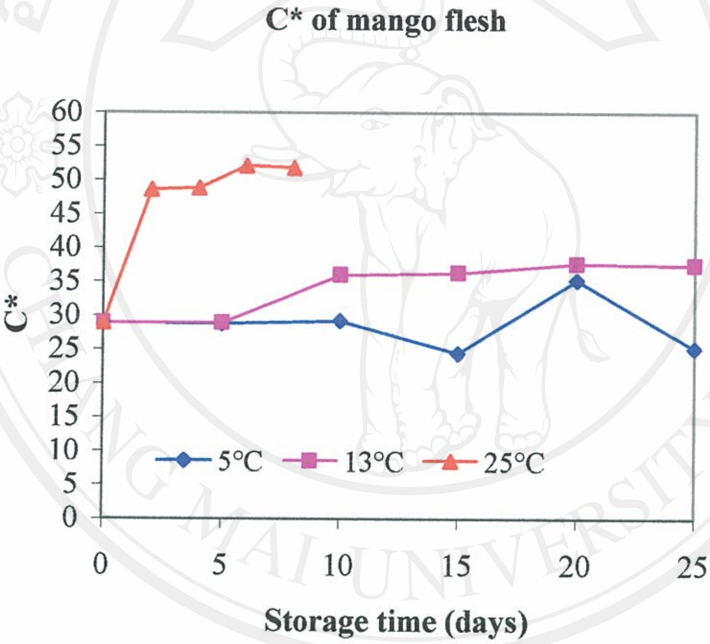

Figure 4.32 The profile of C* value for Nam Dok Mai Si Thong mango stored in the incubator at 5, 13 and 25°C.

The change in color intensity or chroma value (C*) of the mango flesh stored at 13 and 25°C was found to increase with storage time from the initial value of 28.95 on the first day to 52.9 and 37.52 on the 8^{th} and 25^{th} day of storage at 25 and 13°C, respectively (Fig. 4.32). The increase of chroma value of the mango flesh was the result of elevation of a* and b* values which was in accordance with the present observation. The storage at high temperature (25°C) aided the color development at a faster rate. Because at this temperature, the enzyme responsible for the color change could operate at a better efficiency than the lower temperature range of 13 and 5°C. The opposite was observed for the mango flesh stored at 5°C whose chroma value dropped with storage time from the initial value of 28.95 to 25.17 on the 25th day (Fig. 4.32). This was the evident of a slower color development for the mango flesh as indicated from the decrease in a* and b* which in turn resulted in the lower color intensity of the mango flesh stored at 5°C.

4.5.5.1.5 The change in hue angle value of mango flesh

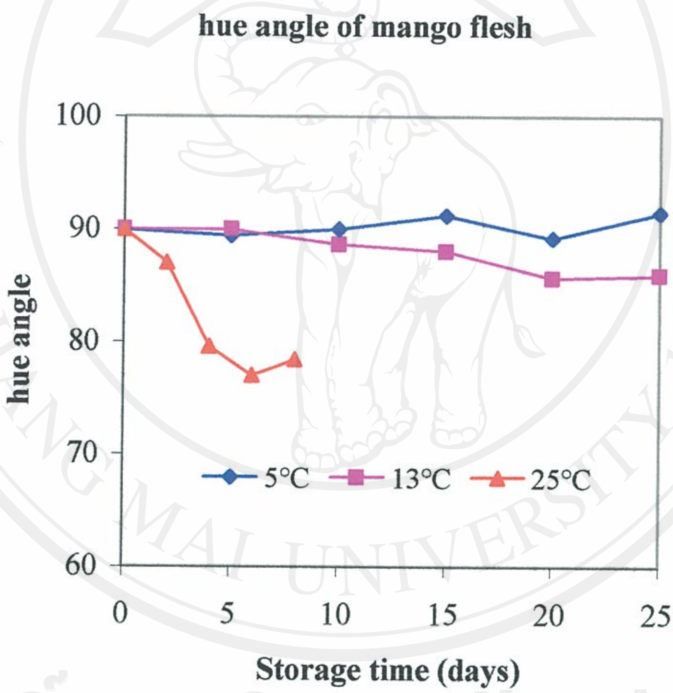

Figure 4.33 The profile of hue angle value of Nam Dok Mai Si Thong mango flesh stored in the incubator at 5, 13 and 25°C.

The hue angle value or actual color of mango flesh stored at 13 and 25°C decreased with storage time. The change of color in the mango flesh when stored at 25°C was faster than at 13°C. Initially h° of mango flesh was 89.97 which indicated the yellowish or yellowish-green color (90-135°), then decreased to 78.43 and 85.94 (45-90° represented red-orange to yellow color) when stored for 8 and 25 days at 25 and 13°C. Or in other words, at the end of storage period the color of mango flesh turned to red-orange to yellow (Fig. 4.34:B and 4.34:C). Whereas mango flesh stored at 5°C yielded h° value of 91.49 (Fig. 4.33) which was slightly different from the initial hue angle value in comparison to the storage at 13 and 25°C. Because there was no further development in the color of the flesh, therefore the color was still in the range of yellow to yellowish-green (Fig. 4.34:A).

The storage of mango fruit at 13 and 25°C resulted in the development of mango flesh's color from the initial color of yellow (h° = 89.97) to yellowish-orange (h° = 78.43) for the mango stored at 25°C for 8 days. Whereas the mango flesh being kept at 13°C turned into yellow color (h° = 85.94) after 25 days. The speed of color development depended greatly on the temperature as evident from the storage at 25°C at which development into yellow color occurred at a faster rate than at 13°C (Fig. 4.33). The yellow color change of the mango flesh was the result of carotenoid synthesis during ripening process that influenced the color change in mango flesh from yellowish-green to yellow and from yellow to dark yellow and orange eventually (Fennema, 1996). The process of carotenoid synthesis could be stopped when the storage was carried out at low temperature. Thomas (1975) reported that the storage of mango at 7°C for the period of 16 days would influence the carotenoid content in the mango flesh eventhough the mango was later allowed to ripe naturally at room temperature. The mango which was not pretreated at low temperature possessed higher caroteniod content by 22-53%. Similar result was also observed in the study conducted by Moore (2003) who discovered that the storage of Tommy Atkins mango at 5°C resulted in the lower carotenoid content than at 20°C. It was confirmed that storage at low temperature limited the activity of enzyme phosphatase that was related to carotenoid synthesis as also evident from the lowering of enzyme activity (Will et al., 1991). This was in agreement with current experimental result in which the color of mango flesh stored at 5°C still maintained its original yellowish color (h°=91.49) (Fig. 4.34). The storage of mango at other low temperature (13°C) could also slow down the change in color of the mango flesh. However, if the temperature was lower than the critical level such as at 5°C, color development in the ripening stage could be affected as evident from the incomplete color development or brownish color of the mango treated previously in the low temperature condition and later allowed to ripe at 25°C. In addition, Srivichein (2006) also reported the darkening color of mango flesh when the fruits were kept at 5°C for the period of 20 days before incubation at 25°C for 4 days. The symptom was less severe for the mango kept at 13°C.

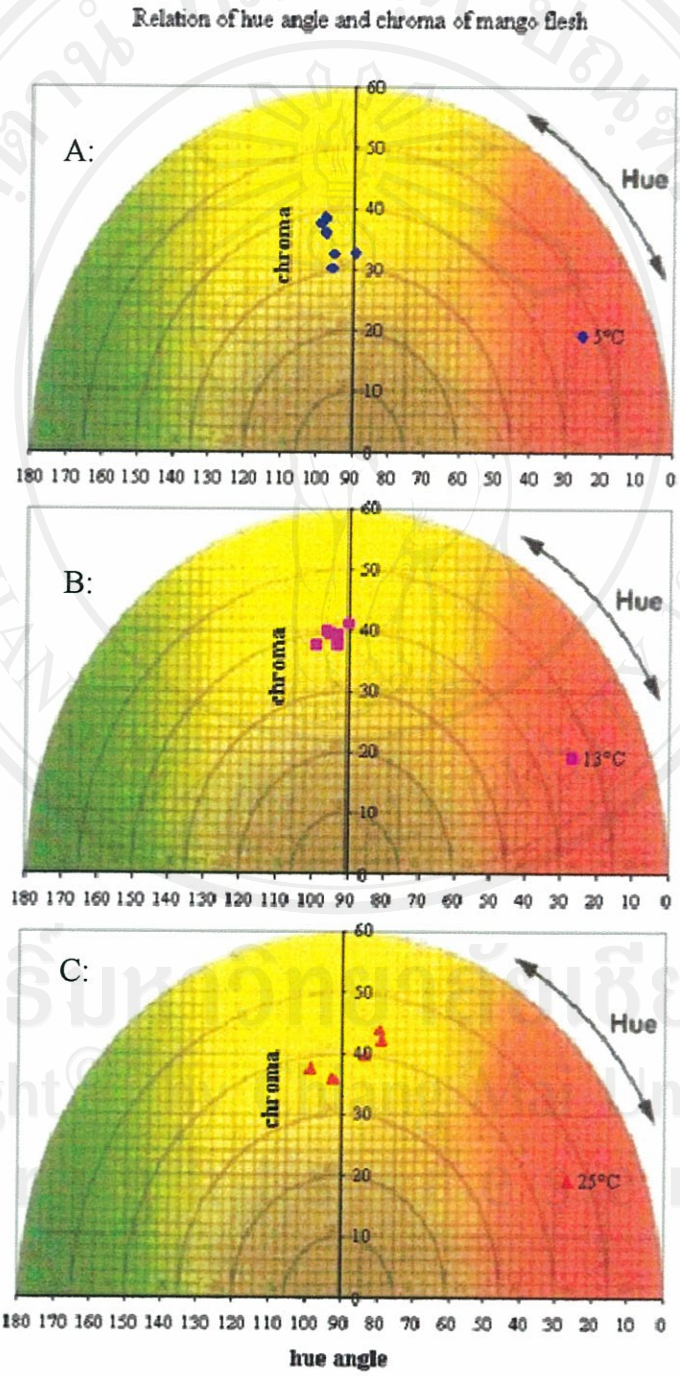

Figure 4.34 The change in hue angle value of Nam Dok Mai Si Thong mango flesh stored in the incubator at A:5, B: 13 and C: 25 °C.

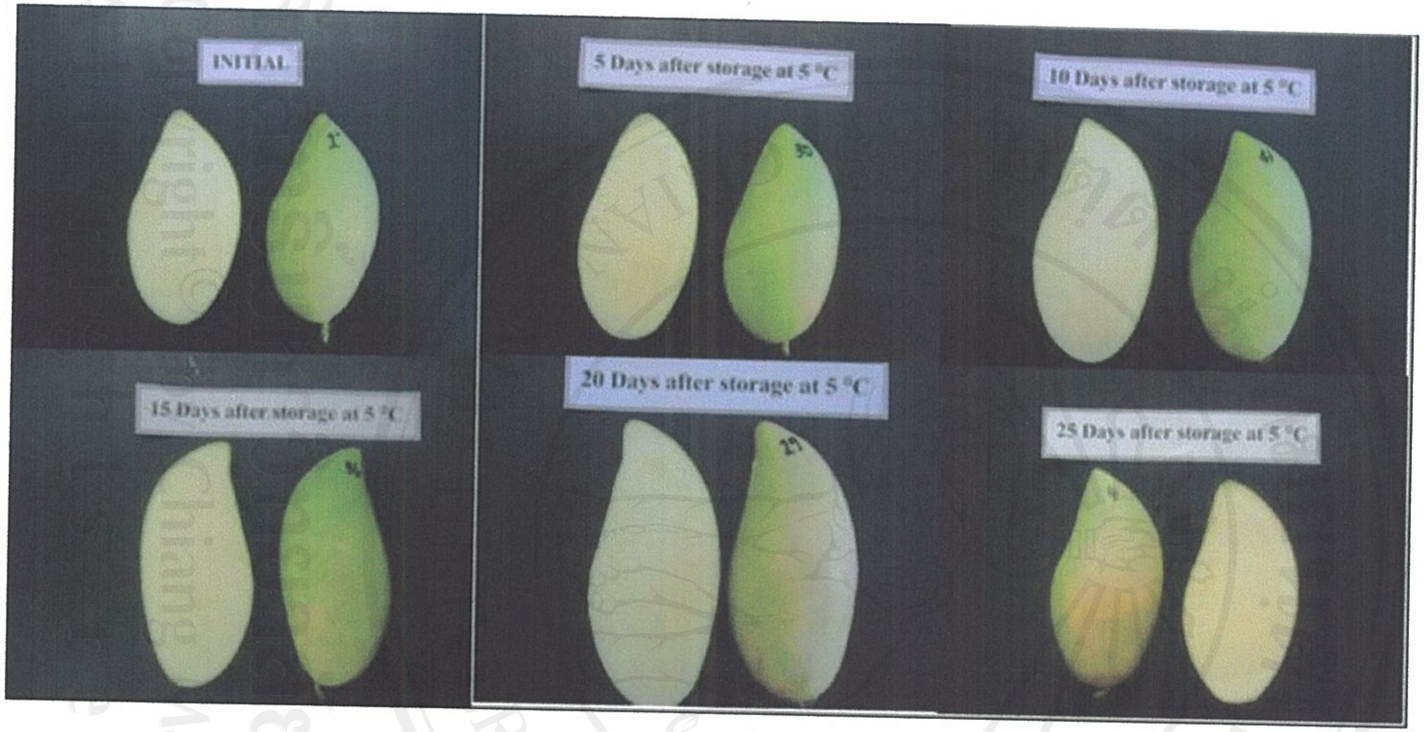

Figure 4.35 The change of Nam Dok Mai Si Thong's pericarp and mango flesh stored in a temperature controlled cabinet at 5±0.5°C.

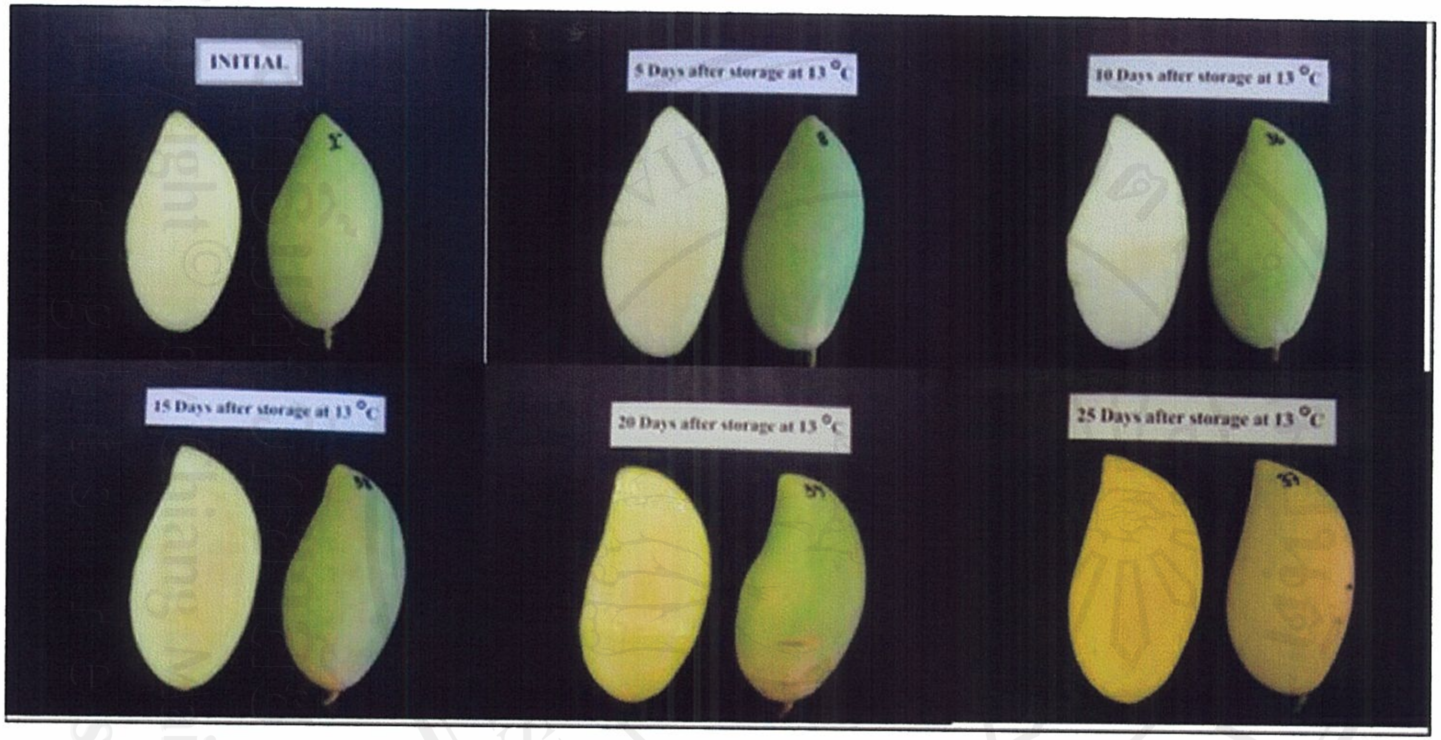

Figure 4.36 The change of Nam Dok Mai Si Thong's pericarp and mango flesh stored in a temperature controlled cabinet at 13±0.5°C.

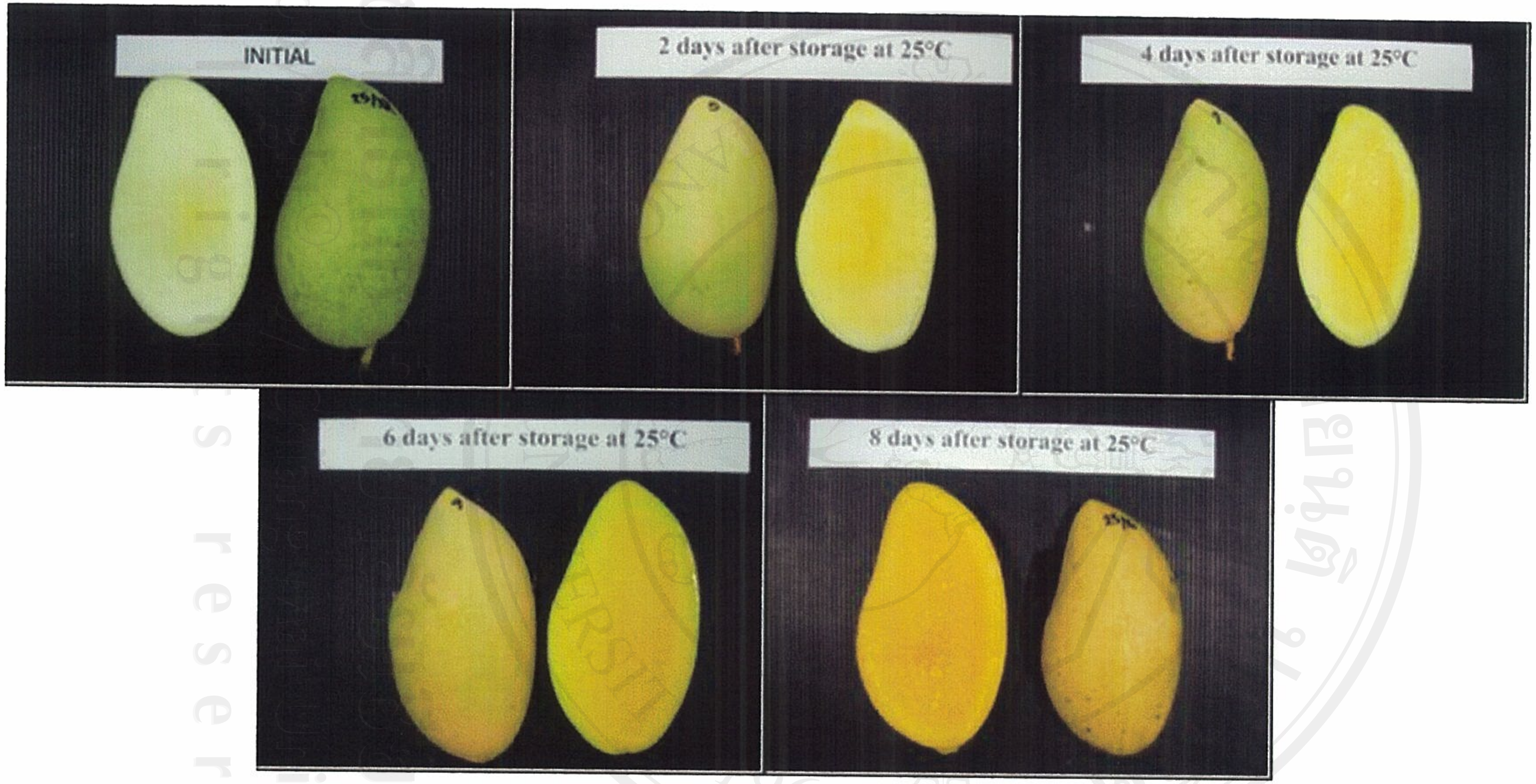

Figure 4.37 The change of Nam Dok Mai Si Thong's pericarp and mango flesh stored in a temperature controlled cabinet at 25±0.5°C.

4.5.5.2 Firmness

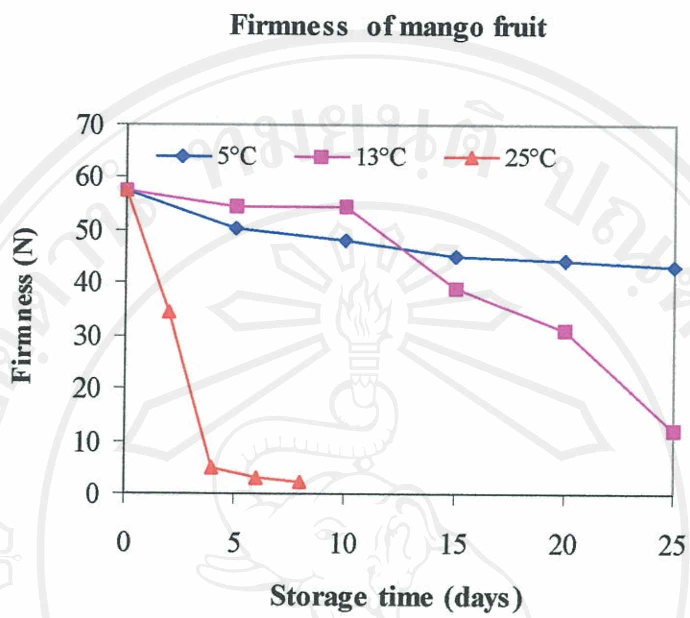

Figure 4.38 Firmness profile of Nam Dok Mai Si Thong mango flesh in the incubator at 5, 13 and 25°C.

Fig. 4.38 illustrated the change in firmness of mango flesh being stored at 5, 13 and 25°C. The firmness of mango stored in the 25°C incubator decreased with the storage time at the fastest rate in comparison to storage conditions at 13 and 5°C. The initial firmness value of 57.52 N on the first day was dropped to 2.4, 12.04 and 43.1 N on the 8th and 25th day of storage at 25, 13 and 5°C, respectively. The storage at low temperature helped prevent the change in firmness of mango flesh. This result was in accordance with the experiment performed by Uthaibutra *et al.* (2005) who tested the storage of Maha Chanok mango at 10 and 13°C. The changes in firmness at both temperatures were only slight whereas the storage at room temperature resulted in the rapid decline in the firmness of mango flesh within 7 days. In addition, Chaplin *et al.* (1991) reported that Kensington mango being maintained at 20°C for the period of 7 days was in the ripening stage with the decrease in firmness of mango flesh while the firmness at 15°C began to diminish after storage period of 14 days. In fact, the firmness of mango fruits stored at 1, 5 and 10°C for 21 days had barely changed in the same manner as Keitt mango (Lederman et al., 1997). The decrease in firmness of mango flesh was the direct result of cell wall modification during fruits ripening that in turn decreased cells rigidity and eventually generated softness (Speer, 1997; Beaulieu and Gorny, 2001). Other explanations included the degradation of carbohydrate and lipid as well as cell wall deterioration (Tucker and Seymour, 1991) which were in accordance with the studies by Katawatcharakul (2000), Vasanasong (1998), Chidtragool (1996) and Bartley (1982).

From the study of cell wall structural characteristics under electron microscope of various fruits, it was found that the middle lamella of unripe fruit was heavily colored which was in contrast to the ripened area where the previously colored area began to fade out (Jringtae, 2006). This characteristic was also observed in nonclimacteric fruit such as pomelo (Sawaddipoon, 1994). The close investigation on the modification of plant cell wall was also carried out with a transmission electron microscope (TEM). Whereas the cells of green mango fruits were attached to each other with only minimum intercellular space, the cell walls of the adjacent cells in ripe fruits were separated from each other and revealed the increase of intercellular space (Luza *et al.*, 1992). This was in accordance with the study of structural change of Nam Dok Mai cells during ripening which also pointed out the increasing appearance of intercellular space (Wangchai, 2000). The transformation of insoluble pectin to the soluble form during ripening process was related to polygalacturonase (PG) and pectin methylesterase (PME). PG was subjected to changes during ripening process. Its main function was to degrade polygalacturonic acid molecule, which was considered a free carboxyl group, to a smaller size polymer. The activity of this enzyme was clearly enhanced in mango (Roe and Bruemmer, 1981; Laza *et al.*, 1986; Chaimanee, 1992; Chirdtragool, 1996), durian (Dangkanit, 1995) and papaya (Chan and Tam, 1982). The role of PME was to break the ester bond to eliminate methyl group from the molecule of galacturonan. It was evident that the activity of this enzyme was enhanced during ripening process of fruit (King and O'Donohue, 1995; Sethu et al., 1996). The storage at high temperature elevated the activity and catalytic rate of PG and PME. Therefore the fruits being stored at high temperature had a more rapid descend of firmness relative to the fruit being stored at lower temperature (Chaimanee, 1992 and Aina and Pladynjoye, 1993). The decline in firmness of mango flesh at 25°C in comparison to 5 and 13°C also followed the same trend of other studies mentioned previously.

When the relationship between the change in firmness and respiratory rate during various storage conditions at 5, 13 and 25°C were taken into account, the storage at high temperature (25 and 13°C) resulted in the descend of firmness level at a faster rate than the storage at low temperature (5°C). This was due to the higher respiratory rate of mango at higher temperature which in turn furthered the speed of development into ripening process. Thus the firmness value of mango stored at 25°C declined at a faster rate than the storage at 13 and 5°C, respectively (Fig. 4.39 to 4.41).

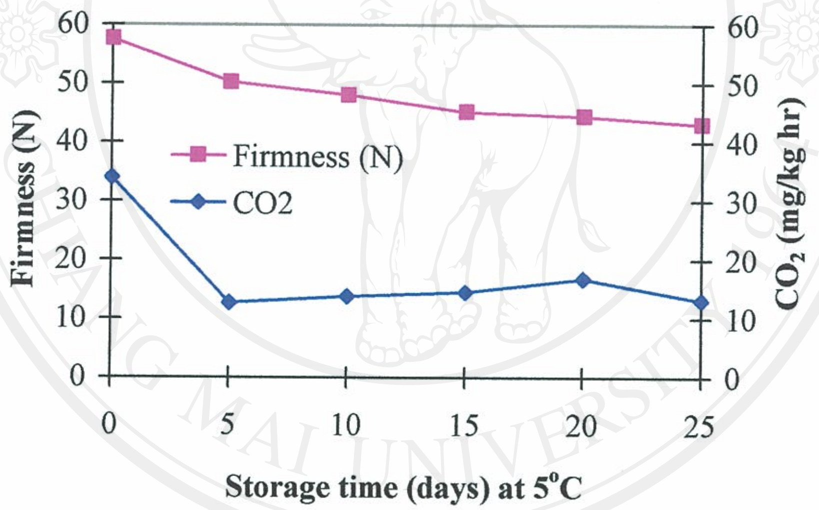

Figure 4.39 The relationship between the change in firmness of mango flesh and the respiratory rate of Nam Dok Mai Si Thong mango stored in the incubator at 5°C.

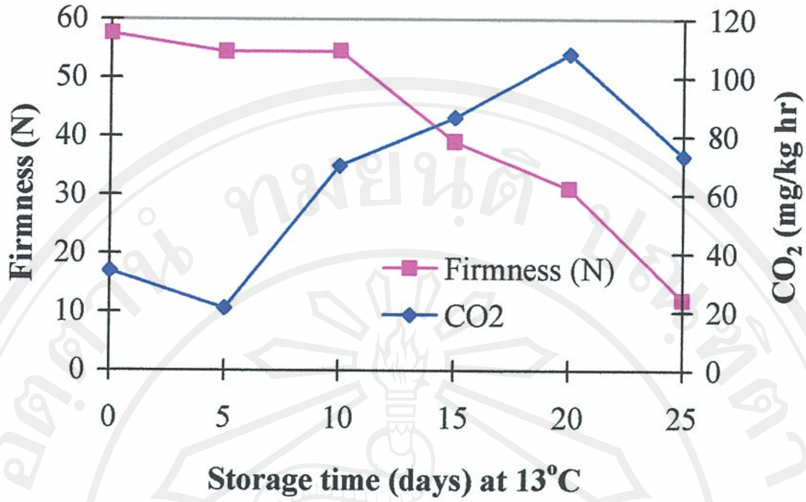

Figure 4.40 The relationship between the change in firmness of mango flesh and the respiratory rate of Nam Dok Mai Si Thong mango stored in the incubator at 13°C.

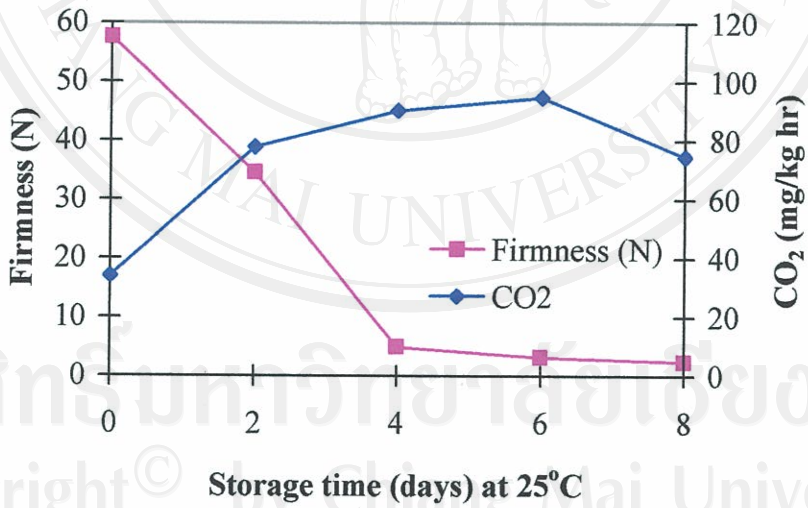

Figure 4.41 The relationship between the change in firmness of mango flesh and the respiratory rate of Nam Dok Mai Si Thong mango stored in the incubator at 25°C.

4.5.5.3 Weight loss

The weight loss percentage increased with storage time at all storage temperature being investigated.

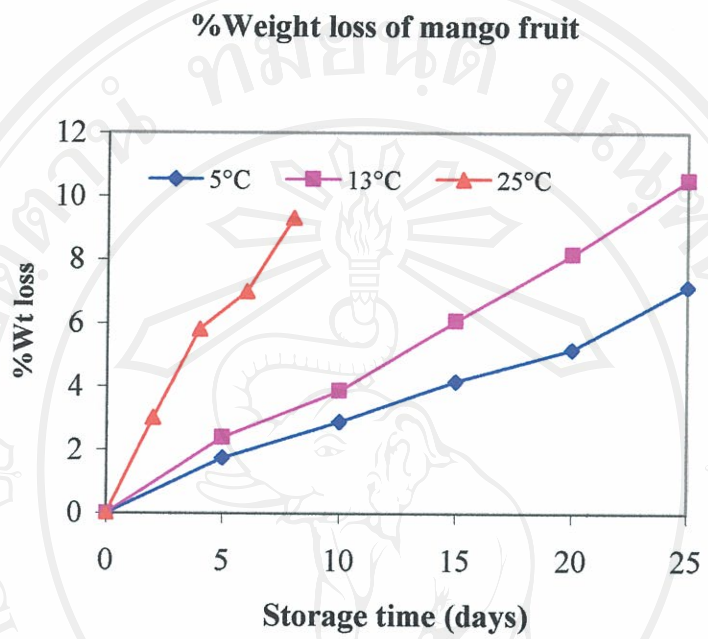

Figure 4.42 The weight loss profile of Nam Dok Mai Si Thong mango stored in the incubator at 5, 13 and 25 ± 0.5°C.

The level and rate of weight loss during storage of Nam Dok Mai Si Thong mango were the highest at 25°C when comparison was made with the other storage conditions at 13 and 5°C. As various enzyme activities occurred in the fresh product were slowed down by storage at low temperature. This result was found to be in good agreement with the study on other mango varieties including Julie (Sankat *et al.*, 1993), Manila (Hidalgo *et al.*, 1996), Chok Anan (Vasanasong, 1998; Intalook, 2005), Nam Dok Mai (Wangchai, 2000) and Nang Klang Wan (Katawatcharakul, 2000). The natural weight loss was the result of mango transpiration through stomata, lenticel and other openings (Mendoza and Wills, 1984). Water loss was the main factor in weight loss of mango. Relative moisture, temperature of product and environments were all playing important roles in weight loss of product (Wilson, 2006). The mango responded to storage at high temperature by transpiring in greater amount than at lower temperature (Ketsa, 1993). The internal activity within the mango fruit was enhanced at high temperature and thus resulted in the higher rate of transpiration (Wilson, 2006). In addition, the storage of fruit at low temperature slowed down the enzyme activity and metabolism process which in turn delayed the ripening process and hence the decrease in weight loss (Patterson, 1987). The storage in the conditions of different relative humidity contributed to the difference in weight loss because the relative humidity represented the ability of air to uptake the water vapor at a specific temperature (Pongsawaddimanich, 2001). The relative humidity in the temperature controlled incubator at 25°C was 75% whereas the figures were 78-80 and 82-85% for the storage temperature of 13 and 5°C respectively. Therefore the mango being stored at 25°C would lose more water than the storage at 13 and 5°C.

The discrepancy between the water vapor pressure inside and outside the mango fruit was not the sole cause that led to the weight loss in mango. The loss of water could still be occurring even when the surrounding air was saturated with water or 100% relative humidity. Because fruits could be considered as living organisms with respiration and the release of heat to the surrounding atmosphere, the exothermal heat would result in the elevated temperature and hence the decrease in relative humidity that allowed extra space for water vapor (Siripanich, 2001). The high temperature of storage increased the driving force between vapor pressure of water within the mango and air. In addition, the development of ripening process in mango also led to the increase in water loss (Kader and Rolle, 2004). This corresponded to the experimental result which stated that the storage of mango at 25°C had the higher level and rate of respirations than at 13 and 5°C. Based on this reason, the storage at 25°C would experience a higher weight loss than at other temperatures of 13 and 5°C. Such observation was in agreement with the investigations carried out in other mango varieties of Nam Dok Mai (Wangchai, 2000) and Maha Chanok (Andkard, 2004) as well as cucumber (Kang *et al.*, 2002) which also reported the greater rate of respiration and weight loss at high temperature and correlated the weight loss at 25 and 13°C to ripening process.

4.5.5.4 Moisture Content

4.5.5.4.1 Moisture content at the peel

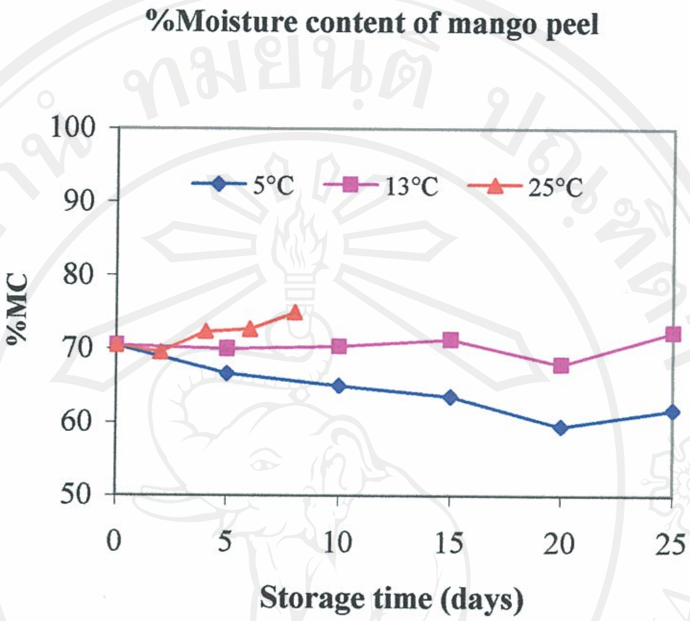

Figure 4.43 The moisture content profile of Nam Dok Mai Si Thong peel being maintained in the incubator at 5, 13 and 25°C.

The moisture content in the peel of mango being stored at 5°C decreased from the initial value of 70.43% to 61.72% on the 25th day of storage (Fig. 4.43). The loss in moisture content at the peel was the result of difference in water vapor pressure between the mango (high value) and the air surrounding mango fruit within the storage incubator (the average relative humidity in the cabinet was 82-85%). The water loss from the peel was through the natural openings of the fruit such as stomata or lenticel. In addition, the mango fruits being stored at this temperature also exhibited the chilling injury. Such deterioration of the cell membrane disabled the capability of controlling the flow of materials and water. Chilling injury was thus considered as another cause that contributed to the decrease in moisture content of the peel.

The opposite trend was observed for the mango storage at 13 and 25°C whose moisture content of the peel was found to increase from the initial value of 70.43% to 72.26 and 74.94% on the 25th and 8th day of storage at 13 and 25°C, respectively. This phenomenon corresponded to the fact that mango fruit was developed into ripening process as evident from the rising rate of respiration or development of yellowish color peel.

4.5.5.4.2 Moisture content of the mango flesh

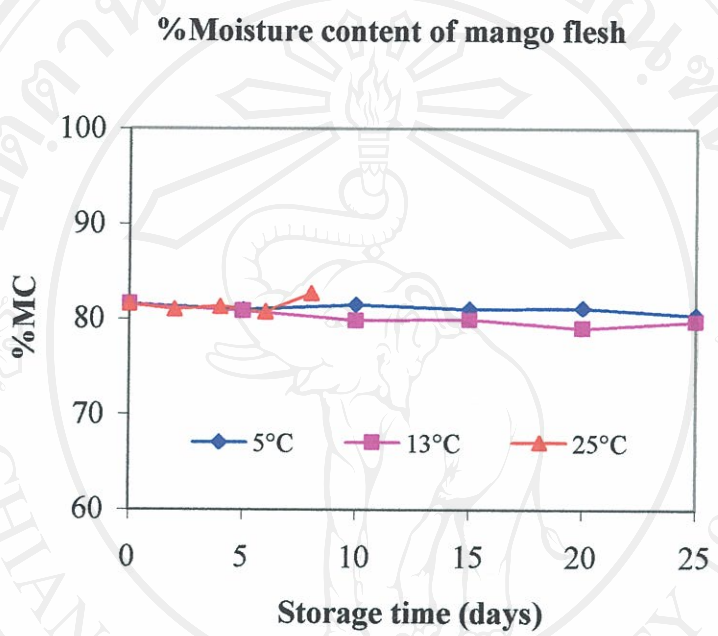

Figure 4.44 The moisture content profile of Nam Dok Mai Si Thong mango flesh being maintained in the incubator at 5, 13 and 25°C.

Fig. 4.44 illustrated the change in moisture content of mango flesh being stored at 5, 13 and 25°C. The moisture content of mango flesh stored at 5°C remained constant throughout the first 20 days of storage and decreased slightly after 25 days. However, such difference was not found to be significant at the confidential interval level of 95%. At 13°C, the period of constant moisture content level was during the first five days at 81.61% which was followed by the decrease until the moisture content leveled off to 79.77% until the 25th day of storage. The mango flesh maintained at 5°C contained a higher level of moisture content than at 13°C because the storage at low temperature slowed down various metabolism processes, especially the respiratory rate. Therefore, the mango flesh stored at 5°C would retain higher level of moisture content than at 13°C.

The moisture content profile of mango flesh being stored at 25°C was also monitored. There was no detectable change in moisture content during the first six days of storage as observed at 5°C. In fact, the moisture content of the mango flesh had increased from the initial value of 81.61% to 82.70% on the 8th day. The ripening process was responsible for such rise in moisture content as supported by the experiment of Siriboon and Banlusilp (2006) who found that the moisture content of banana increased with each stage of ripening.

4.5.5.5 The change in chemical compositions

4.5.5.5.1 Total soluble solid

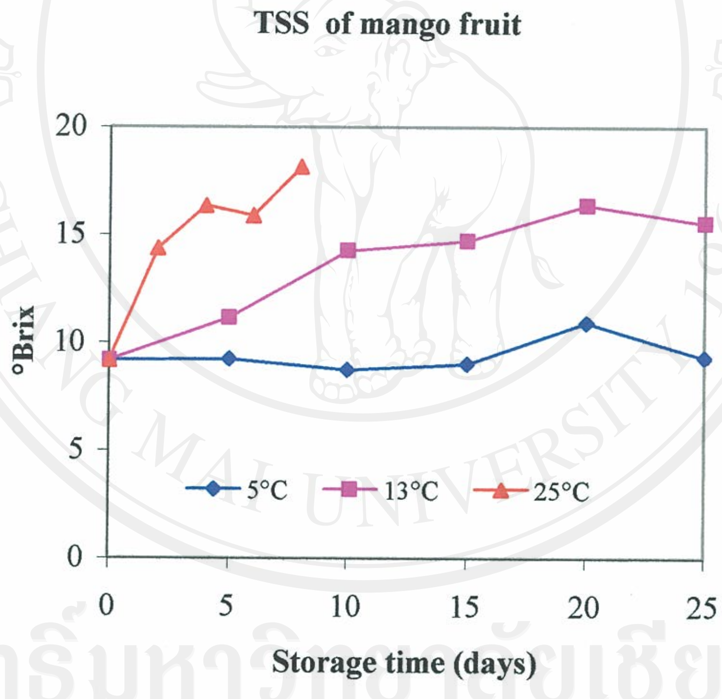

Figure 4.45 The profile of total soluble solid of Nam Dok Mai Si Thong mango stored in the incubator at 5, 13 and 25°C.

The profile of total soluble solid of Nam Dok Mai Si Thong being stored in the temperature controlled incubator at 5, 13 and 25°C shown Fig. 4.45 indicated that the mango at 13 and 25°C contained higher level of total soluble solid during storage. The initial value of 9.17 in the first day had increased to 18.15 and 15.55°Brix on the 8th and 25th day of storage at 25 and 13°C, respectively. The observed elevation in total soluble solid was the result of starch degradation through hydrolysis process to sugar. The total soluble solid which could be measured in term of sugar content (Kalra, 1995; Kapse and Katrodia, 1996) was therefore raised throughout the storage period. This was in accordance with the decrease in solid content of total non-structural carbohydrate (TNC) in Chok Anan mango being stored at 20 and 13°C resulting from the conversion to sugar during ripening process (Vasanasong, 1998). As could be seen from the relationship between the respiratory rate of mango and the profile of total soluble solid content of mango stored at 13 and 25°C (Fig. 4.46 and 4.47) where the elevation in respiratory rate was followed by the simultaneous increase of total soluble solid content from the conversion of starch to sugar.

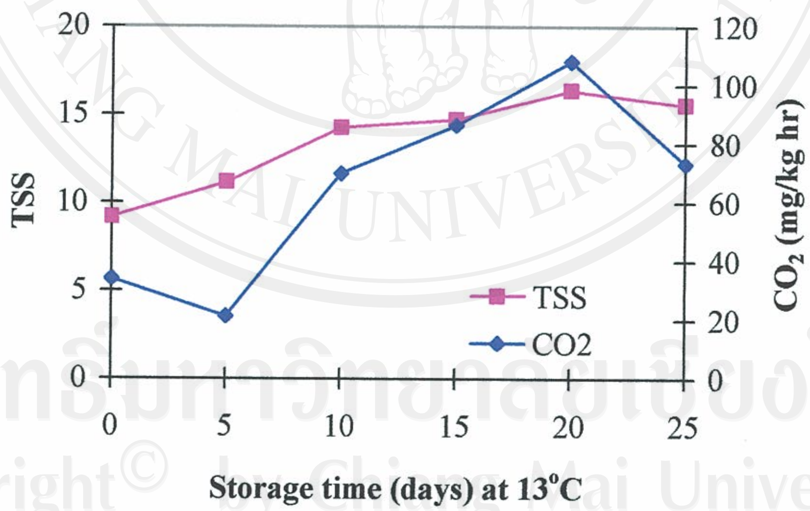

Figure 4.46 The relationship between the total soluble solid and the respiratory rate of Nam Si Thong mango being stored at 13°C.

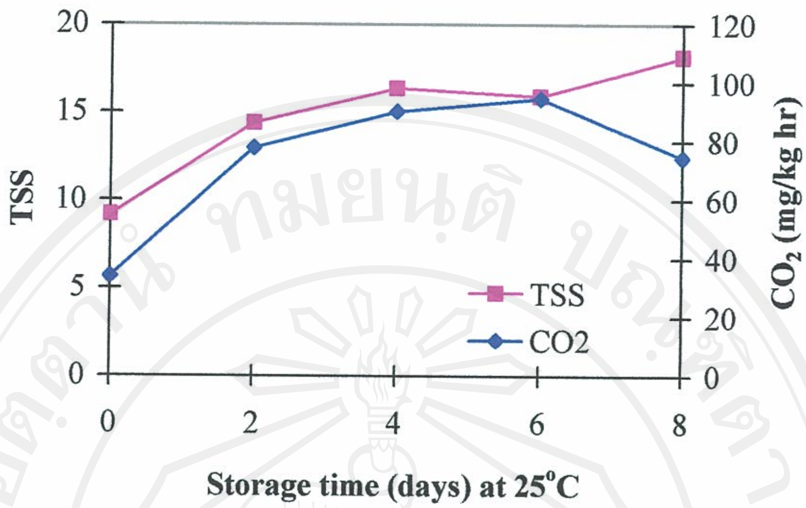

Figure 4.47 The relationship between the total soluble solid and the respiratory rate of Nam Si Thong mango being stored at 25°C.

The profile of total soluble solid content indicated that the storage at 5°C did not cause the major change of solid content in comparison to the storage at other temperatures of 13 and 25°C. The initial value of 9.17°Brix was elevated to 9.31°Brix on the 25th day of storage. Low temperature storage might contribute to this observation as a number of metabolism processes, including the conversion of starch to sugar, were slowed down. The correlation could also be made to the subsided respiratory rate of mango being stored at 5°C in which the rate became constant since the 5th until the 25th day of storage. Because the storage at 5°C slowed down the ripening process or prevented it from happening at all, the increase of total soluble solid was thus occurring at a much slower pace and reached a lower steady level than at 13 and 25°C where the ripening process was set in (Fig. 4.47). The same trend was observed with the storage of other mango varieties such as Keitt (Laderman et al. 1997) and Chok Anan (Posawang, 2003; Intalook, 2005).

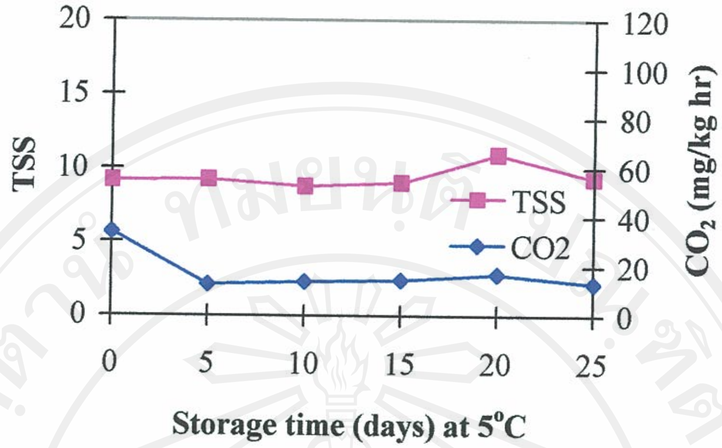

Figure 4.48 The relationship between the total soluble solid and the respiratory rate of Nam Si Thong mango being stored at 5°C.

4.5.5.5.2 The change in titable acidity content and pH

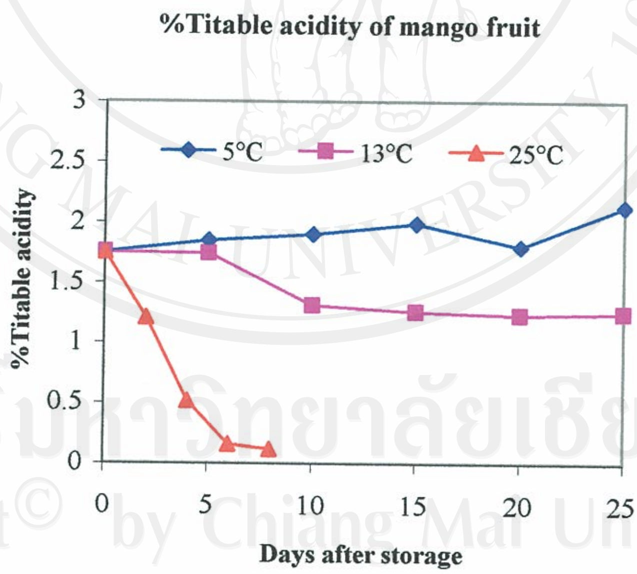

Figure 4.49 The profile of titable acidity content of Nam Dok Mai Si Thong mango stored in the incubator at 5, 13 and 25°C.

Fig. 4.49 showed the profile of titrable acidity content of Nam Dok Mai Si Thong being stored in the temperature controlled incubator at 5, 13 and 25°C. The storage at 13 and 25°C resulted in the decrease of titable acid content with storage time. The faster rate of decrease in titrable acid content was observed at 25°C than at 13°C. The initial value of 1.73% was dropped to 0.12 and 1.25% on the 8th and 25th day of storage at 25 and 13°C, respectively. The decrease could be explained by utilization of acid during respiration process of the mango fruit. The acid was also used as a substrate in the formation of sugar during ripening (Patterson, 1970). The extent of acid usage was varied and depended on temperature and duration of storage. The storage at low temperature slowed down the respiration rate of plant (Siripanich, 2001), thus the degradation of acid through respiratory process that employed it as a substrate was only minimal at low temperature (Tucker, 1993). The accumulation of acids, especially citric acid, was thus inevitable (Rattanpanno and Boonyakiat, 1990). Such findings was in accordance with the result which indicated the rise in citric acid content from 1.73% on the first day to 2.13% on the 25th day of storage at 5°C. Vasanasong (1998) also reported the elevation of citric acid level in Chok Anan mango being kept at 3°C.

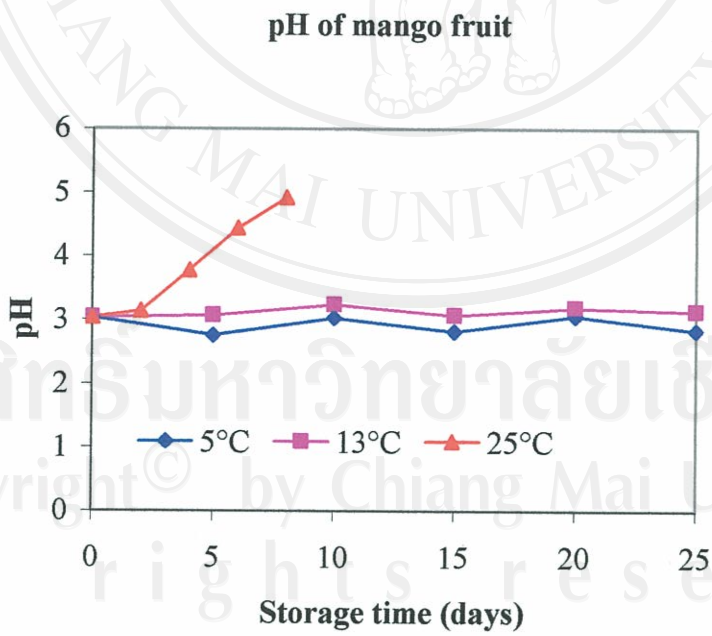

Figure 4.50 The pH profile of Nam Dok Mai Si Thong mango stored in the incubator at 5, 13 and 25°C.

Fig. 4.50 indicated the pH profile of mango being stored at 5, 13 and 25°C. The pH trend of mango kept at 13°C was increasing from the initial value of 3.04 to 3.14 on day 25th, however this was not found to differ significantly at 95% CI level whereas the storage at 25°C resulted in the significant increase (95% CI) of pH from the original value of 3.04 to 4.44 on the 8th day of storage. It could thus be concluded that storage at high temperature produced a faster rate of pH change than at lower temperature as shown by the higher value of measured pH at 25 than at 13°C. The shift in pH value during storage was the result of acids replacement which constituted a part of respiratory process in plant as evident from the relationship between the pH value and the titratable acid content in the mango being maintained at 25°C (Fig. 4.51).

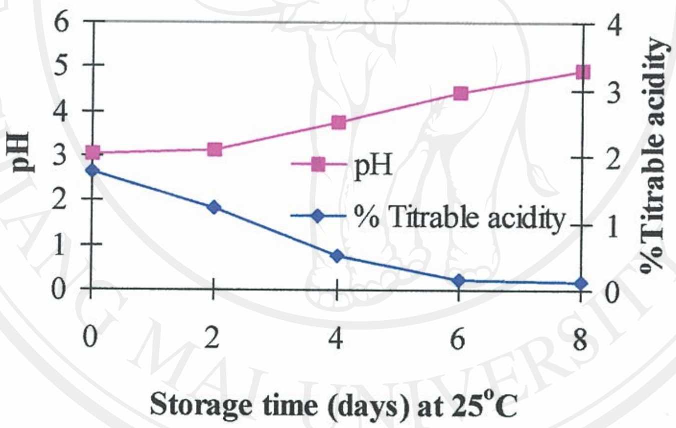

Figure 4.51 The relationship between the titratable citric acid content and the pH of Nam Dok Mai Si Thong mango being stored at 25°C.

The measured pH of the extracted mango juice stored at 25°C was found to increase with storage period as illustrated in Fig. 4.51. This could be correlated to the dropping in titratable acid content in the mango juice. The change in pH was one of three steps relating to the respiratory process in which a six carbon molecule of glucose was converted to a three carbon compound of pyruvic acid in glycolysis pathway which was later transformed to carbon dioxide in tricarboxylic acid (TCA cycle) in which citric acid was also an intermediate. Other compounds being generated in TCA cycle also included $NADH+H^+$, $FADH_2$ and ATP which could be used later in the process of electron transport. Because the respiratory rate of mango being stored at 25°C was faster than at 13°C, the acid content must therefore dropped at a faster rate than at 13°C and resulted in a higher pH value.

The investigation of pH and titratable acid content profiles of mango suggested the similar correlation between the storage at 13 and 25°C. After the storage period of 10 days, the pH and titratable acid content profiles of mango were steady as shown in Fig. 4.52.

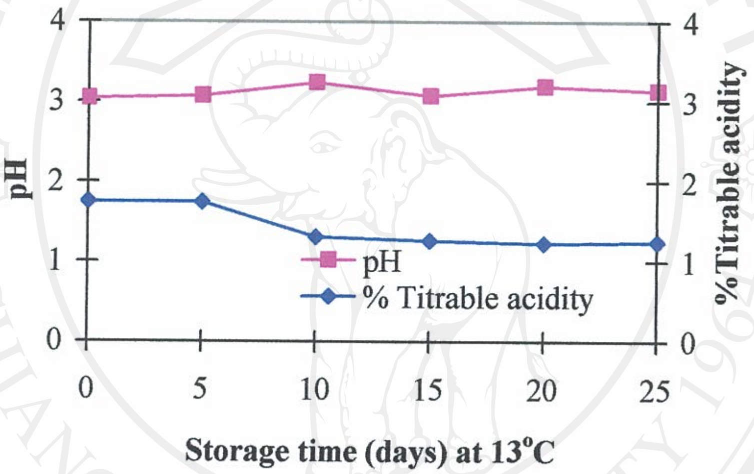

Figure 4.52 The relationship between the titratable citric acid content and the pH of Nam Dok Mai Si Thong mango being stored at 13°C.

This was in accordance with the measured pH from numerous varieties of mango such as Nam Dok Mai, Chok Anan and Nang Klang Wan which stated that the storage at room temperature would result in the higher pH value than at lower temperature. In fact, the pH profile was found to increase with storage period (Vasanasong, 1998; Chidtragool, 1996; Katawatachakul, 2000; Chaiwong, 2004).

However, the storage at 5°C would produce a decrease in pH from the first day of storage until a steady value was reached and remained constant at this value throughout the storage period. Similar trend was observed with titratable acid content from the mango juice whose value increased during the first 5 days until it leveled off on the 20th day of storage (without significant difference at 95% CI). In fact, the storage on the 25th day showed the elevation of Titrable acid content (Fig. 4.53) as the storage at this temperature resulted in the deceleration of respiratory rate and the level of generated CO_2. From the experiment, the level of generated CO_2 was relatively low when compared to the storage at 13 and 25°C (Fig. 4.28). Such condition would slow down a number of metabolism processes and promoted the accumulation of acid as evident from the enhanced level of titratable acid which in turn corresponded to the lower value of pH.

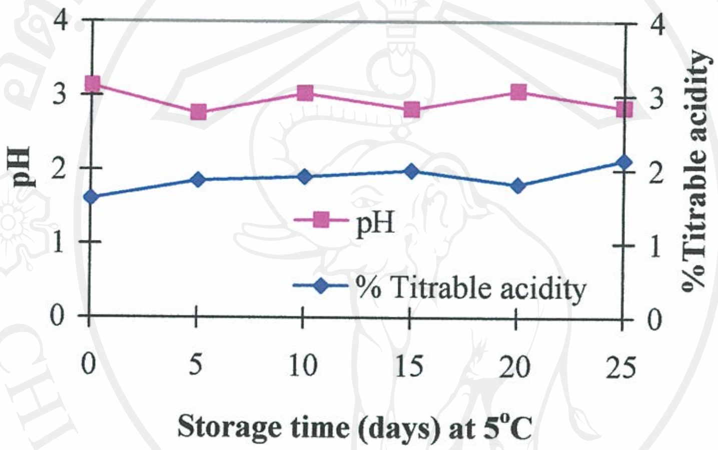

Figure 4.53 The relationship between the titratable citric acid content and the pH of Nam Si Thong mango being stored at 5°C.

4.5.5.5.3 The electrolyte leakage of mango flesh

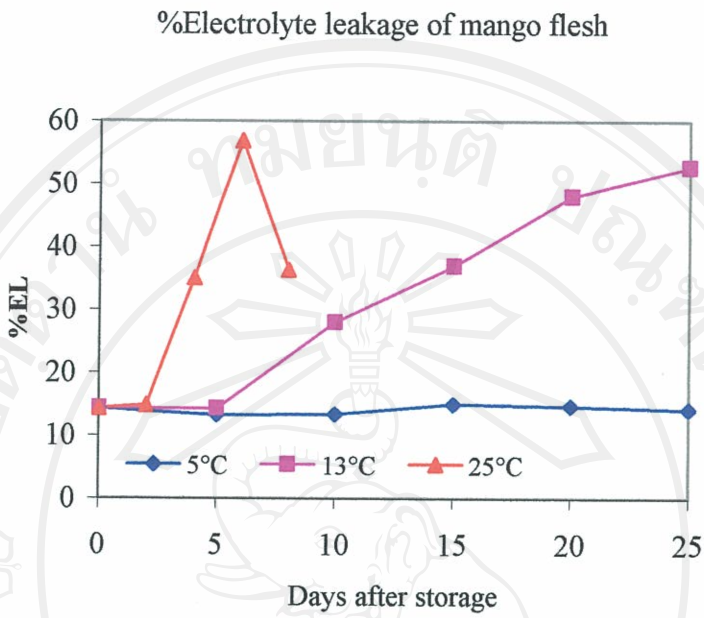

Figure 4.54 The electrolyte leakage profile of Nam Dok Mai Si Thong mango flesh stored in the temperature controlled incubator at 5, 13 and 25°C.

4.5.5.5.3.1 storage at 5°C

Fig. 4.54 showed the electrolyte leakage profile of mango flesh being stored at 5, 13 and 25°C. The leakage of electrolyte at 5°C was stable throughout the storage period (without significant difference at 95% confidential interval). The storage at low temperature slowed down a number of processes that occurred during ripening which was in accordance with the storage at 5°C in which the respiratory rate was low and constant during the period of 5 to 25 days (Fig. 4.55). Other activities that occurred during ripening process such as the color of mango, b* value (Fig. 4.56), firmness (Fig. 4.57) and total soluble solid content (Fig. 4.58) only occurred in a minimal extent which supported the fact that the storage at 5°C prohibited the ripening process.

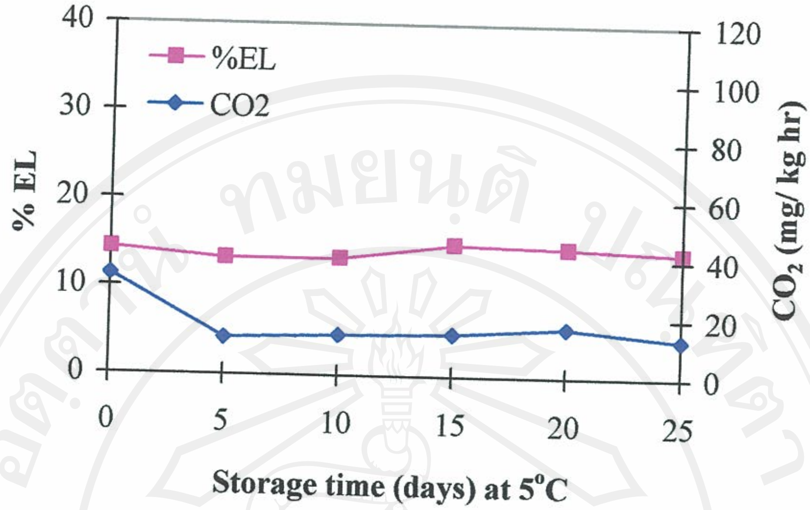

Figure 4.55 The relationship between the respiratory rate and electrolyte leakage of Nam Si Thong mango flesh being stored at 5°C.

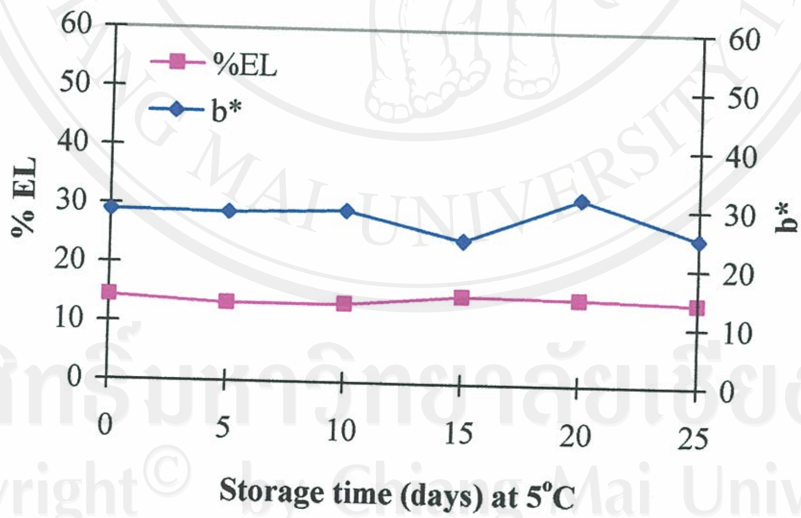

Figure 4.56 The relationship between the profile of b* value and electrolyte leakage of Nam Si Thong mango flesh being stored at 5°C.

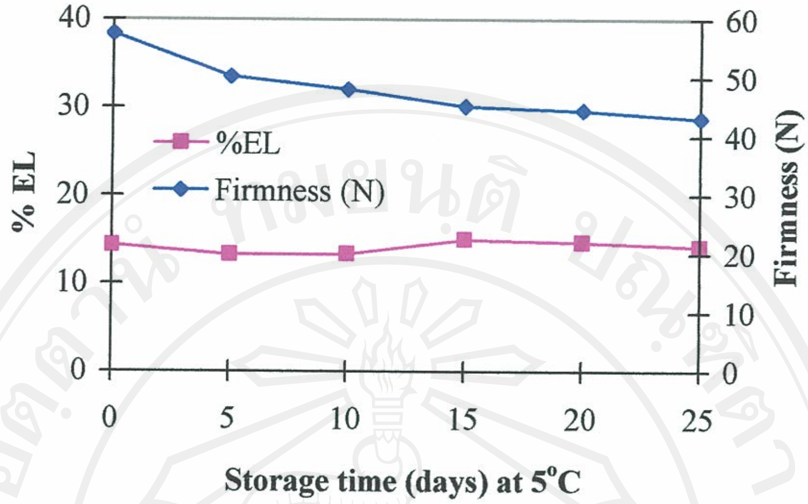

Figure 4.57 The relationship between the profile of firmness and electrolyte leakage of Nam Si Thong mango flesh being stored at 5°C.

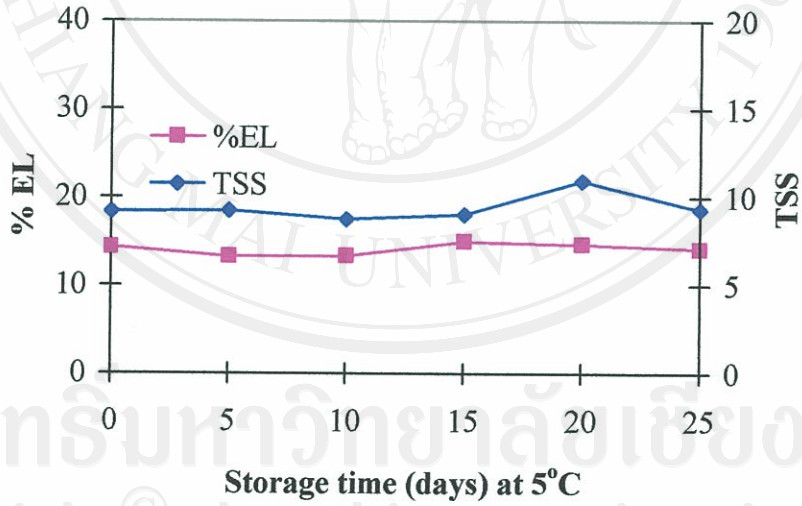

Figure 4.58 The relationship between the profile of total soluble solid (TSS) and electrolyte leakage of Nam Si Thong mango flesh being stored at 5°C.

4.5.5.5.3.2 The storage at 13 and 25°C

Because the electrolyte leakage profiles of mango flesh being maintained at 13 and 25°C were quite similar. It was thus necessary to explain both results together. From Fig. 4.52, the trend of electrolyte leakage from the mango flesh at 13 and 25°C increased with storage period. The highest rate of electrolyte leakage occurred at 25°C in comparison with 13°C. The initial value of electrolyte leakage at 14.34% of the mango flesh was increased to the highest values of 56.84 and 52.73% when the fruits were stored for the period of 8 and 25 days at 25 and 13°C, respectively. The elevation of electrolyte leakage at both temperatures stemmed from ripening process as observed from the more yellowish color of the mango flesh with higher b* value (positive b* value indicated the yellowish color). The starting b* value of 28.94 was increased to 52.16 and 37.42 on the 6th and 25th day of storage at 25 and 13°C, respectively (Fig. 4.59 and 4.60).

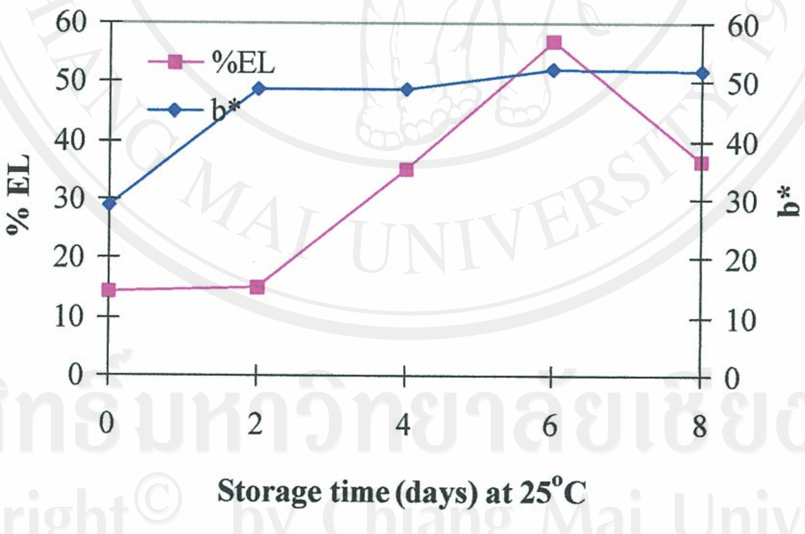

Figure 4.59 The relationship between the profile of b* value and electrolyte leakage of Nam Si Thong mango flesh being stored at 25°C.

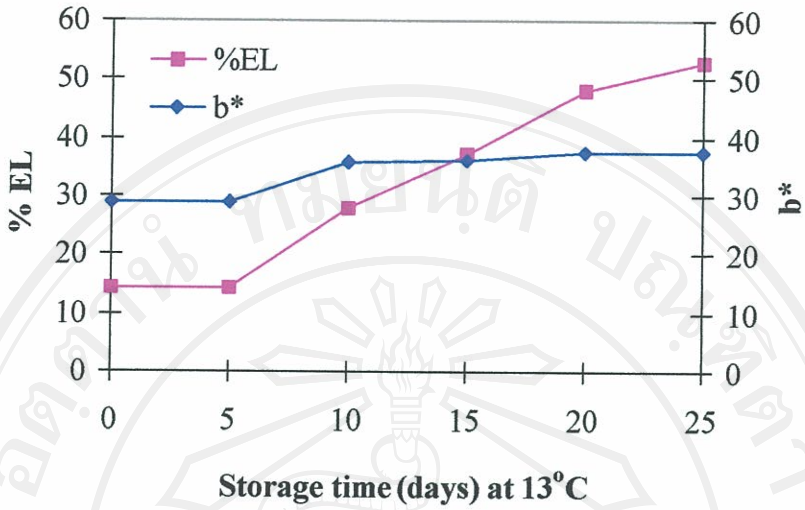

Figure 4.60 The relationship between the profile of b* value and electrolyte leakage of Nam Si Thong mango flesh being stored at 13°C.

The similar trend was also observed for the firmness of mango flesh which was found to decrease from the initial value of 57.52 N to 3.15 N in the 6th day of storage at 25°C. This level of flesh firmness was suitable for consumption. Further storage resulted in the lower value of firmness to 2.4 N on the 8th day (Fig. 4.61), the mango in this stage was not suitable for consumption. Such finding was in agreement with the experiment performed on Chok Anan mango in which the firmness of expired mango was decreased to 3.95 N (Vasanasong, 1998). The storage at 13°C also resulted in the diminished firmness from the original value of 57.52 N to 12.04 N on the 25th day of storage (Fig. 4.62).

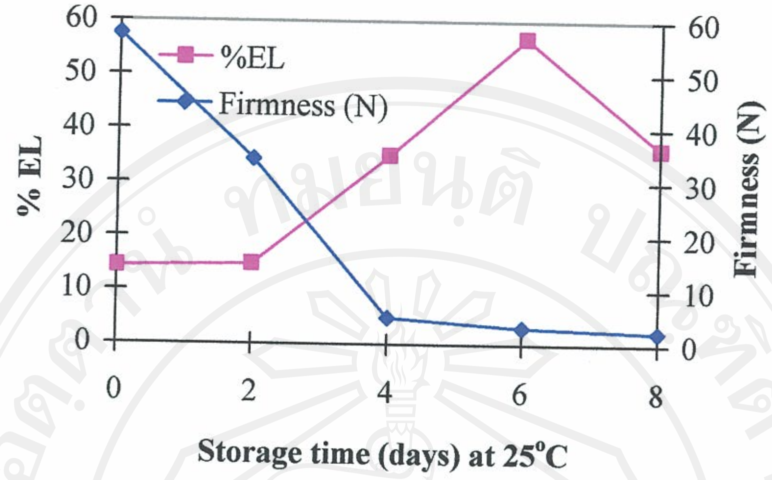

Figure 4.61 The relationship between the profile of firmness and electrolyte leakage of Nam Si Thong mango flesh being stored at 25°C.

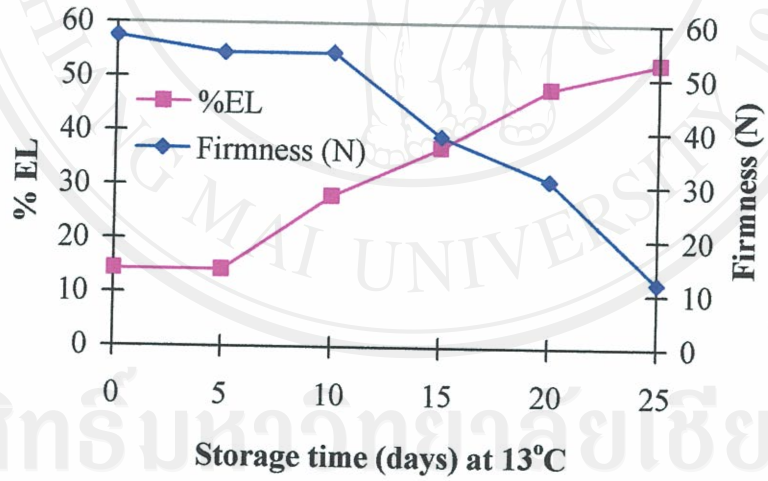

Figure 4.62 The relationship between the profile of firmness and electrolyte leakage of Nam Si Thong mango flesh being stored at 13°C.

There existed a direct relationship between the electrolyte leakage and the respiratory rate of the mango flesh being stored at 25 and 13°C. The rise in electrolyte leakage of the mango flesh was accompanied by the increase in respiratory rate (Fig.

4.63 and 4.64) as supported by the study of Sacher (1996) as well as Baur and Workman (2001) who found that the electrolyte leakage and respiratory rate were increased with the ripening stage or storage period during the storage of banana at 18°C. The increase in respiratory rate was necessary to satisfy the requirement of the cells in the maintenance of cellular membrane. The degradation of cell membrane occurred during ripening process which required energy in various metabolism processes such as enzyme synthesis, conversion of starch to sugar and other processes that might arise during ripening. Thus the electrolyte leakage of mango flesh being kept at 13 and 25°C was caused mainly by the ripening process.

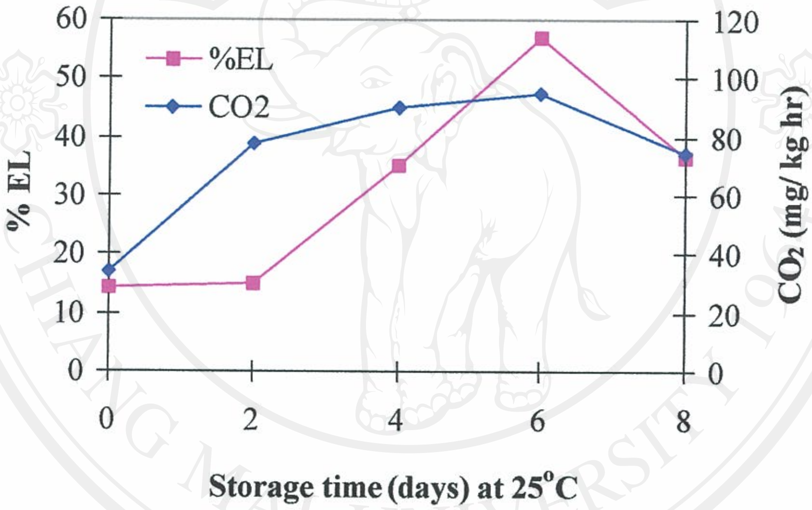

Figure 4.63 The relationship between the profile of respiratory rate and electrolyte leakage of Nam Si Thong mango flesh being stored at 25°C.

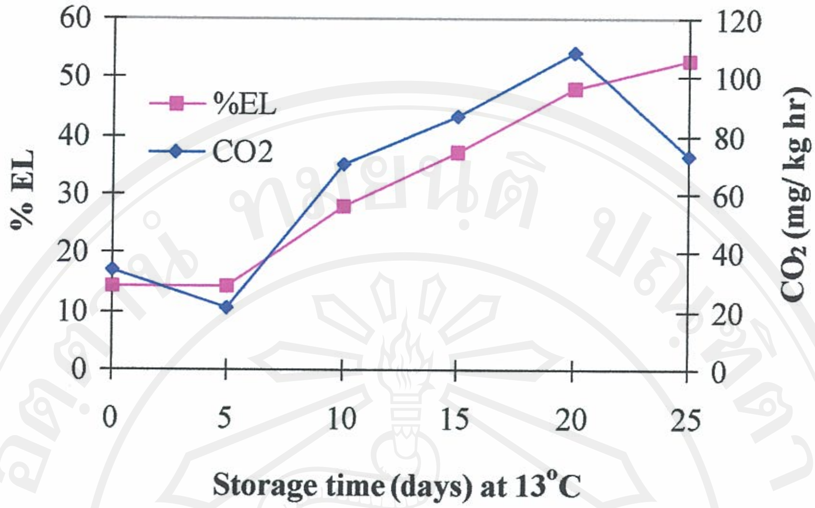

Figure 4.64 The relationship between the profile of respiratory rate and electrolyte leakage of Nam Si Thong mango flesh being stored at 13°C.

The ripening process affected the total soluble solid content as evident from the rise in total soluble solid content from the initial value of 9.17% in the first day to 18.15 and 15.55% in the 6th and 25th day of storage at 25 and 13°C, respectively (Fig. 4.65 and 4.66). The charged substances were subsequentially leaked from the cells in larger quantity and further promoted electrolyte leakage from the mango flesh. The electrolyte leakage of mango flesh being stored at 13 and 25°C was thus caused mainly during ripening process.

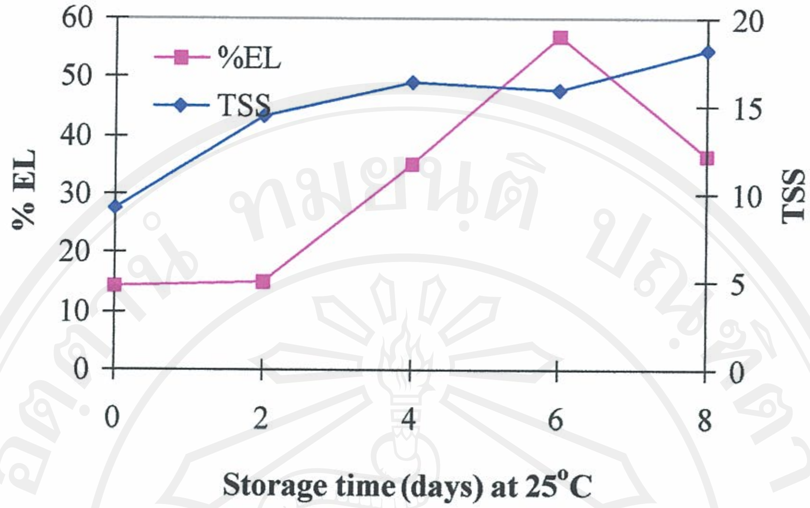

Figure 4.65 The relationship between the profile of total soluble solid (TSS) and electrolyte leakage of Nam Si Thong mango flesh being stored at 25°C.

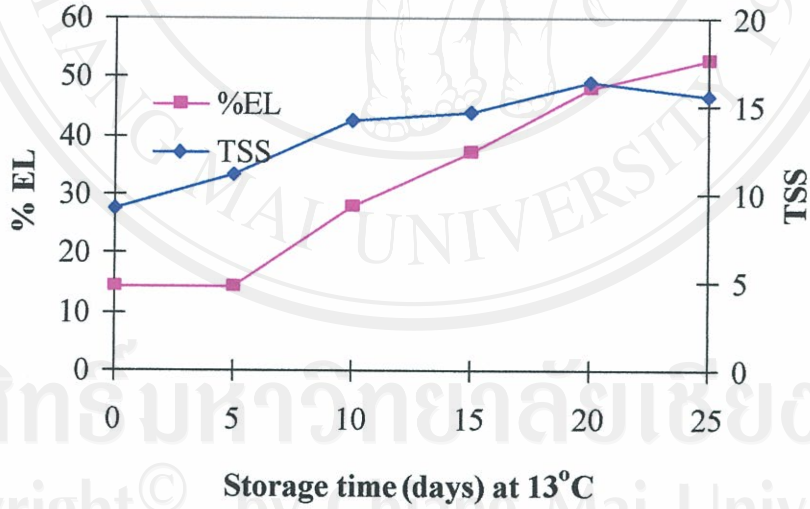

Figure 4.66 The relationship between the profile of total soluble solid (TSS) and electrolyte leakage of Nam Si Thong mango flesh being stored at 13°C.

4.5.6 The change in thermal properties of Nam Dok Mai Si thong during storage at 5, 13 and 25°C

The thermal properties being investigated included the specific heat capacity (Cp), thermal conductivity, density (ρ) and thermal diffusivity (α)

4.5.6.1 The specific heat capacity of mango peel

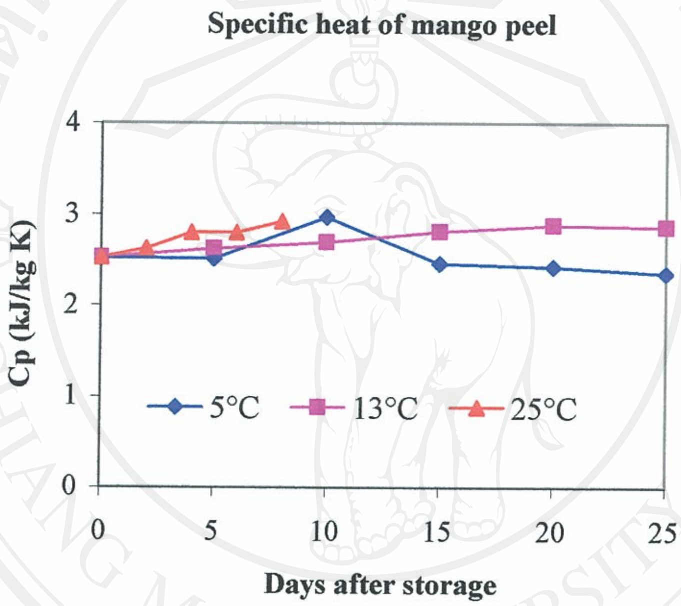

Figure 4.67 The profile of specific heat capacity of Nam Dok Mai Si Thong peel stored in the incubator at 5, 13 and 25°C.

The specific heat capacity at the peel of mango being stored at 13 and 25°C increased with storage period. The initial specific heat capacity value of 2.52 kJ/kg.K was increased to 3.56 and 2.86 kJ/kg.K or 41.27 and 13.49% on the 8th and 25th day of storage at 25 and 13°C, respectively (Fig. 4.67). The specific heat capacity of the peel being stored at 25°C increased in the faster rate to the higher level than at 13°C. It could be thus be stated that the storage temperature was responsible for the change in specific heat capacity of the peel. This was in accordance to the finding of Gabas et al. (2005) who found that the specific heat capacity of plum had the polynomial relationship with the temperature. Thus, the mango kept at 25°C had the higher specific heat capacity than at 13°C. In addition, the rise in specific heat capacity of the peel being stored at 13 and 25°C also had the relationship with ripening process as evident from the development of ripening process at 13 and 25°C, for example, the change of peel color from yellowish-green to yellow (b* value, Fig. 4.68 and 4.69) or the rise in respiration (Fig. 4.70 and 4.71).

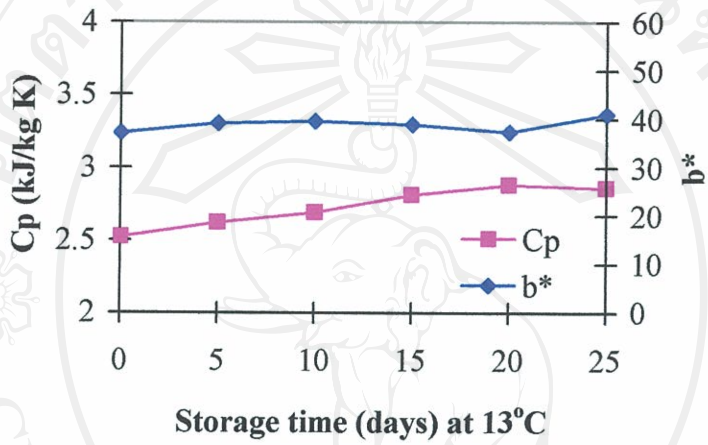

Figure 4.68 The relationship between the specific heat capacity and b* value of Nam Dok Mai Si Thong peel being stored at 13°C.

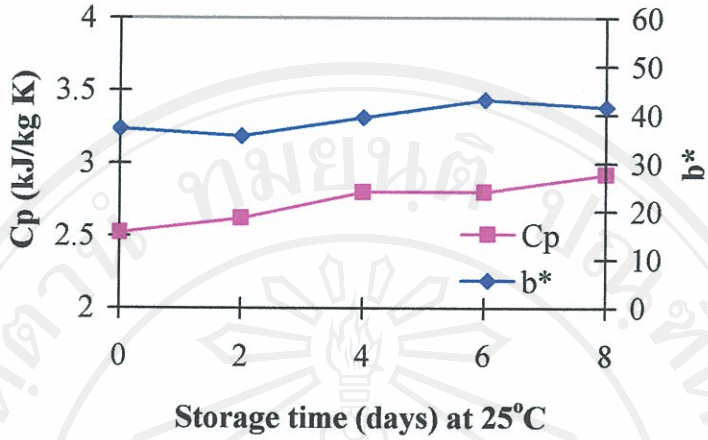

Figure 4.69 The relationship between the specific heat capacity (C_p) and b* value of Nam Dok Mai Si Thong peel being stored at 25°C.

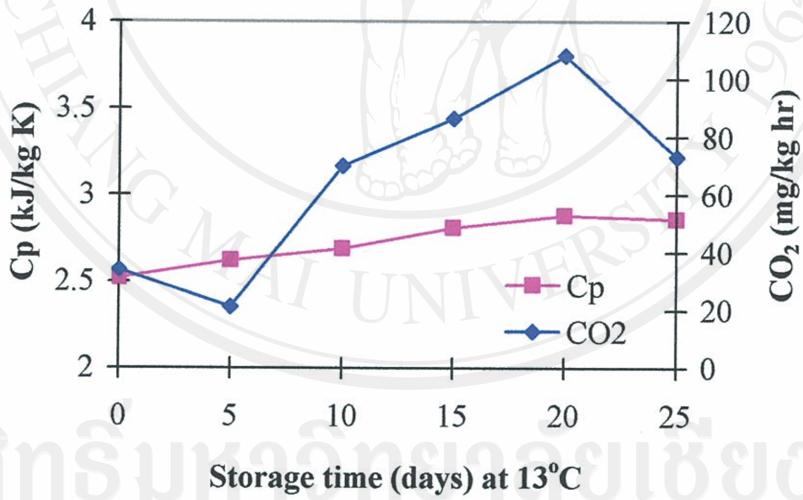

Figure 4.70 The relationship between the specific heat capacity (C_p)of the peel and the respiration rate of Nam Dok Mai Si Thong peel being stored at 13°C.

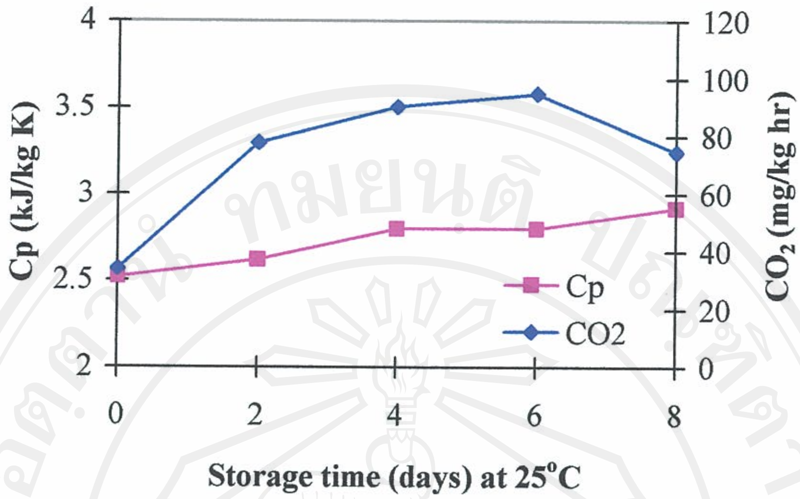

Figure 4.71 The relationship between the specific heat capacity (C_p) of the peel and the respiration rate of Nam Dok Mai Si Thong peel being stored at 25°C.

The detail examination of specific heat capacity at the peel was in concert with the chilling index score of the mango being stored at this temperature and indicated that the specific heat capacity of had increased with the ripening period. The initial value of 2.52 kJ/kg K was increased to 2.88 kJ/kg K or 14.23% on the 20^{th} day of storage in which the chilling injury symptom was strongly pronounced with the highest value (Fig. 4.72). This was in accordance with the change in specific heat capacity at the peel being stored at 25°C suggested that the value had increased with the ripening stage of the fruit. The rise in specific heat capacity at the peel being stored at 13°C was the result of cell senescence as evident from the increase in electrolyte leakage (Fig. 4.73 and 4.74) and ripening process was also a part of cell degradation process (Siripanich, 2003 and 2006).

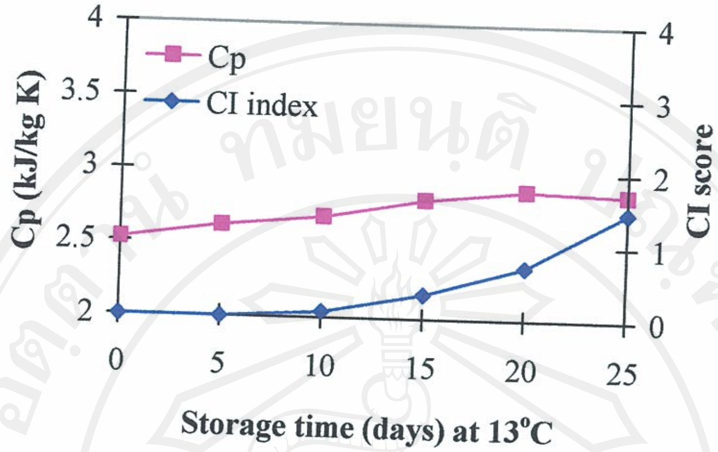

Figure 4.72 The relationship between the specific heat capacity (C_p) of the peel and the chilling index score of Nam Si Thong peel being stored at 13°C.

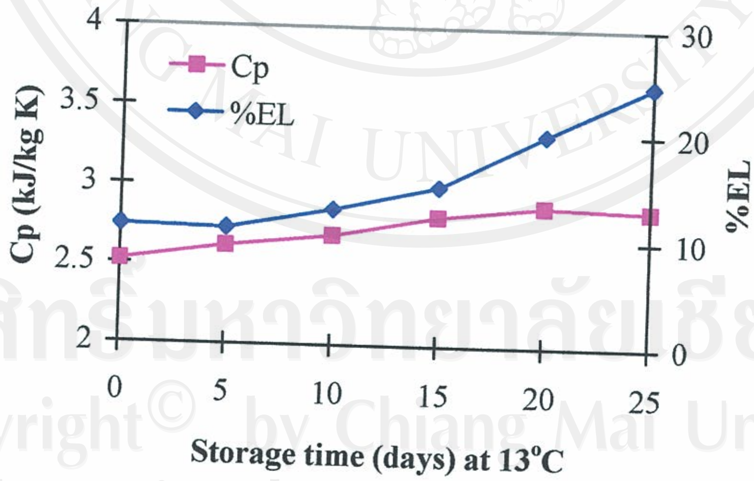

Figure 4.73 The relationship between the specific heat capacity (C_p) of the peel and the electrolyte leakage of Nam Si Thong peel being stored at 13°C.

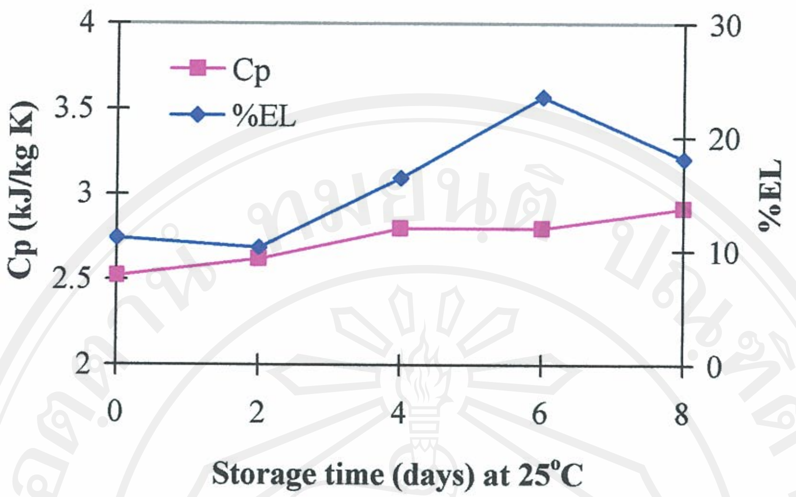

Figure 4.74 The relationship between the specific heat capacity (C_p) of the peel and the electrolyte leakage of Nam Si Thong peel being stored at 25°C.

Whereas the specific heat capacity of peel being stored at 5°C during the first five days of storage was constant and increased to the highest value on the 10^{th} day of storage at 2.97 kJ/kg.K. The chilling injury symptom of the peel at this period was clearly observed (chilling index score of 0.98, Fig. 4.75). The specific heat capacity was later dropped to 2.35 kJ/kg K on the 25^{th} day of storage without significant difference from the first day as evident from the statistical analysis at 95%. The change of specific heat capacity of the peel stored at 5°C was difference from the increase observed at 13 and 25°C due to the absence of ripening process development as evident from the slower color development of the peel. The positive b* value which indicated yellowish color of the fruit being stored at 5°C (Fig. 4.76) was lower than at 13 and 25°C with the value of 30.03, 40.94 and 41.47 at 5, 13 and 25°C, respectively. In addition, Fig. 4.77 illustrated the low and constant respiration rate throughout the storage period at 5°C. The first symptom of chilling injury of the peel appeared on the 10^{th} day of storage with 15.87% rise in specific heat capacity which was then followed by the decrease throughout storage period. Such change was in contrary to the ripening process development where the specific heat capacity of the peel increased with the storage period.

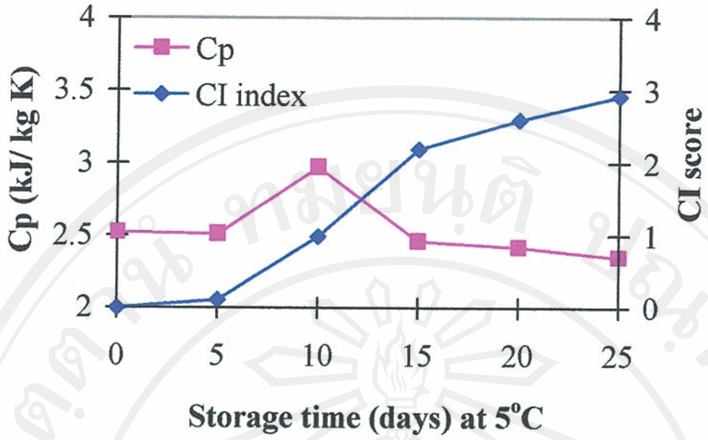

Figure 4.75 The relationship between the specific heat capacity (C_p) of the peel and the chilling index score of Nam Si Thong peel being stored at 5°C.

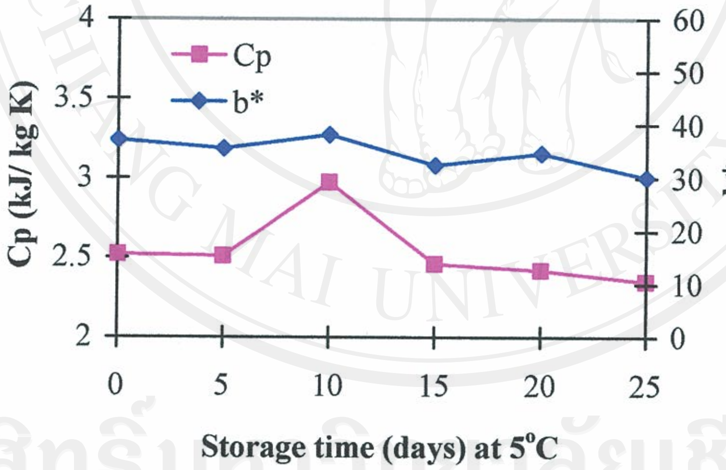

Figure 4.76 The relationship between the specific heat capacity (C_p) of the peel and b* value of Nam Dok Mai Si Thong peel being stored at 5°C.

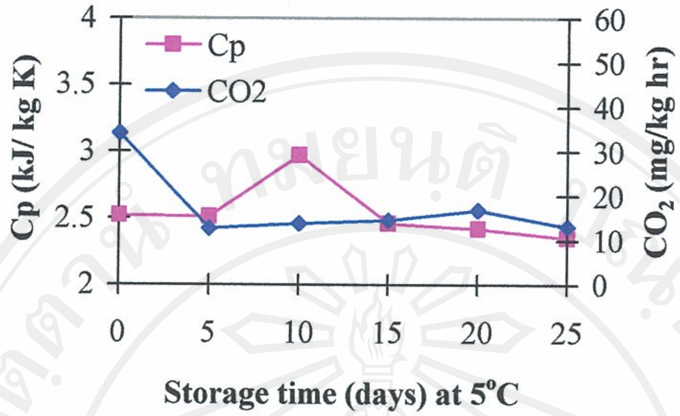

Figure 4.77 The relationship between the specific heat capacity (C_p) of the peel and respiratory rate of Nam Dok Mai Si Thong peel being stored at 5°C.

The relationship between the specific heat capacity of the peel and electrolyte leakage was considered at 5°C. During the first 10 days of storage, the specific heat capacity of the peel increased with the electrolyte leakage which was then followed by the decrease until the final value on the 25^{th} day of storage was closer to the initial value again. In addition, the electrolyte leakage at the peel increased with the severity of chilling injury (Fig. 4.78).

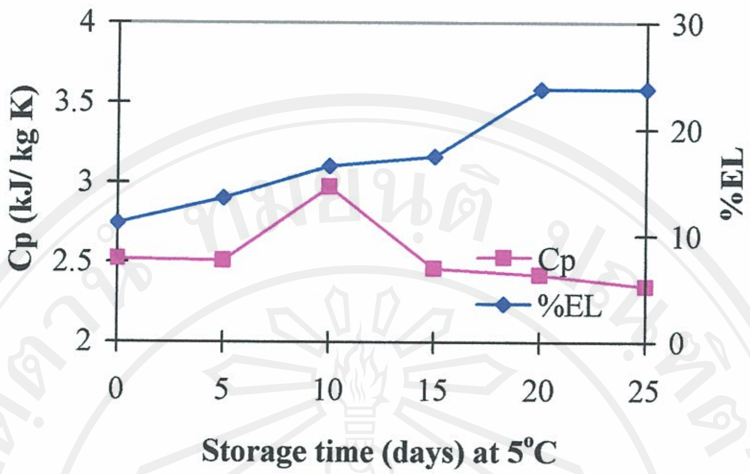

Figure 4.78 The relationship between the specific heat capacity (C_p) of the peel and the electrolyte leakage of Nam Dok Mai Si Thong peel being stored at 5°C.

It could be concluded that the specific heat capacity of the peel increased with the storage period and ripening process. The mango stored at 25°C had the increase value of specific heat capacity at a faster rate than at 13°C. The peel with chilling injury had the increase specific heat capacity at the beginning but was later decreased to the initial value.

4.5.6.2 The specific heat capacity of mango flesh

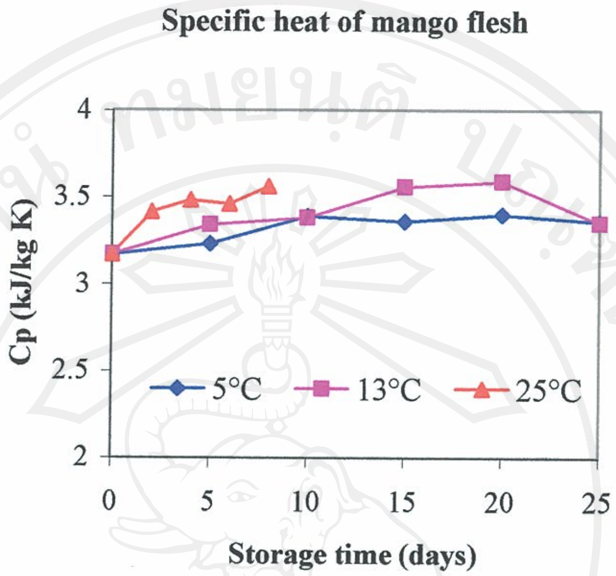

Figure 4.79 The profile of specific heat capacity of Nam Dok Mai Si Thong mango flesh stored in the incubator at 5, 13 and 25°C.

The rate of increase in specific heat capacity of mango flesh being stored at 5°C occurred during the first 10 days of storage from the initial value of 3.17 kJ/kg K to 3.39 kJ/kg K. After this period the specific heat capacity remained constant at 3.36 kJ/kg K ± 0.21 until the 25th day of storage (Fig. 4.79). The relatively constant moisture content of the mango flesh might contribute to the unchanging specific heat capacity. In fact, there was no difference in moisture content of the mango flesh being stored at 5°C at 95% confidential interval (Fig. 4.80). Furthermore, the chilling injury only happened to the pericarp therefore the specific heat capacity of the mango flesh was unaffected. Besides, the physical appearance of the mango flesh was quite similar to the initial state of storage as evident from the color of the mango flesh which was still relative green without transformation to yellowish color (Fig. 4.81). It should be pointed out as well that the storage at this temperature delayed or prohibited color development of the mango flesh which was one step of ripening process. The result was also correlated to the respiratory rate of mango in which the observation of low and constant value was recorded throughout the storage period (Fig. 4.82). The same trend was further noticed on the minimal changes of chemical compositions such as total soluble solid content (Fig. 4.83). The comparison of changes in chemical composition of other compounds such as electrolyte leakage from the mango flesh (Fig. 4.84) and firmness (Fig. 4.85) at this temperature indicated a small degree of variation at low speed which was in contrary to the mango being stored at 13 and 25°C. Srivichien (2006) reported the abnormal ripening process of Nam Dok Mai mango previously stored at 5°C for the period of 15 days then followed by incubation at 25°C. The physical and chemical properties were significantly differed from the fruit underwent normal ripening process at 95% confidential interval. It could be stated that the relatively constant specific heat capacity of the mango being stored at 5°C after the storage period of 15 to 25 days was the result of chilling injury effect.

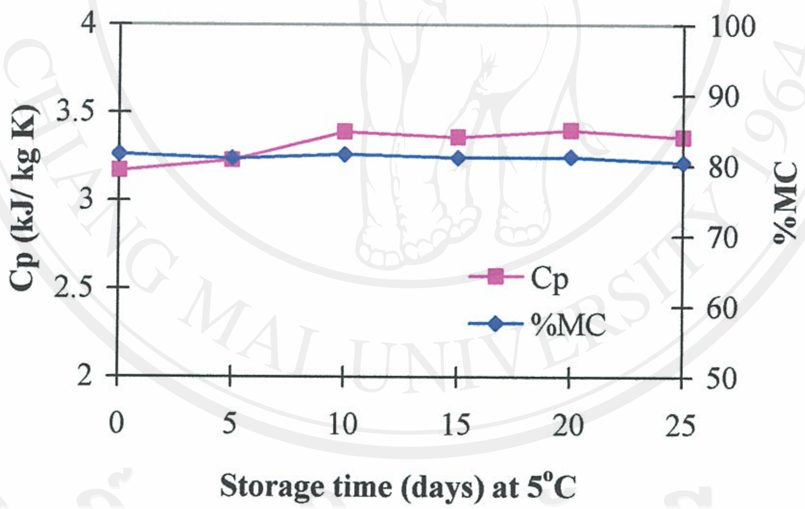

Figure 4.80 The relationship between the specific heat capacity and moisture content of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

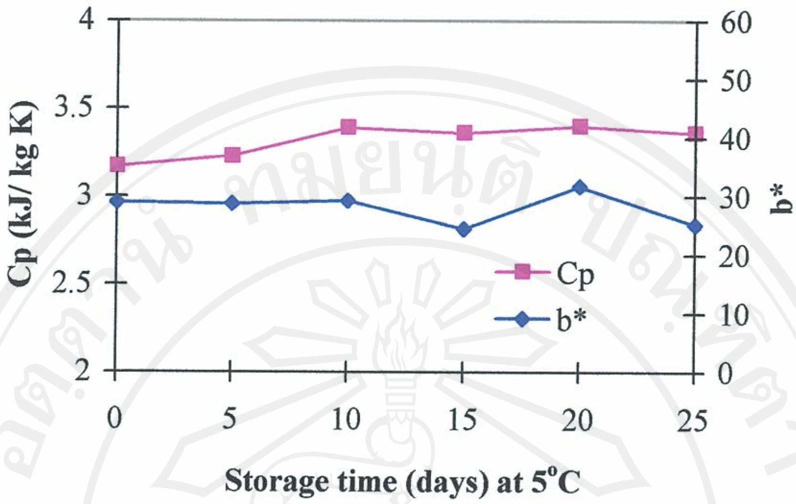

Figure 4.81 The relationship between the specific heat capacity and b* value of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

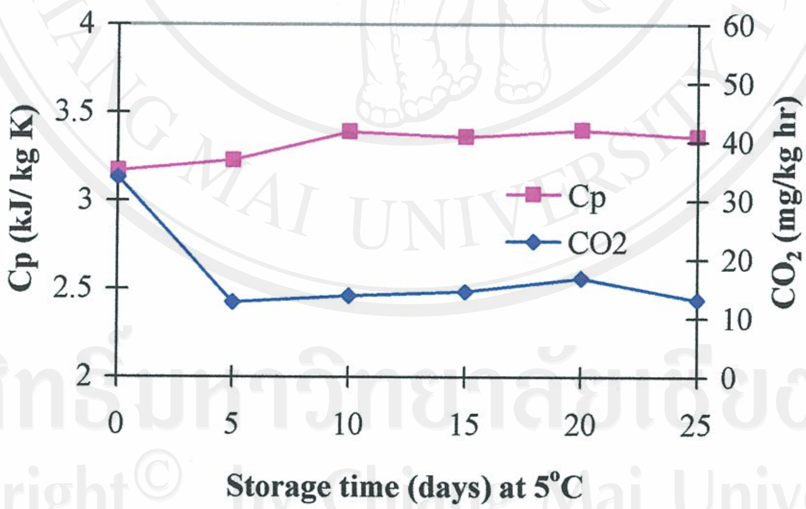

Figure 4.82 The relationship between the specific heat capacity and respiratory rate of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

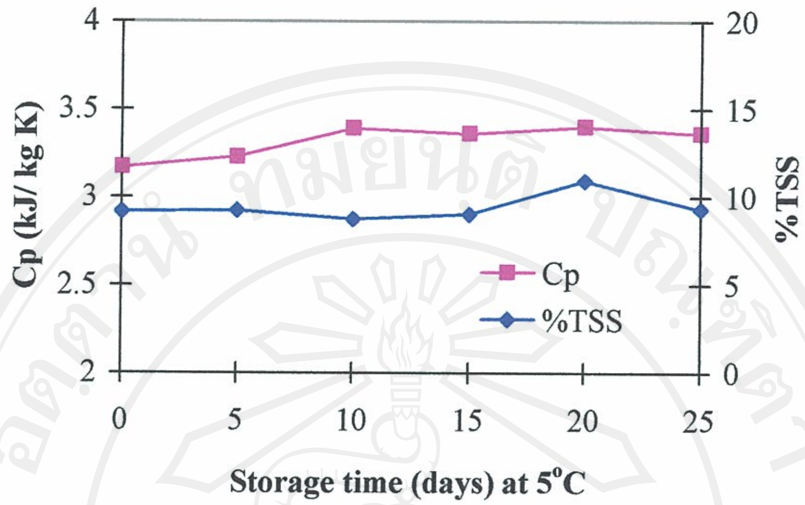

Figure 4.83 The relationship between the specific heat capacity and total soluble solid content of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

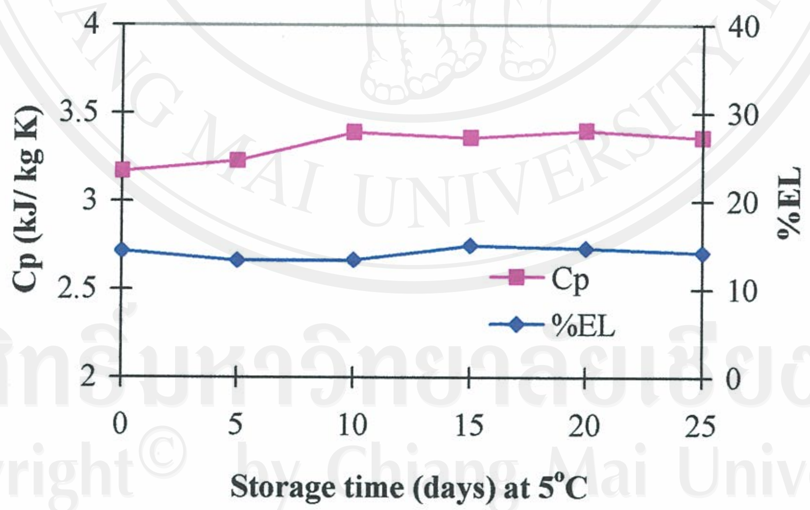

Figure 4.84 The relationship between the specific heat capacity and electrolyte leakage of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

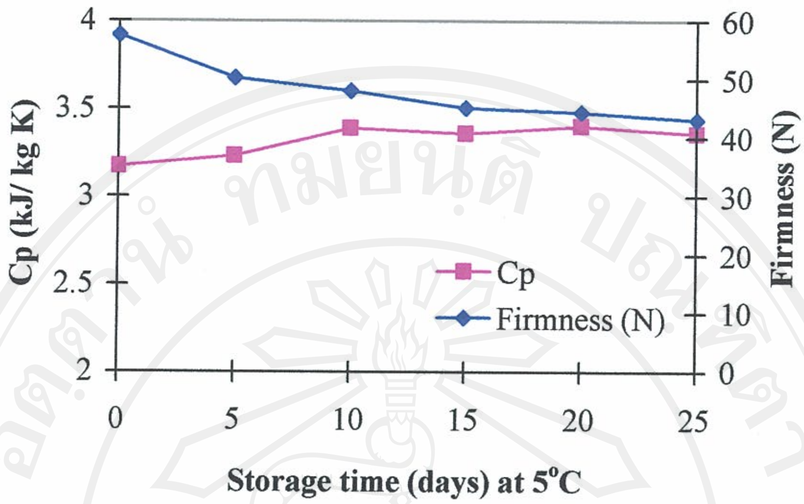

Figure 4.85 The relationship between the specific heat capacity and firmness of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

The increasing trend of specific heat capacity in the mango flesh was observed for the storage at 13°C. The initial value of 3.17 kJ/kg.K was increased to the maximum value of 3.40 then dropped to 3.36 kJ/kg.K on the 25th day of storage (Fig. 4.79). Similar result was obtained from the mango stored at 25°C in which the value of specific heat capacity of the mango flesh increased from the initial value of 3.17 kJ/kg.K to 3.56 kJ/kg.K in the 8th day (12.30% rise) of storage (Fig. 4.79). The increase in specific heat capacity of the mango flesh being kept at 13 and 25°C was the result of chemical composition changes during ripening process such as the elevation of color change in mango flesh (Fig. 4.86 and 4.87), the rise in respiratory rate (Fig. 4.88 and 4.89) and total soluble solid content (from 9.17°Brix in the first day to 15.55 and 18.15°Brix on the 25th and 8th day of storage at 13 and 25°C, Fig. 4.90 and 4.91). Both the increase in electrolyte leakage (Fig. 4.90 and 4.93) and the drop in firmness of mango flesh due to the conversion of insoluble to soluble pectin (Fig. 4.94 and 4.95) were the result of fruit ripening process. However, when the moisture content of mango flesh during storage was taken into account, there was no correlation between the moisture content and specific heat capacity of the mango flesh during storage at 13 and 25°C. It could thus be concluded that the increase in specific heat capacity of the mango flesh being kept at both temperatures was influenced by changes in chemical compositions during fruit ripening.

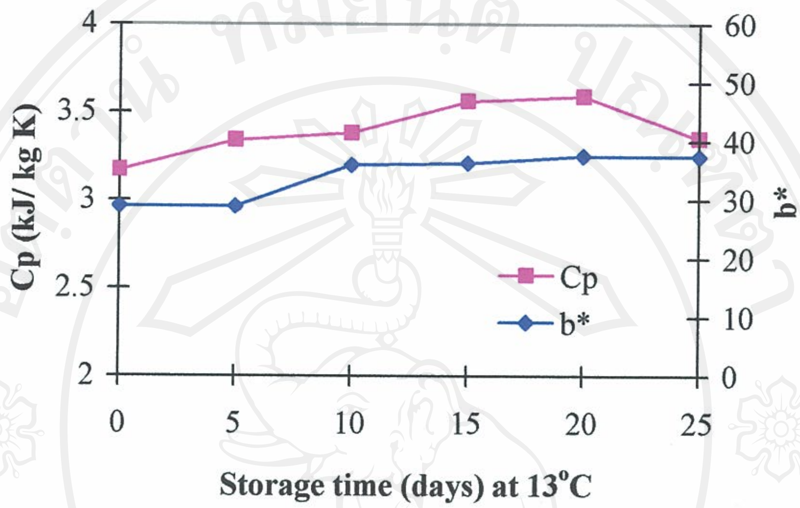

Figure 4.86 The relationship between the specific heat capacity and b* value of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

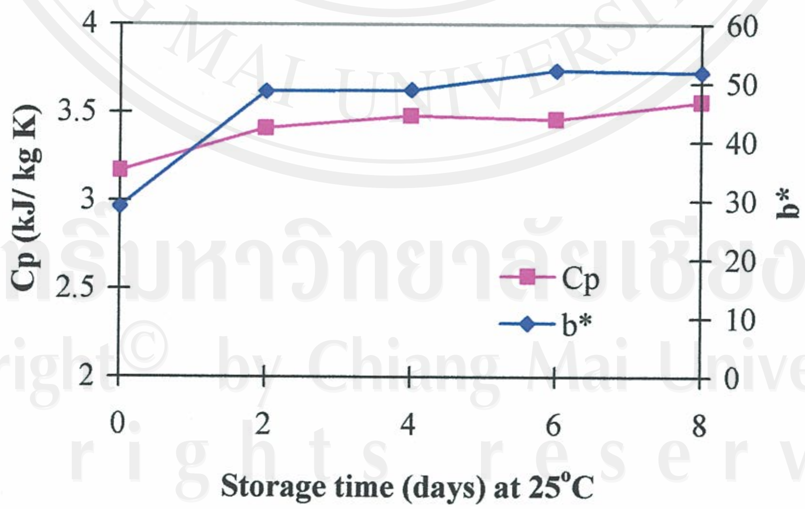

Figure 4.87 The relationship between the specific heat capacity and b* value of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

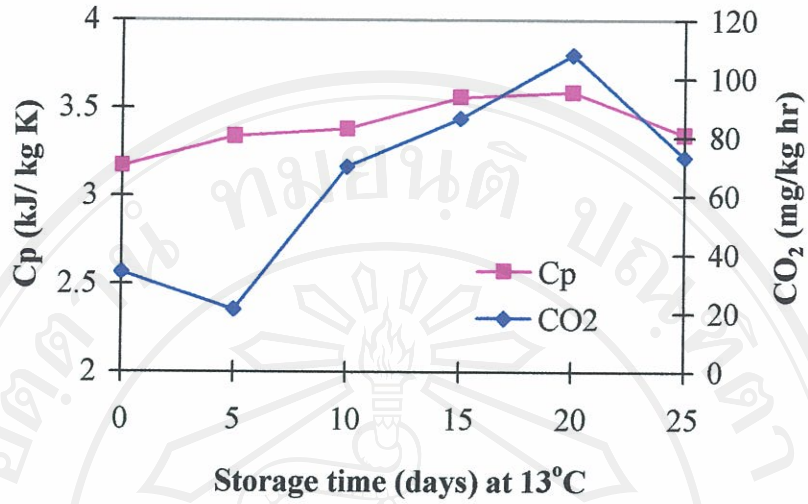

Figure 4.88 The relationship between the specific heat capacity and respiratory rate of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

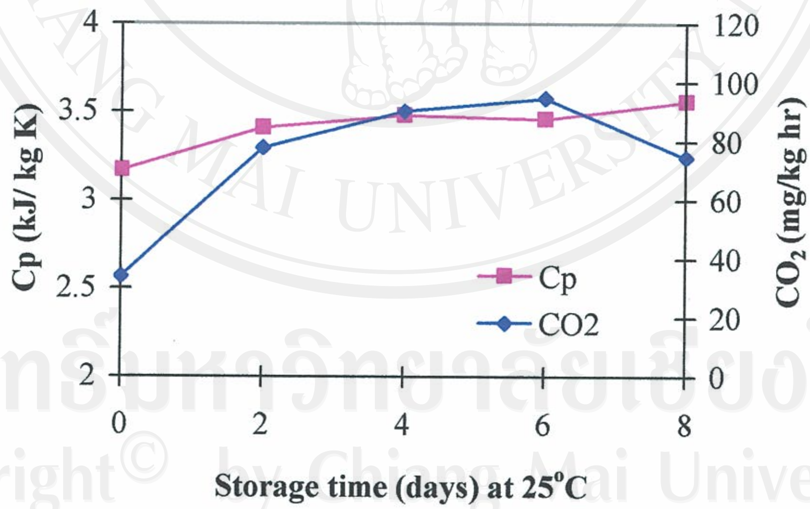

Figure 4.89 The relationship between the specific heat capacity and respiratory rate of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

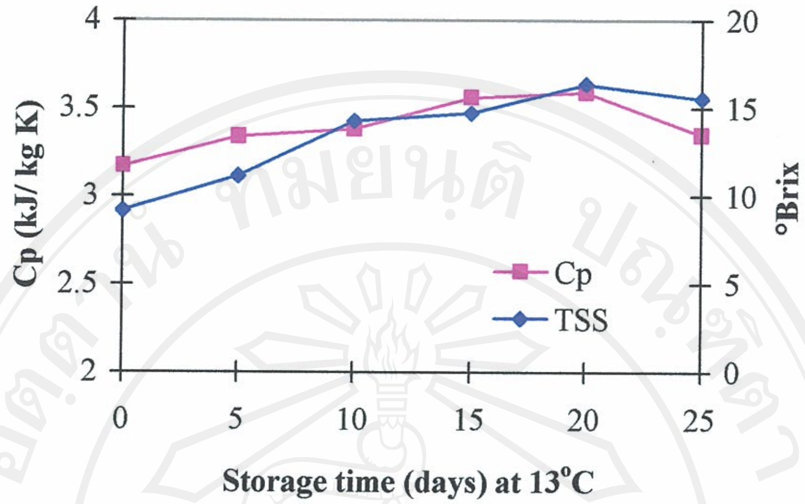

Figure 4.90 The relationship between the specific heat capacity and total soluble solid of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

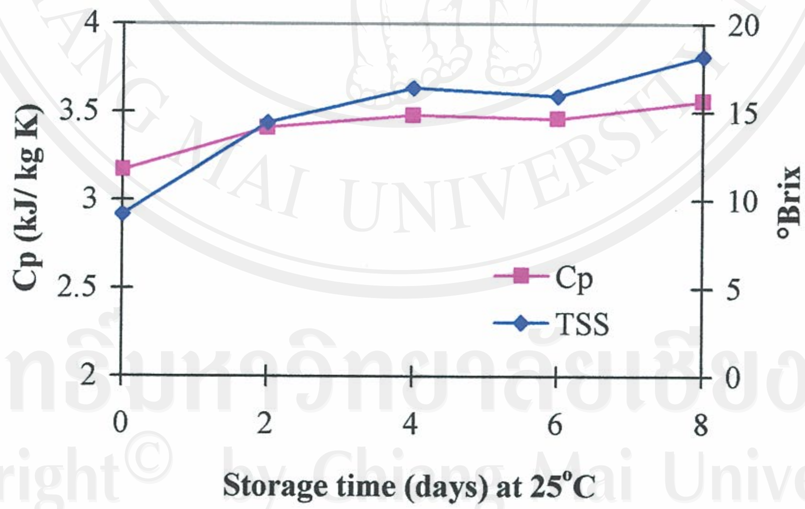

Figure 4.91 The relationship between the specific heat capacity and total soluble solid of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

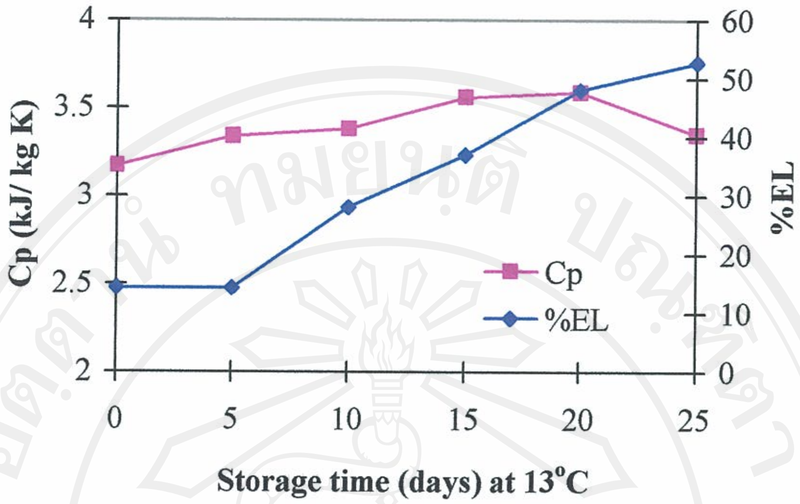

Figure 4.92 The relationship between the specific heat capacity and electrolyte leakage of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

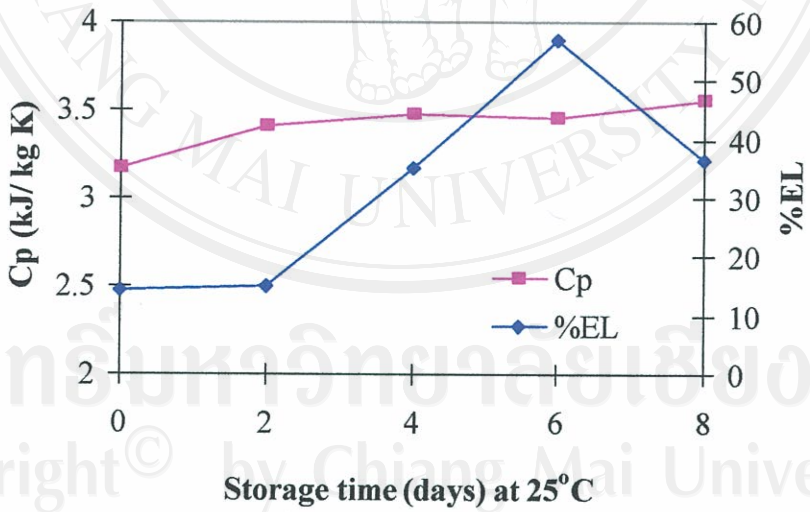

Figure 4.93 The relationship between the specific heat capacity and electrolyte leakage of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

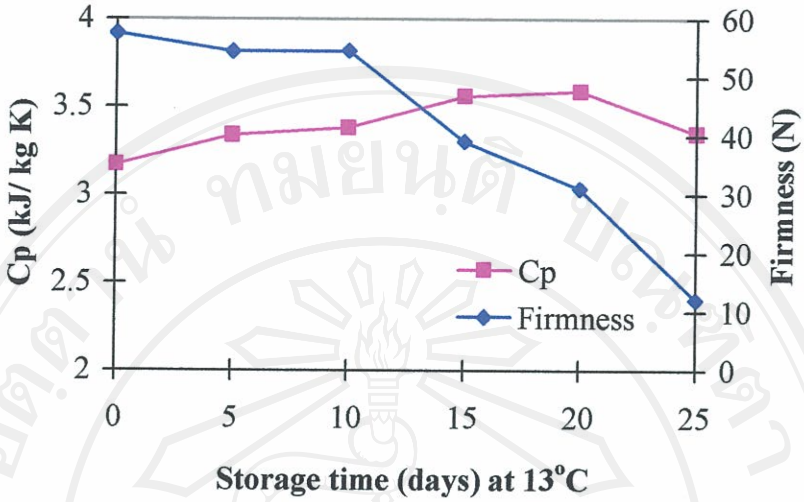

Figure 4.94 The relationship between the specific heat capacity and firmness of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

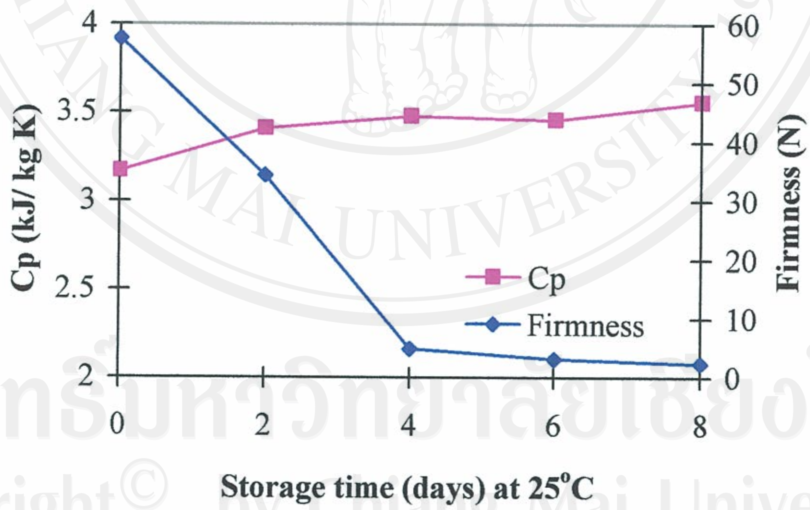

Figure 4.95 The relationship between the specific heat capacity and firmness of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

4.5.6.3 Thermal conductivity (k) of mango peel and mango flesh

The analysis of thermal conductivity was carried out using the methodology of ASTM (1998). Thick and thin slabs of samples were prepared for the peel and mango flesh with the following results.

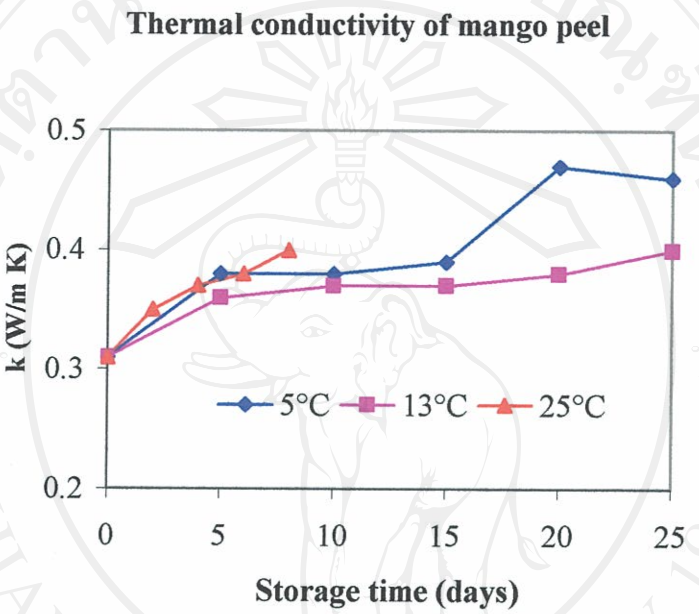

Figure 4.96 The profile of thermal conductivity of Nam Dok Mai Si Thong peel stored in the temperature controlled incubator at 5, 13 and 25°C.

Fig. 4.96 illustrated the thermal conductivity profile of Nam Dok Mai Si Thong peel being stored in the temperature controlled cabinet at 5°C. The initial thermal conductivity value of the peel at 0.31 W/m.K increased to 0.38 W/m.K (22.58%) during the first 5 days and remained constant until the 15th day of storage. Another increase was followed on the 20th day of storage with the maximum value of 0.47 and dropped slightly to 0.46 on the 25th day. Such difference during the last five days of storage at this temperature was not found to be significant statistically at 95% confidential interval. The chilling injury could be observed since the 5th day of storage with CI score of 0.11. This was the same period of elevation in thermal conductivity and specific heat capacity of the peel. At the end of storage period of 25 days, the thermal conductivity of the peel had risen by 48.93% from the first day with the CI score of 2.92 (Fig. 4.97). The similar observation was made in apple where the bruised fruit had the higher thermal conductivity than normal apple by 9-26% depending on the age and severity of bruised symptom (Varith, 2001). Within this time period, the peel being stored at 5°C had the higher specific heat capacity of the peel. The initial value of 2.52 kJ/kg.K on the first day was shifted to the maximum value of 2.97 kJ/kg.K (17.86% rise). The clear evidence of chilling injury for the mango being stored at 5°C was clearly observed in the 10th day with CI score of 0.98. (The area of chilling injury symptom was less then <10%) (Fig. 4.97).

Therefore the increase in electrolyte leakage (Fig. 4.98) and the specific heat capacity at the peel (Fig. 4.99) were resulted from the deterioration of cell membrane (second event). It was thus possible to use the thermal conductivity as a predictor of chilling injury symptom which occurred first. This could be seen clearly from the relationship similarity between the thermal conductivity and chilling injury score (Fig. 4.97) as well as leakage of electrolyte (Fig. 4.98) of the peel being stored at 5°C. Thus, the elevated thermal conductivity value was greatly influenced by chilling injury symptom at the peel.

The consideration of relationship between the change in physical characteristic such as b*value was also made. The yellowish color of peel could be represented by b* value. In fact, there was no color development during storage at this temperature (Fig. 4.99) which was in contrary to the observed change in color at 13 and 25°C. The absence of color development was a clear indication of prohibited ripening process. The correlation also extended to the low and steady respiratory rate (Fig. 4.100). Therefore, the increase in thermal conductivity of the mango peel was due to the occurrence of chilling injury at the peel.

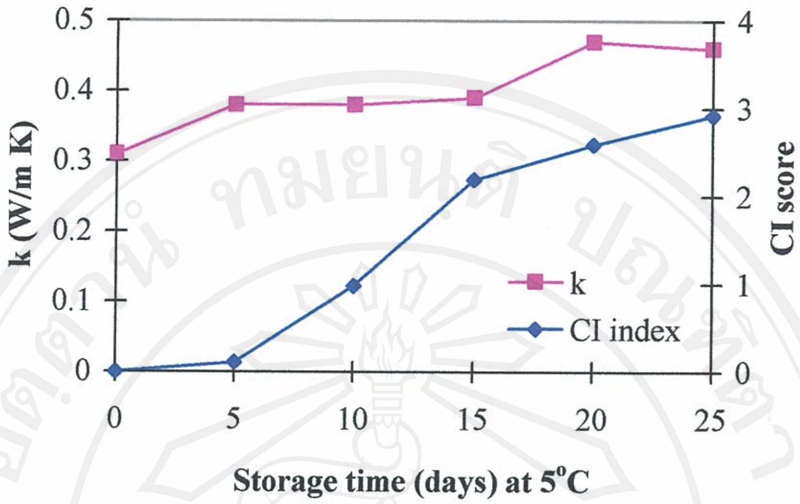

Figure 4.97 The relationship between the thermal conductivity (k) and chilling injury of Nam Dok Mai Si Thong peel being stored at 5°C.

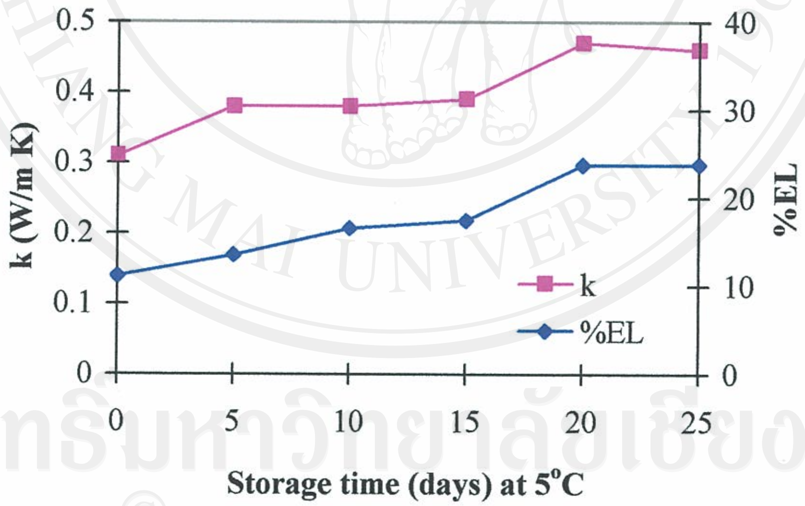

Figure 4.98 The relationship between the thermal conductivity (k) and electrolyte leakage of Nam Dok Mai Si Thong peel being stored at 5°C.

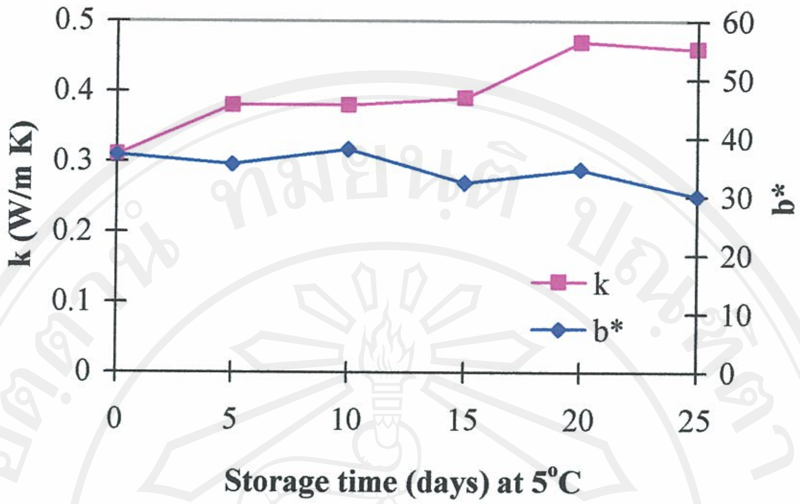

Figure 4.99 The relationship between the thermal conductivity (k) and b* value of Nam Dok Mai Si Thong peel being stored at 5°C.

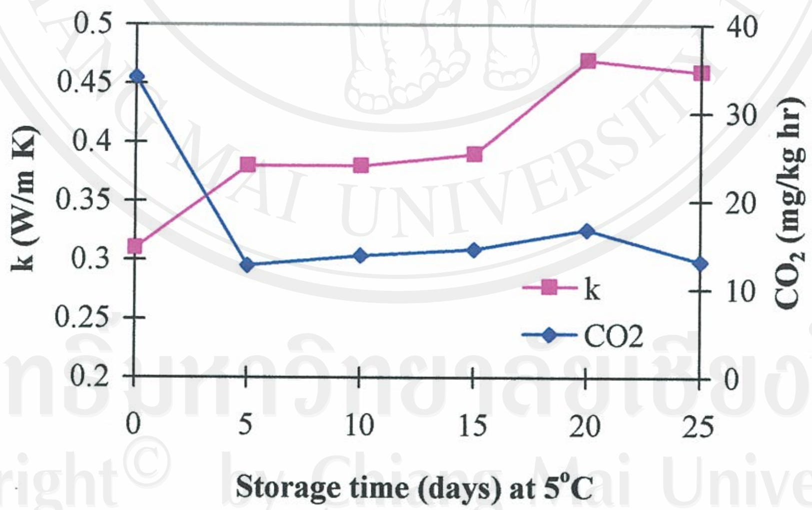

Figure 4.100 The relationship between the thermal conductivity (k) of the peel and respiratory rate of Nam Dok Mai Si Thong being stored at 5°C.

The change in thermal conductivity of the peel at 13°C was similar to 5°C with the slower rate of increase than the thermal conductivity of the peel being maintained at 5°C. The faster rate of increased thermal conductivity with storage period was observed at 25°C. The initial value of 0.31 W/m.K had increased to 0.4 W/m.K on the 8th day of storage. Such rise in thermal conductivity of the peel being maintained at 13 and 25°C was related to the onset of development into ripening process. The b* value which indicated the yellowness of the peel being stored at 13 and 25°C had increased from the initial value of storage at 37.13 to 40.94 and 41.47 on the 25th and 8th day at 13 and 25°C, respectively (Fig. 4.101 and 4.102) which was in accordance to the rising respiratory rate throughout the storage period (Fig. 4.103 and 4.104). Thus, the increase in thermal conductivity of the peel being kept at 13 and 25°C was mainly due to the ripening process.

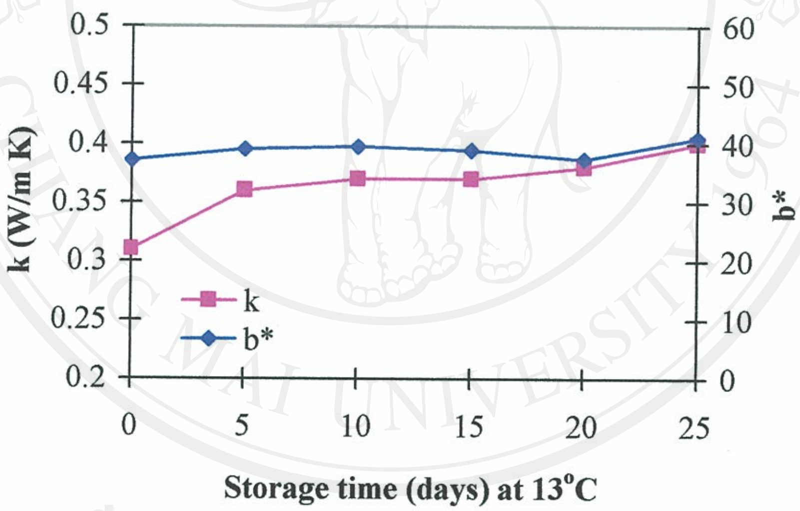

Figure 4.101 The relationship between the thermal conductivity (k) and b* value of Nam Dok Mai Si Thong peel being stored at 13°C.

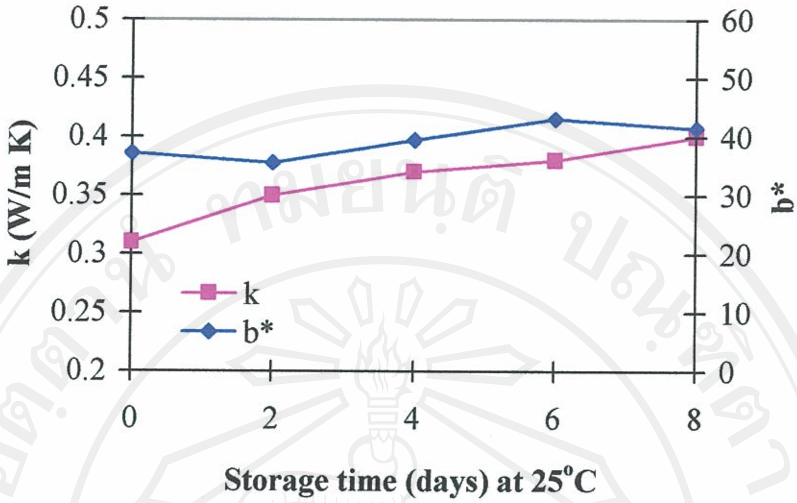

Figure 4.102 The relationship between the thermal conductivity (k) and b* value of Nam Dok Mai Si Thong peel being stored at 25°C.

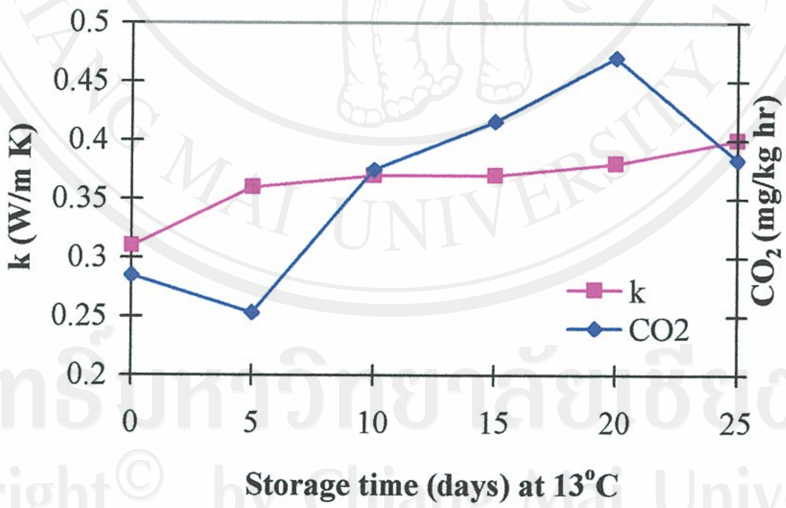

Figure 4.103 The relationship between the thermal conductivity (k) and respiratory rate of Nam Dok Mai Si Thong peel being stored at 13°C.

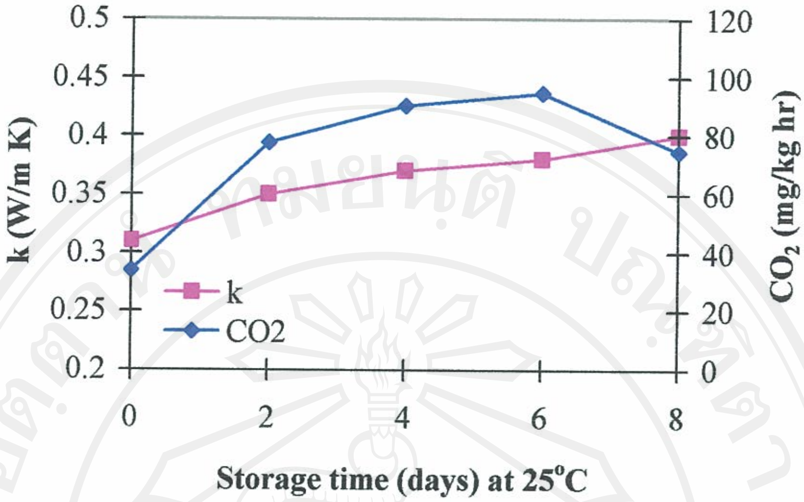

Figure 4.104 The relationship between the thermal conductivity (k) and respiratory rate of Nam Dok Mai Si Thong peel being stored at 25°C.

There existed a relationship between the thermal conductivity and chilling injury score of mango. The chilling injury symptom of the mango being stored at 13°C was clearly noticeable on the 20th day of storage. The similar relationship was also observed at 5°C. After storage for the period of 20 days (Fig. 4.105) in which the mango was ready to develop into ripening stage. The electrolyte leakage increased with the storage time or ripening stage of the fruit (Fig. 4.106) as evident from the relationship between thermal conductivity and electrolyte leakage of peel being maintained at 25°C (Fig. 4.107).

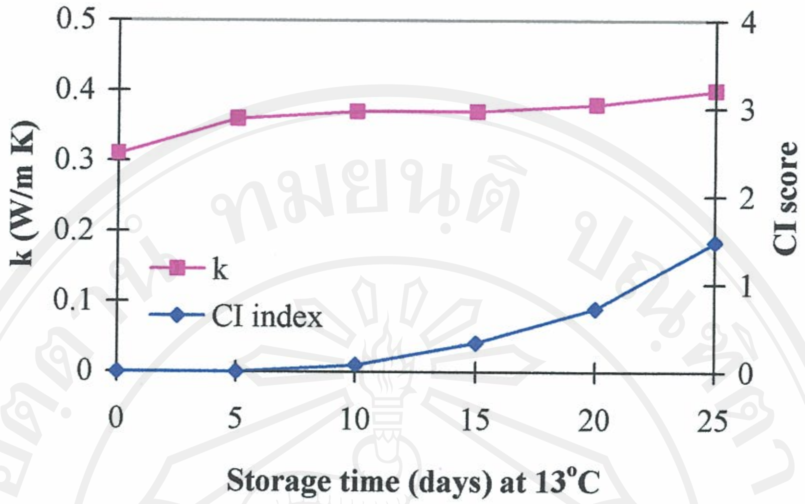

Figure 4.105 The relationship between the thermal conductivity (k) and chilling injury of Nam Dok Mai Si Thong peel being stored at 13°C.

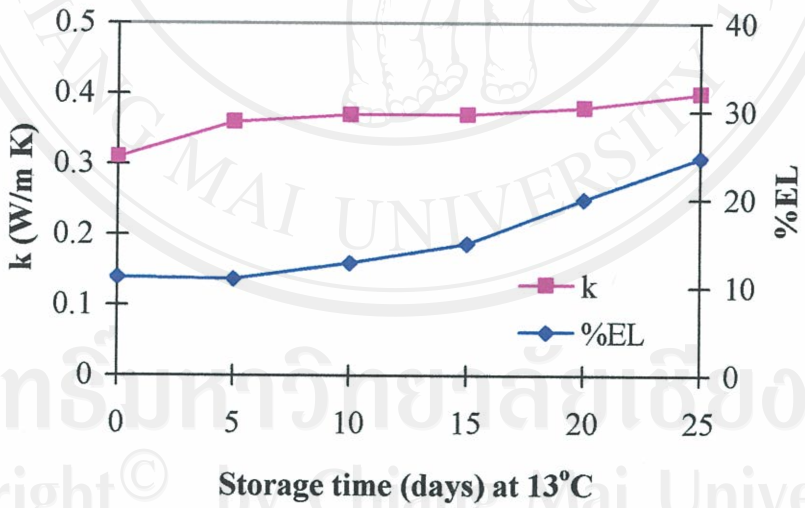

Figure 4.106 The relationship between the thermal conductivity (k) and electrolyte leakage of Nam Dok Mai Si Thong peel being stored at 13°C.

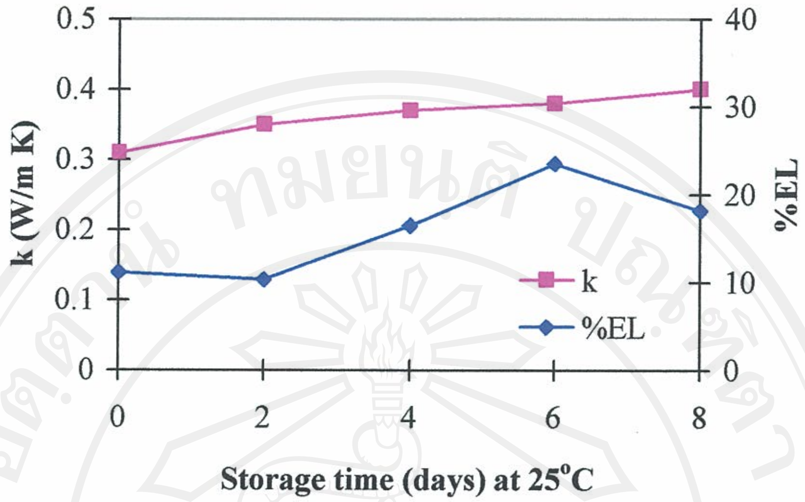

Figure 4.107 The relationship between the thermal conductivity (k) and electrolyte leakage of Nam Dok Mai Si Thong peel being stored at 25°C.

The gradual increase of thermal conductivity of the peel being stored at 13 and 25°C was in contrast to the rapid rise after the storage at 5°C for the period of 15 days. The thermal conductivity value of the peel at 5°C was also higher than at 13 and 25°C. Such increase of thermal conductivity was due to chilling injury effect at the peel whereas the development into ripening process was the main reason of increase thermal conductivity at the storage temperature of 13 and 25°C.

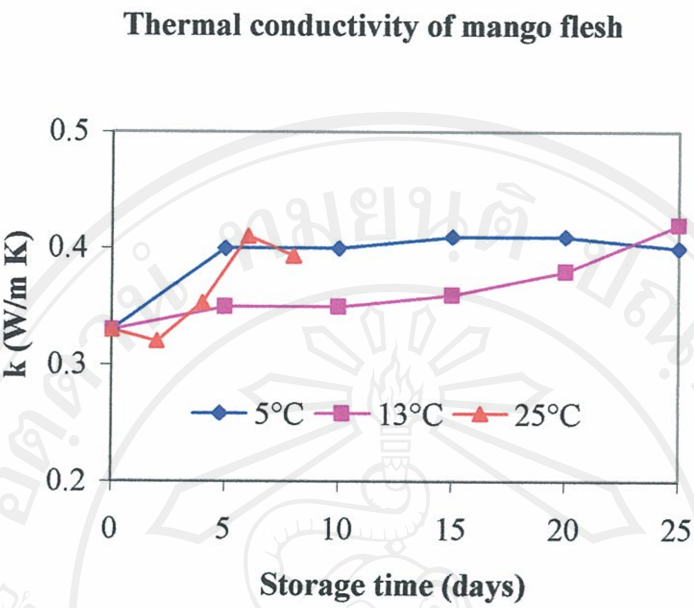

Figure 4.108 The profile of thermal conductivity of Nam Dok Mai Si Thong of mango peel stored in the incubator at 5, 13 and 25°C.

Fig. 4.108 illustrated the profile of thermal conductivity in Nam Dok Mai Si Thong mango flesh being stored at 5, 13 and 25°C. The initial thermal conductivity of the mango flesh at 5°C was 0.33 W/m.K had increased to 0.40 W/m.K during the first 5 days of storage until the steady value was reached at the end of storage after 25 days. When the consideration of physical and chemical characteristics such as b* value (Fig. 4.109), respiratory rate (Fig. 4.110), firmness (4.111), total soluble solid (Fig. 4.112) and electrolyte leakage (Fig. 4.113) of mango were taken into account, it was found that mango had undergone only slight change of these characteristics. It could thus be stated that mango being stored at 5°C did not develop into ripening process or the fruit still remained green. Srivichien (2006) reported that Nam Dok Mai Si Thong mango stored at 5°C for the period of 15 days prior to incubation at 25°C had abnormal development during ripening process which was considered to be a symptom of chilling injury effect. It could therefore be stated that the steady thermal conductivity during storage of Nam Dok Mai Si Thong mango was the result of chilling injury effect that occurred to the mango flesh.

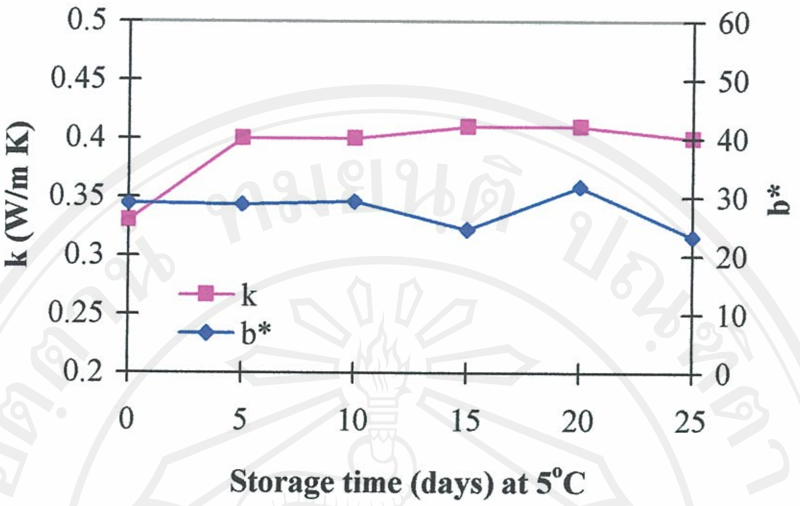

Figure 4.109 The relationship between the thermal conductivity (k) and b* value of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

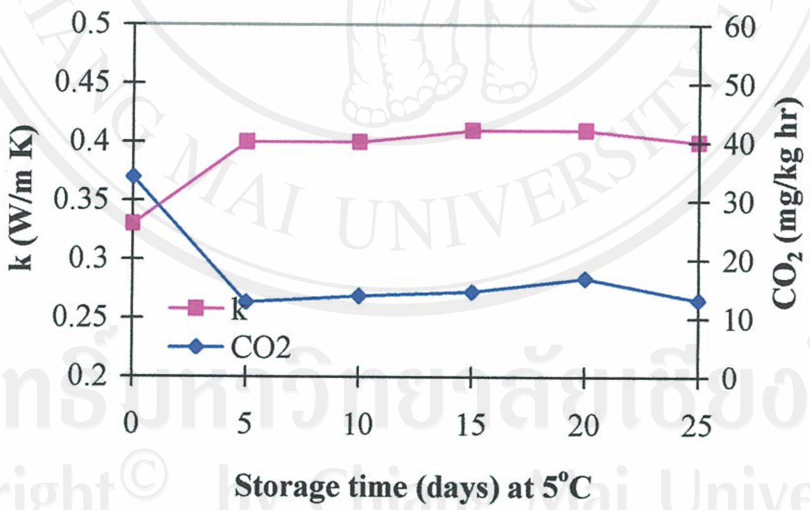

Figure 4.110 The relationship between the thermal conductivity (k) and respiratory rate of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

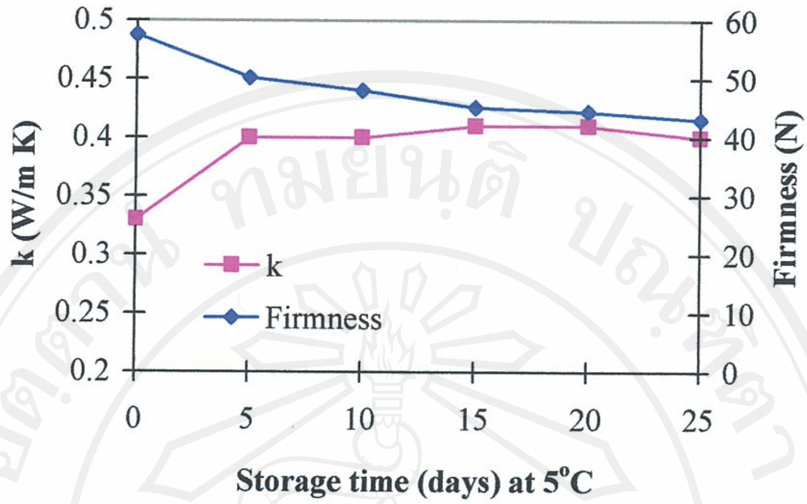

Figure 4.111 The relationship between the thermal conductivity (k) and firmness of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

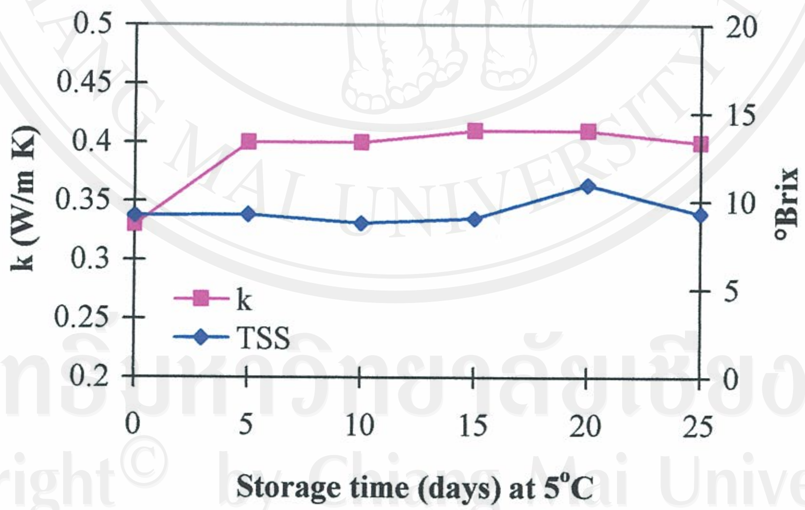

Figure 4.112 The relationship between the thermal conductivity and total soluble solid content of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

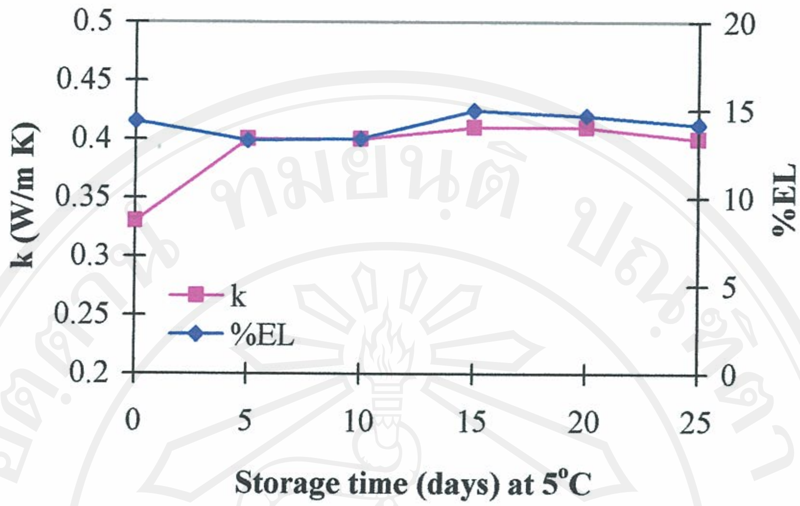

Figure 4.113 The relationship between the thermal conductivity and electrolyte leakage of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

The mango flesh being stored at 13°C had the similar change in thermal conductivity as observed at 5°C. The thermal conductivity of mango flesh was stable at 0.36 W/m.K during the storage period of 5-15 days. This was then followed by the increase to the final value of 0.42 W/m.K on the 25th day of storage (Fig. 4.108). The thermal conductivity of the mango being stored at 25°C had increased with storage period from the initial value of 0.33 W/m.K to 0.39 W/m.K on the 8th day of storage. Such increase was the result of physical and chemical changes during storage of the fruit such as b* value (Fig. 4.114 and 4.115), respiratory rate (Fig. 4.116 and 4.117), firmness (Fig. 4.118 and 4.119), total soluble solid content (Fig. 4.120 and 4.121) and electrolyte leakage (Fig. 4.122 and 4.123).

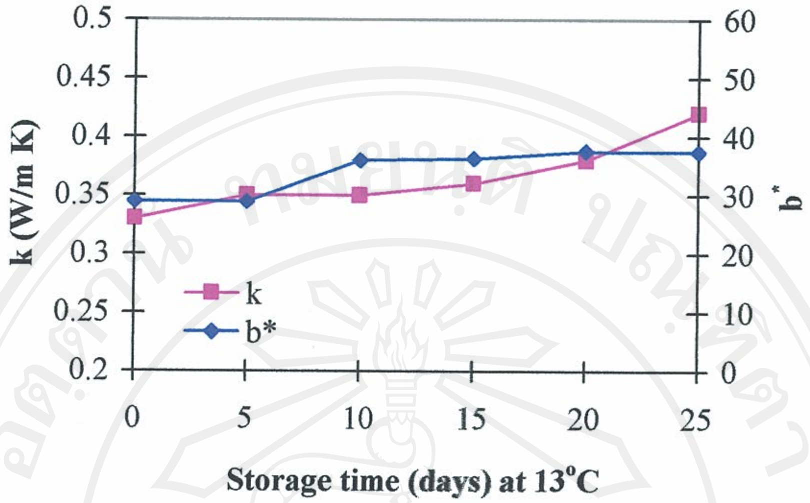

Figure 4.114 The relationship between the thermal conductivity and b* value of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

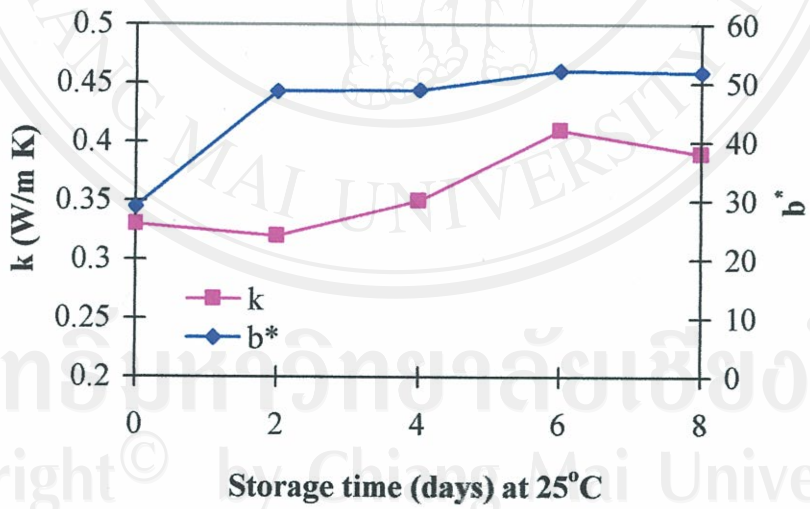

Figure 4.115 The relationship between the thermal conductivity and b* value of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

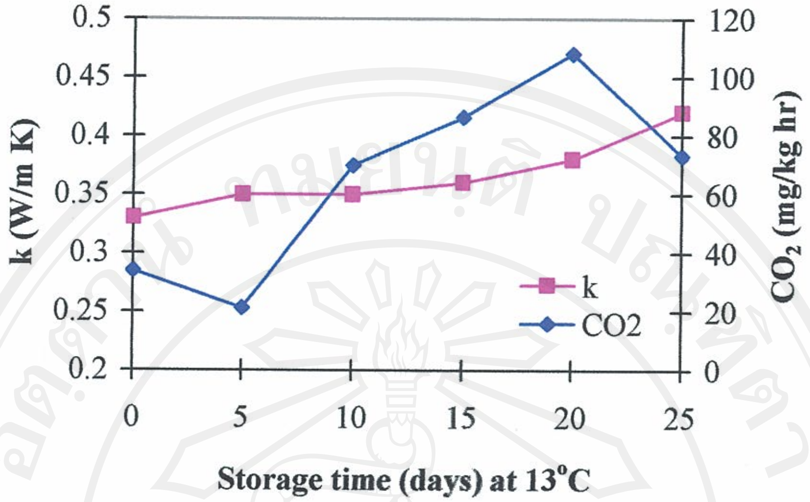

Figure 4.116 The relationship between the thermal conductivity and respiratory rate of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

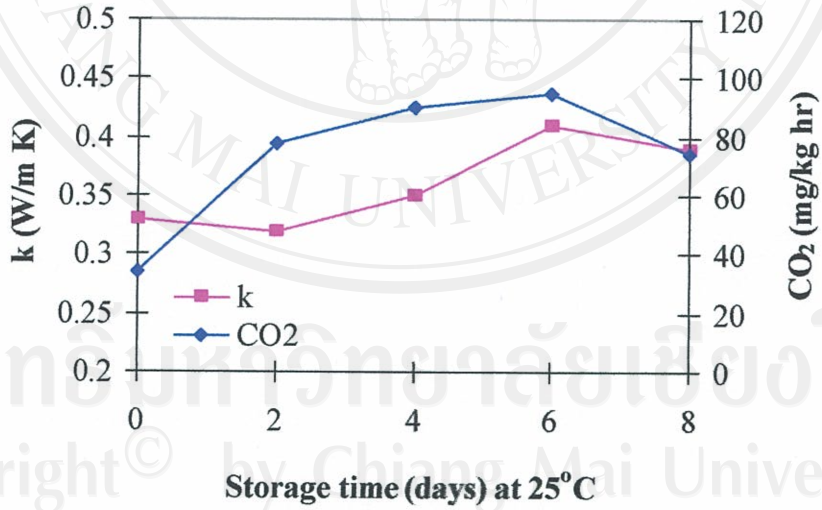

Figure 4.117 The relationship between the thermal conductivity and respiratory rate of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

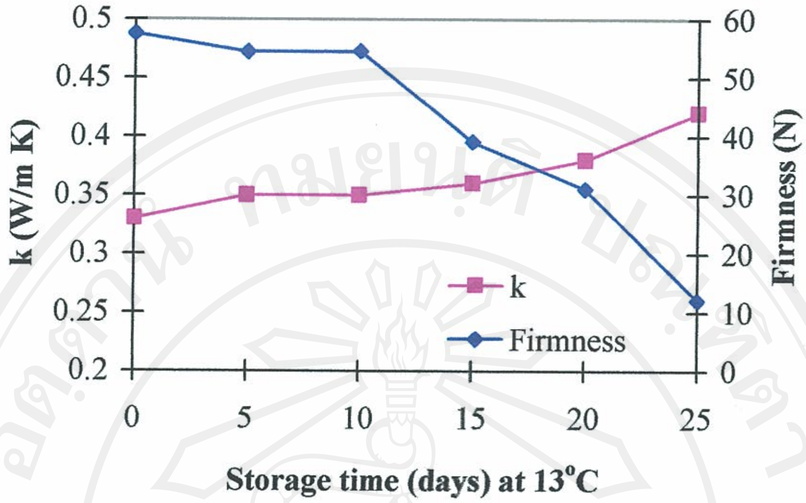

Figure 4.118 The relationship between the thermal conductivity and firmness of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

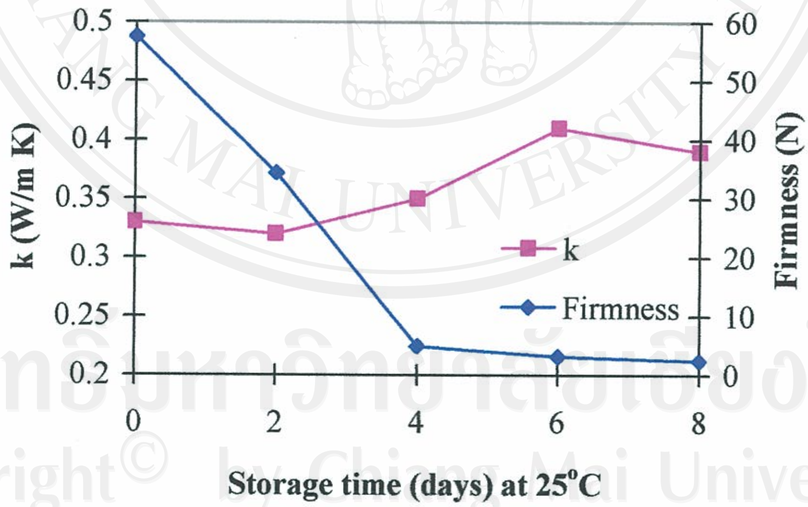

Figure 4.119 The relationship between the thermal conductivity and firmness of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

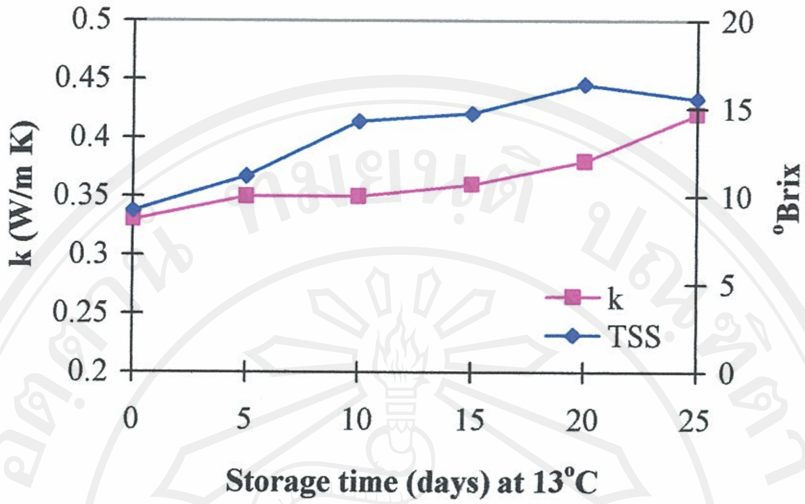

Figure 4.120 The relationship between the thermal conductivity and total soluble solid content of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

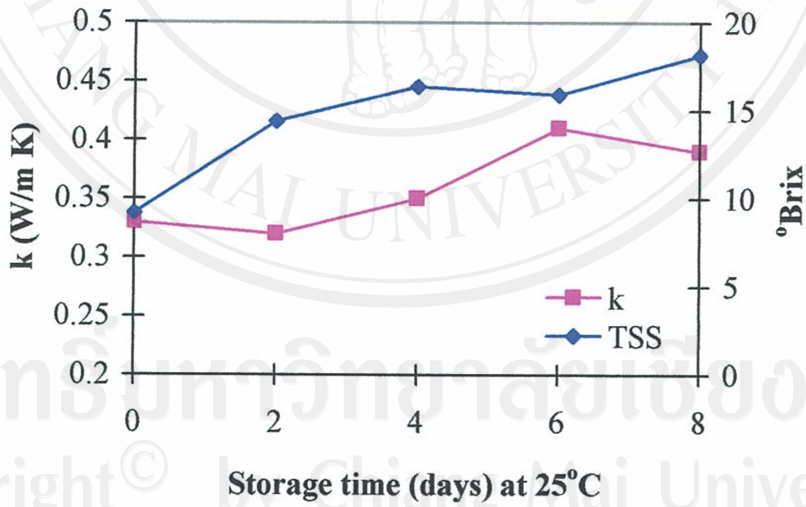

Figure 4.121 The relationship between the thermal conductivity and total soluble solid content of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

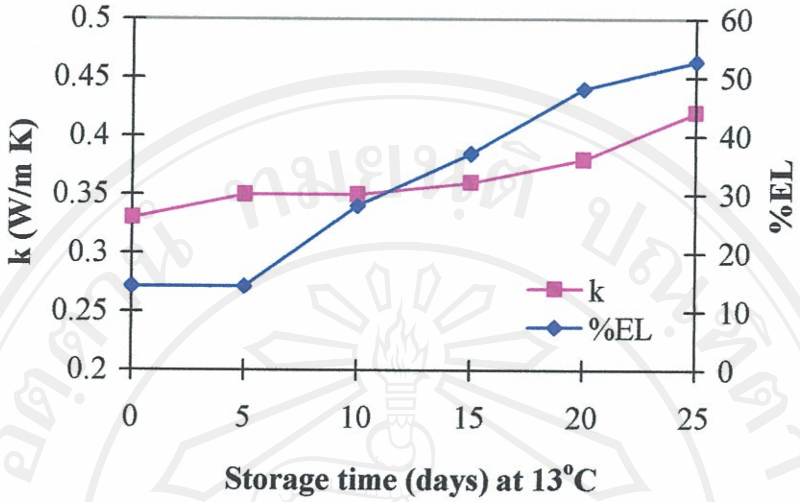

Figure 4.122 The relationship between the thermal conductivity and electrolyte leakage of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

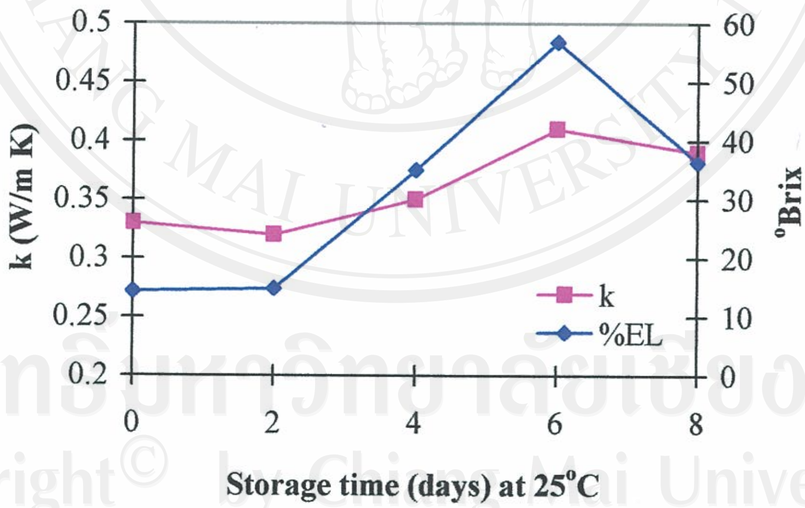

Figure 4.123 The relationship between the thermal conductivity and electrolyte leakage of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

4.5.6.4 Density

Pycnometer was utilised in the density measurement of peel and mango flesh with the following result.

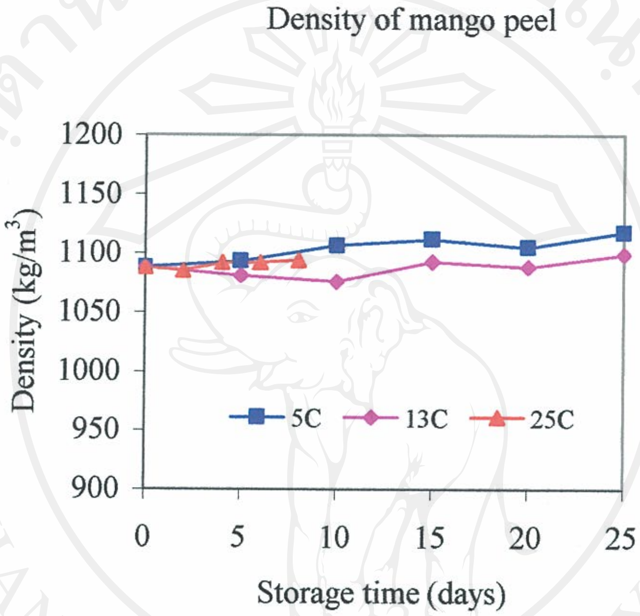

Figure 4.124 The density profile of Nam Dok Mai Si Thong peel stored in the incubator at 5, 13 and 25°C.

Fig. 4.124 illustrated the change in peel density of the mango being stored at 5, 13 and 25°C. The density of the peel had increased with the storage period. The peel being kept at 5°C had the higher density than at 13 and 25°C. The initial value of 1088.28 kg/m^3 had increased to 1117.98 kg/m^3 on the 25th day of storage at 5°C whereas the density of peel being stored at 13 and 25°C had risen to 1099.40 and 1094.20 kg/m^3 on the 25th and 8th day, respectively. Therefore, the storage temperature had a direct influence on the change in peel density. The mango being stored at 5°C had the greater density of peel than at 13°C with the significance difference since the 10th day of storage.

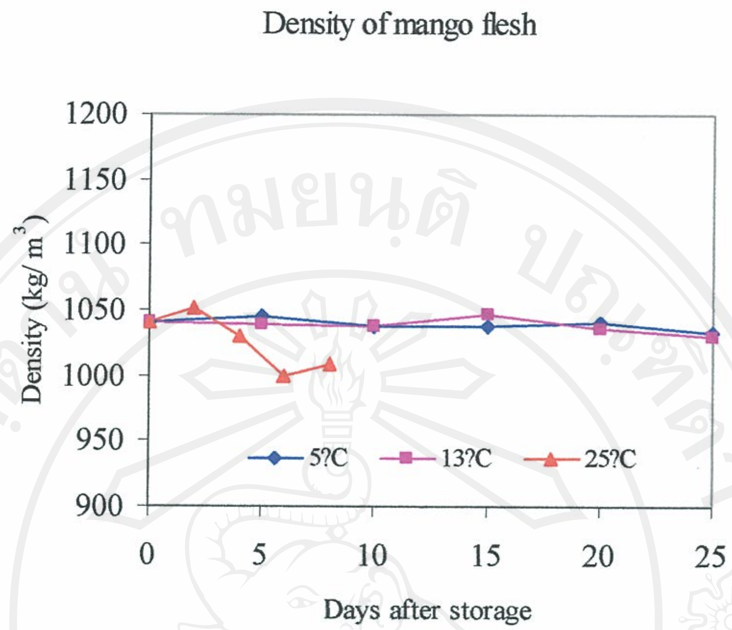

Figure 4.125 The density profile of Nam Dok Mai Si Thong mango flesh stored in the incubator at 5, 13 and 25°C.

Fig. 4.125 illustrated the change in density of mango flesh being kept at 5, 13 and 25°C. The mango flesh density being stored at 5 and 13°C showed similar profile and value. The initial value of 1044.43 kg/m^3 had dropped to 1033.73 and 1030.20 kg/m^3 on the 25th day of storage at 5 and 13°C, respectively. Whereas the rapid decline in density of the mango flesh being stored at 25°C was observed from the initial value of 1044.43 to 1009.11 kg/m^3.

4.5.6.5 Thermal diffusivity

The thermal diffusivity value of the mango peel and mango flesh of Nam Dok Mai Si Thong during storage at 5, 13 and 25°C was computed from equation (3.5).

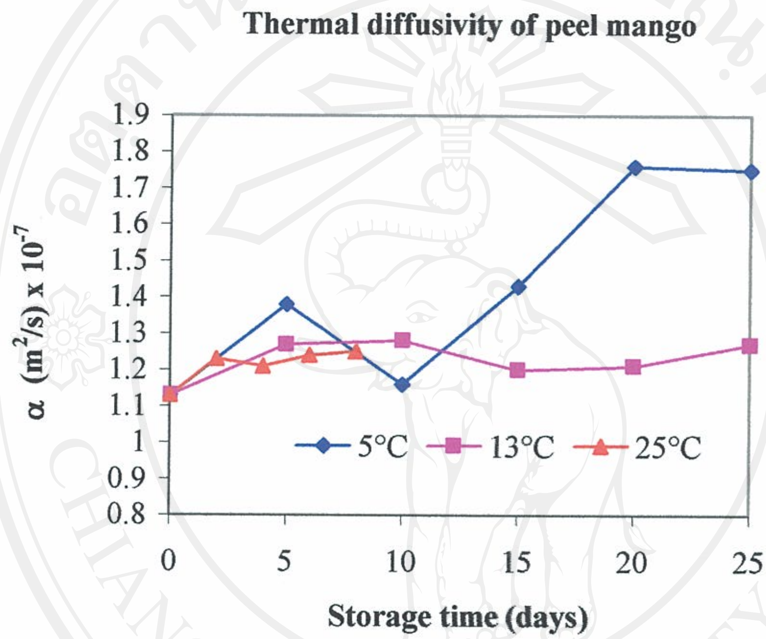

Figure 4.126 The profile of thermal diffusivity of Nam Dok Mai Si Thong of mango peel stored in the incubator at 5, 13 and 25°C.

Figure 4.126 illustrated the change in thermal diffusivity of Nam Dok Mai Si Thong mango peel being stored at 5, 13 and 25°C. The thermal diffusivity of mango peel at 5°C had increased rapidly with the storage time from the initial value of 1.13 x 10^{-7} m^2/s to 1.75 x 10^{-7} m^2/s (+ 54.87%) in the 25^{th} day of storage. In fact, the decline of thermal diffusivity in the 10^{th} day of storage to the similar level of initial value at 1.16 x 10^{-7} m^2/s was occurring during the same period at which the chilling injury of the mango peel could be clearly observed with the chilling injury score at 0.98. There existed a relationship between the chilling injury at the mango peel and thermal diffusivity after 10 days of storage as evident from Fig. 4.127. Further comparison to the electrolyte leakage of the mango peel, which was the indicator of chilling injury, suggested the same relationship as observed previously with the chilling injury (Fig. 4.128). Therefore the increase in thermal diffusivity was stemmed from the chilling injury of the mango peel.

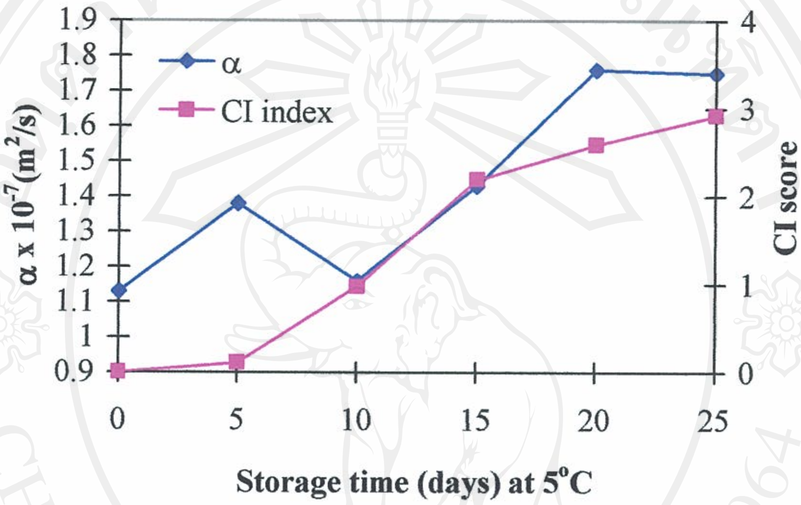

Figure 4.127 The relationship between the thermal diffusivity and chilling injury score of Nam Dok Mai Si Thong of mango peel being stored at 5°C.

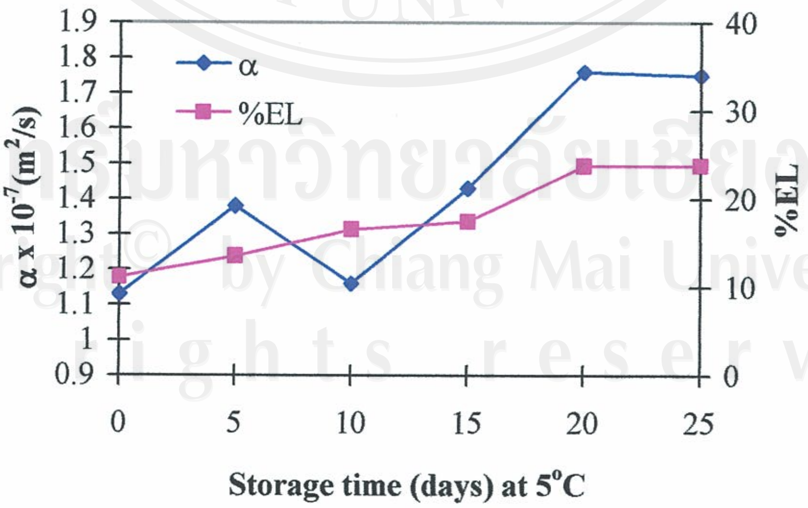

Figure 4.128 The relationship between the thermal diffusivity and electrolyte leakage of Nam Dok Mai Si Thong of mango peel being stored at 5°C.

The increasing trend of thermal diffusivity was observed during the first 2 to 5 days of storage for the mango peel of the mango maintained at 25 and 13°C. The initial value of 1.13 x 10^{-7} m^2/s had increased to 1.23 x 10^{-7} and 1.27 x 10^{-7} m^2/s, respectively. The thermal diffusivity was then leveled off to a constant level until the end of storage period at 1.25 x 10^{-7} and 1.27 x 10^{-7} m^2/s or +10.62 and +12.39% respectively. Both values were lower than the diffusivity being observed at 5°C. Further cross examination with the chilling injury profile was made for the mango being stored at 13 and 25°C. After the storage period of longer than 15 days at 13°C, the formation of brown spots similar to the storage at 5°C was evident on the mango peel. However, the chilling injury of the mango peel at 13°C was the result of cell membrane deterioration due to ripening process with variation of severity in the formation of brown spots on the mango peel depending on the ripening stage of the fruit (Fig. 4.129 and 4.130). Therefore the increase thermal diffusivity of the mango peel at 13°C was the consequence chilling injury as observed at 5°C. The mango peel stored at 13 and 25°C also developed into ripening process as observed from the increasing development to yellowish color, the rise in b* value (Fig. 4.131 and 4.132) and the elevation in respiration rate (Fig. 4.133 and 4.134). In fact, the storage at 25°C yielded a steady trend of thermal diffusivity. It could thus be confirmed that the increase in thermal diffusivity of mango peel was actually the effect of chilling injury as in accordance to the relationship between electrolyte leakage and thermal diffusivity at 13 and 25°C. In that study, the storage of mango at 13°C for the period of 20 days exhibited the relationship between the profile of thermal diffusivity and the rise of electrolyte leakage at the mango peel in similar manner as the storage at 25°C (Fig. 4.135 and 4.136).

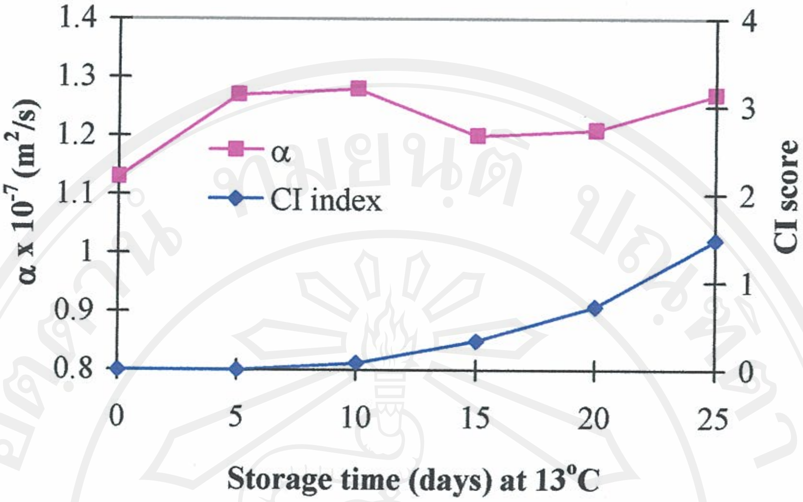

Figure 4.129 The relationship between the thermal diffusivity and chilling injury score of Nam Dok Mai Si Thong of mango peel being stored at 13°C.

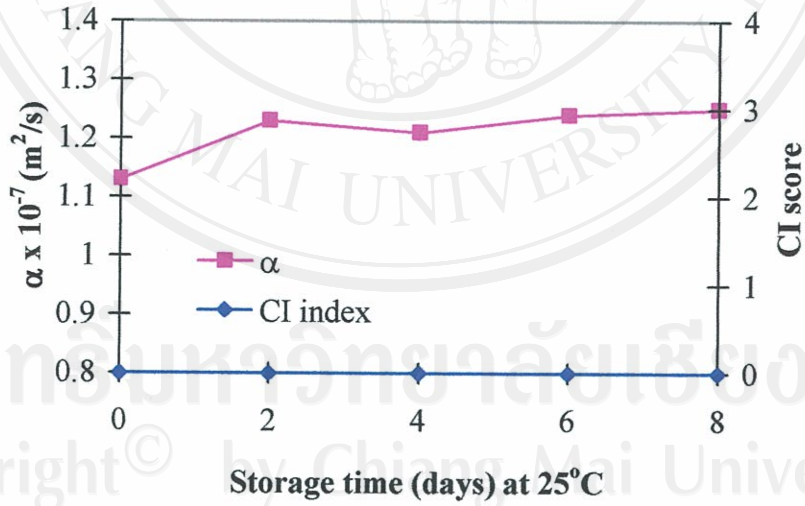

Figure 4.130 The relationship between the thermal diffusivity and chilling injury score of Nam Dok Mai Si Thong of mango peel being stored at 25°C.

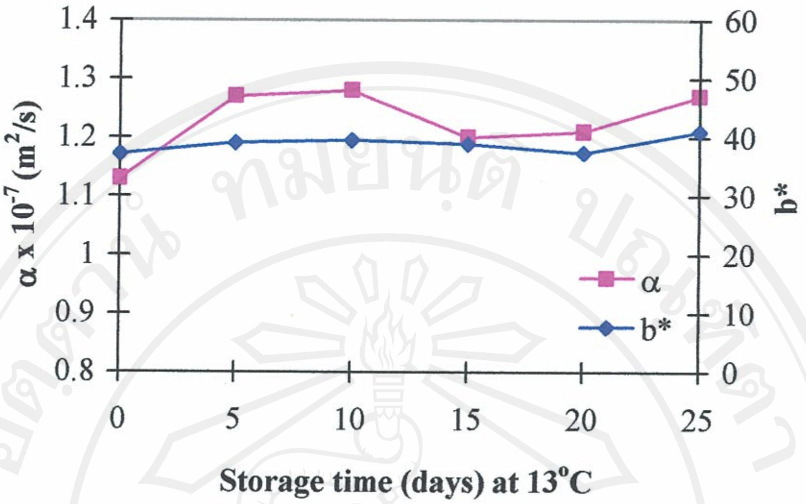

Figure 4.131 The relationship between the thermal diffusivity and b* value of Nam Dok Mai Si Thong of mango peel being stored at 13°C.

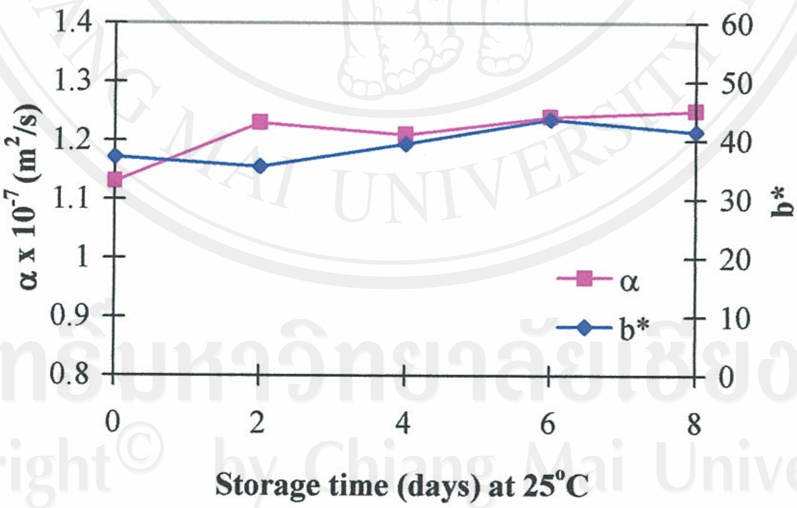

Figure 4.132 The relationship between the thermal diffusivity and b* value of Nam Dok Mai Si Thong of mango peel being stored at 25°C.

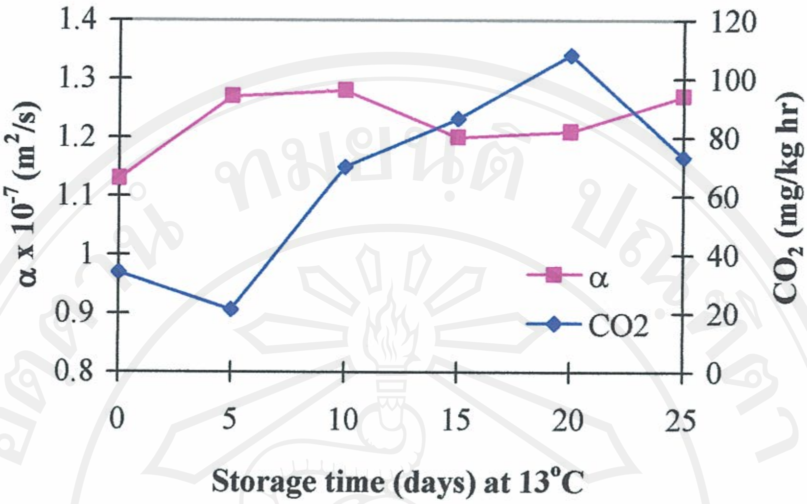

Figure 4.133 The relationship between the thermal diffusivity and respiratory rate of Nam Dok Mai Si Thong mango fruit being stored at 13°C.

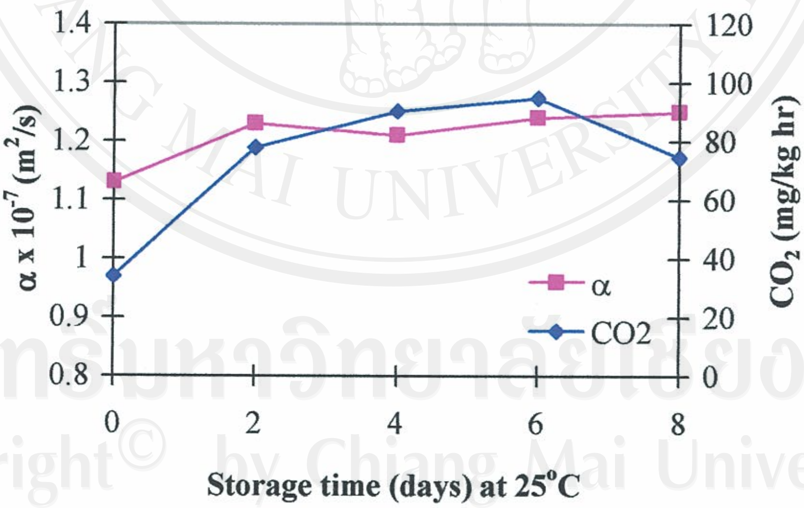

Figure 4.134 The relationship between the thermal diffusivity and respiratory rate of Nam Dok Mai Si Thong mango fruit being stored at 25°C.

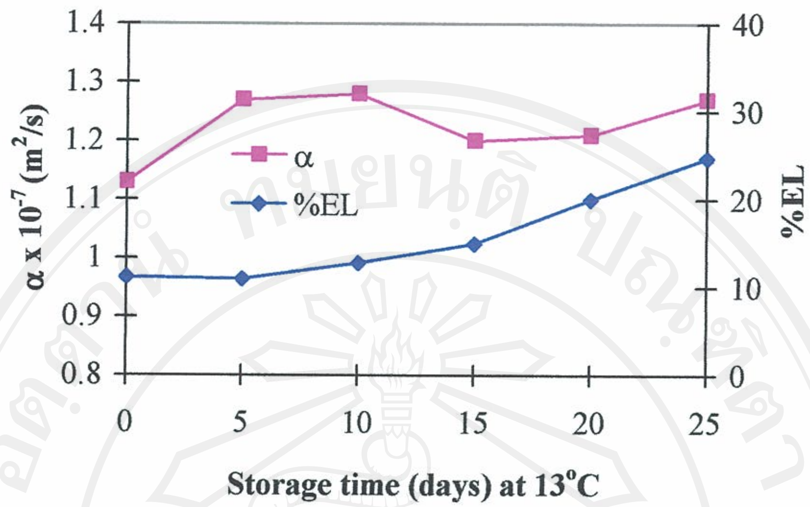

Figure 4.135 The relationship between the thermal diffusivity and electrolyte leakage of Nam Dok Mai Si Thong of mango peel being stored at 13°C.

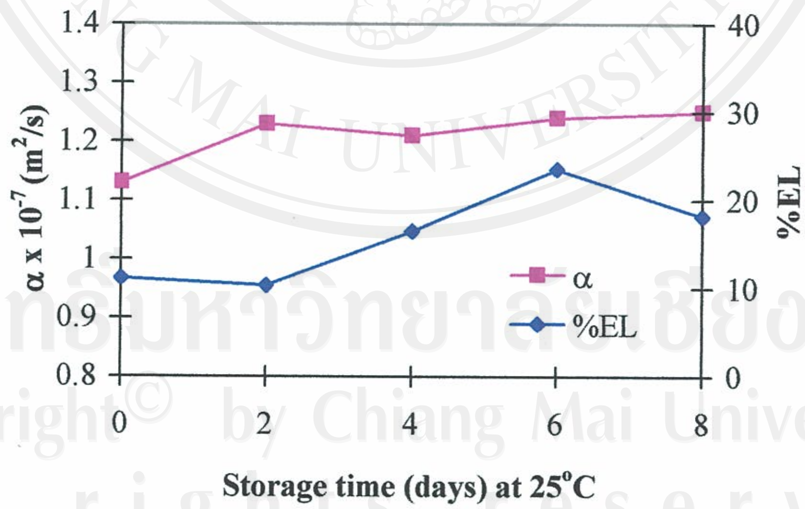

Figure 4.136 The relationship between the thermal diffusivity and electrolyte leakage of Nam Dok Mai Si Thong of mango peel being stored at 25°C.

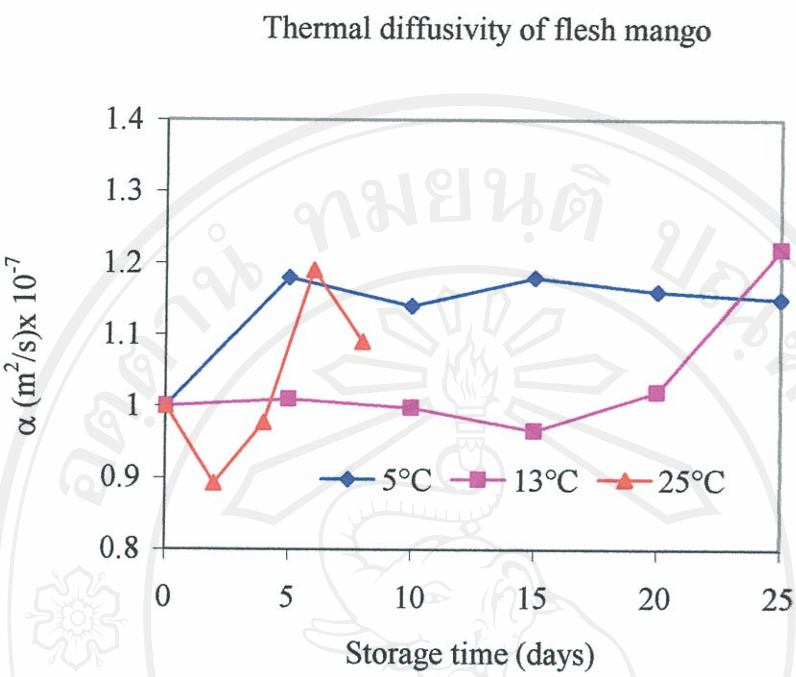

Figure 4.137 The profile of thermal diffusivity of Nam Dok Mai Si Thong mango flesh stored in the incubator at 5, 13 and 25°C.

The effect of storage temperature at 5, 13 and 25°C on the thermal diffusivity was shown in Fig. 4.137. The thermal diffusivity of the mango flesh being kept at 5°C was higher than at 13 and 25°C throughout the storage period. The thermal diffusivity of mango flesh being kept at 5°C had increased since the first five days of storage. The initial value of 1.0 x 10^{-7} m^2/s had risen to 1.18 x 10^{-7} m^2/s (+18%) and leveled off to the constant value throughout the storage period of 25 days. The storage at 13 and 25°C resulted in the increase of thermal diffusivity with storage period. The rapid rise of thermal diffusivity was observed for the mango being stored at 25°C than at 13°C. The initial value of 1.0 x 10^{-7} m^2/s had increased to 1.09 x 10^{-7} m^2/s in the 8^{th} day of storage for the storage at 25°C whereas the steady trend during the first 10 days at 0.998 x 10^{-8} m^2/s was observed at 13°C. The latter value was later dropped on day 15^{th} and increased at a faster rate later until 1.22 x 10^{-7} m^2/s was reached on the 25^{th} day of storage. The rapid rise of thermal diffusivity at 25°C in comparison to 13°C was due to the faster development into ripening process as evident from the relationship between the diffusivity and the firmness of mango flesh at 5, 13 and 25°C (Fig. 4.138 – 4.140). Or in other words, the storage at 5°C prevented the mango from being developed into ripening state as observed from the greenish color of the mango flesh (Fig. 4.141) with steady total soluble solid content throughout the storage period. This was in contrary to the color development of the mango flesh being stored at 13 and 25°C in which yellowish color development was observed (Fig. 4.142 and 4.143) with the increase in total soluble solid due to the conversion of starch to sugar that could be used as energy source in respiratory process (Fig. 4.144 – 4.146). The rise in respiratory rate of the mango being stored at both temperatures (Fig. 4.147 – 4.149) was the clear evidence in the support of such finding. It could thus be stated that the variation in thermal diffusivity of the mango flesh being kept at 5°C was caused by the chilling injury and the initial rapid rise in thermal diffusivity which was then followed by steady state. The thermal diffusivity increased at the faster rate when the fruit was completely ripened on the 6th day at 25°C and 25th day at 13°C.

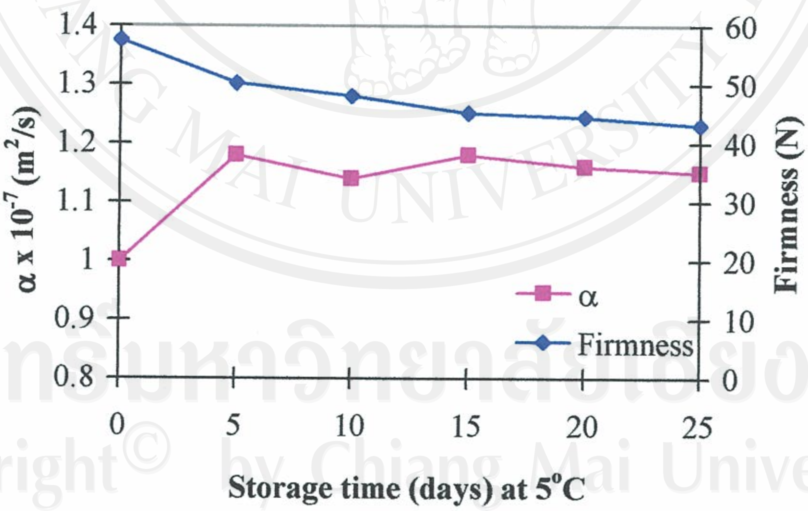

Figure 4.138 The relationship between the thermal diffusivity and firmness of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

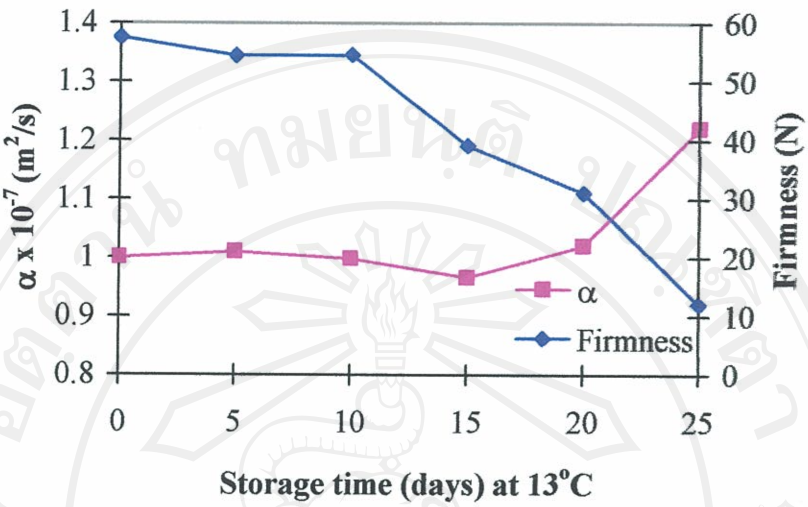

Figure 4.139 The relationship between the thermal diffusivity and firmness of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

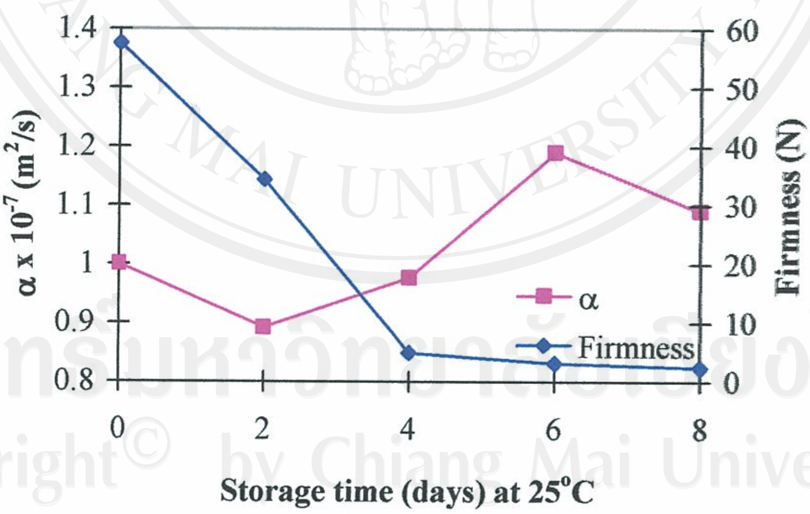

Figure 4.140 The relationship between the thermal diffusivity and firmness of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

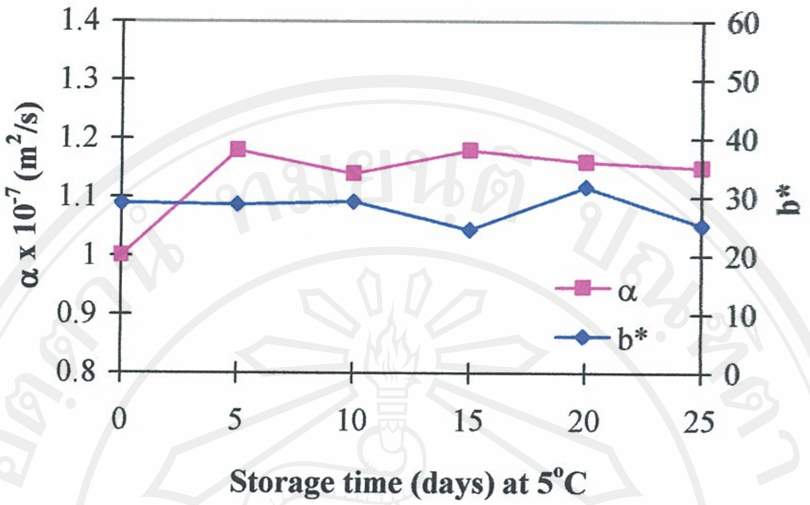

Figure 4.141 The relationship between the thermal diffusivity and b* value of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

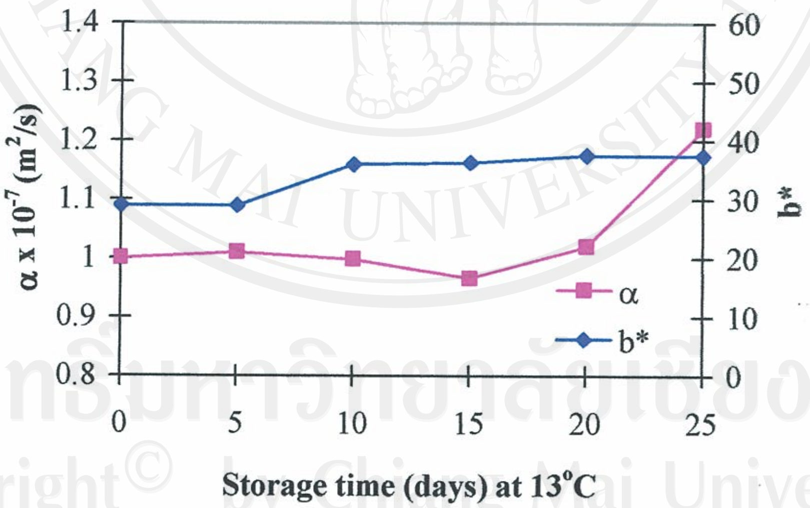

Figure 4.142 The relationship between the thermal diffusivity and b* value of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

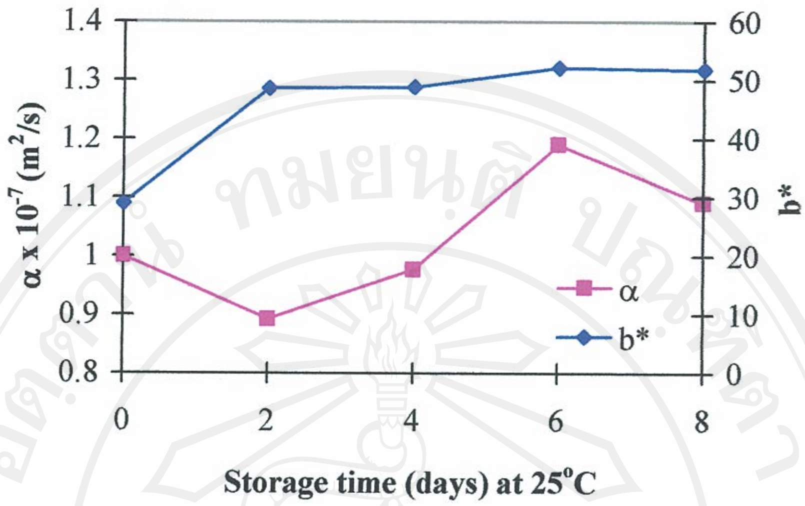

Figure 4.143 The relationship between the thermal diffusivity and b* value of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

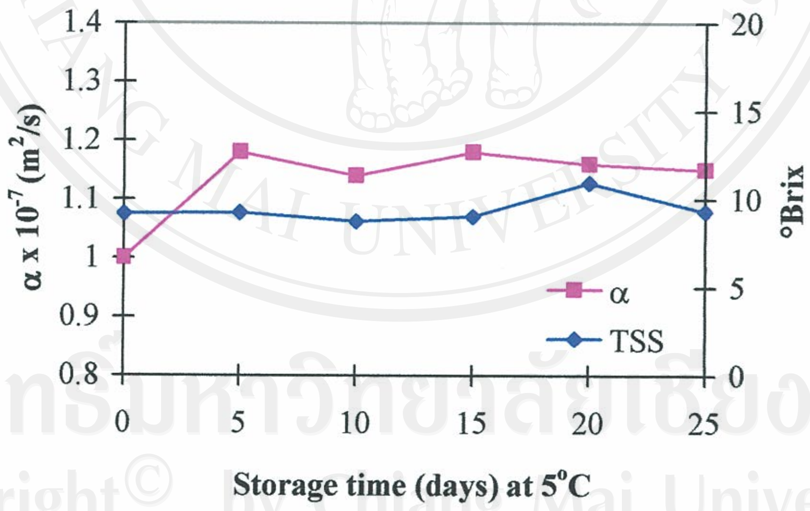

Figure 4.144 The relationship between the thermal diffusivity and total soluble solid content of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

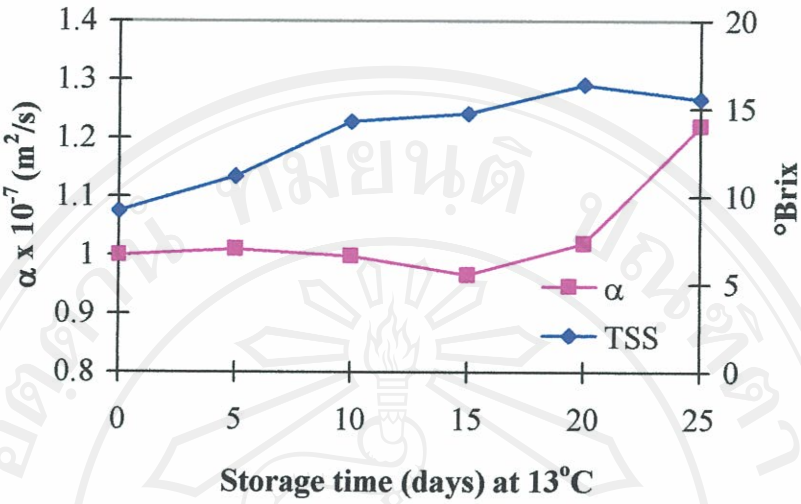

Figure 4.145 The relationship between the thermal diffusivity and total soluble solid content of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

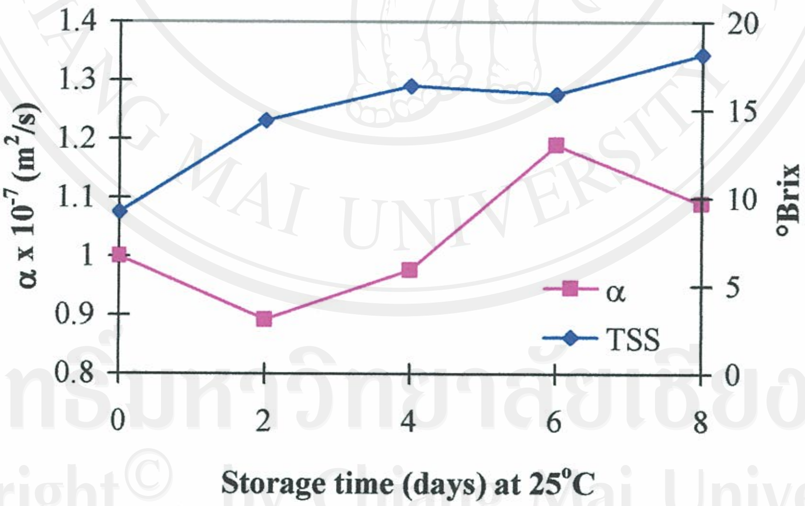

Figure 4.146 The relationship between the thermal diffusivity and total soluble solid content of Nam Dok Mai Si Thong mango flesh being stored at 25°C.

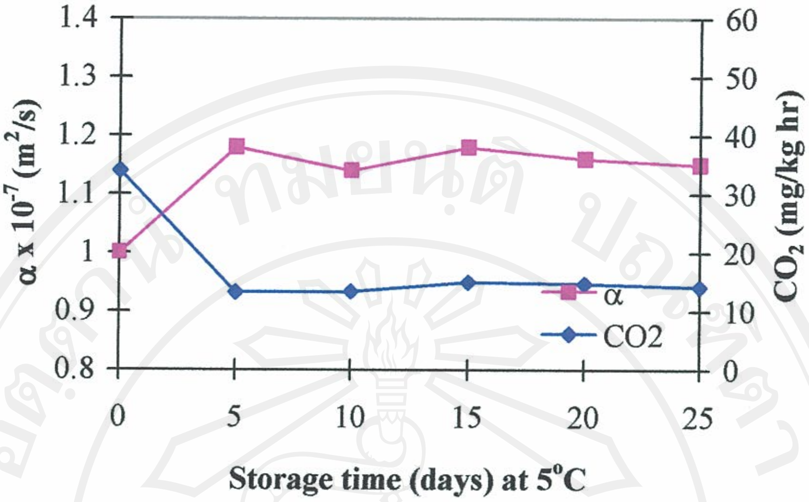

Figure 4.147 The relationship between the thermal diffusivity and respiratory rate of Nam Dok Mai Si Thong mango fruit being stored at 5°C.

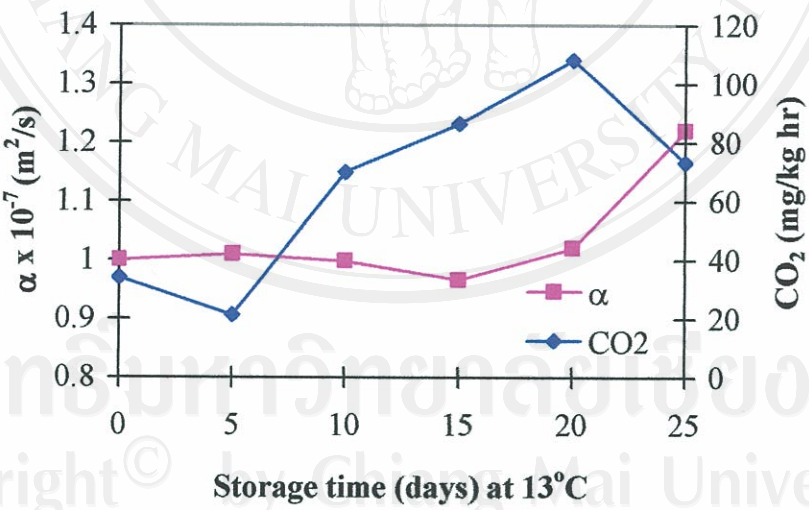

Figure 4.148 The relationship between the thermal diffusivity and respiratory rate of Nam Dok Mai Si Thong mango fruit being stored at 13°C.

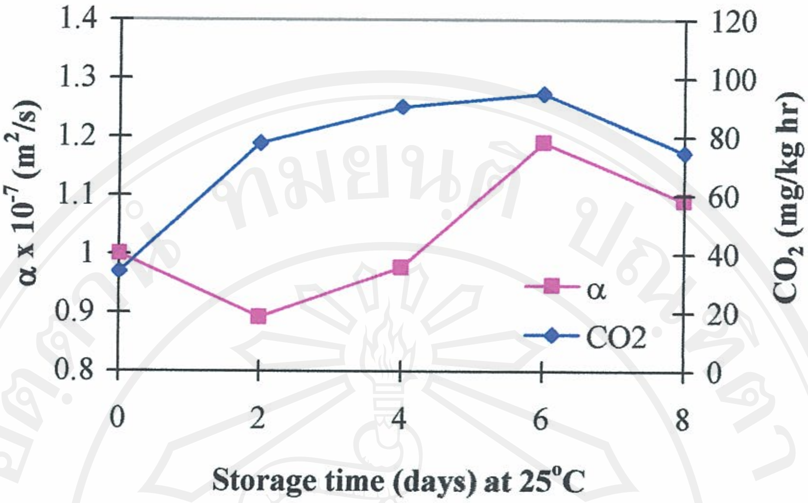

Figure 4.149 The relationship between the thermal diffusivity and respiratory rate of Nam Dok Mai Si Thong mango fruit being stored at 25°C.

This was in accordance with the relationship between thermal diffusivity and the leakage of electrolyte between the storage of mango at 5, 13 and 25°C (Fig. 4.150 - 4.152). The steady trend of thermal diffusivity at 5°C was the consequence of the stable electrolyte leakage throughout the storage period. The correlation was well applied to the storage of mango at 13 and 25°C where the relationship between the thermal diffusivity and electrolyte leakage of the mango flesh increased with storage period and ripening of mango.

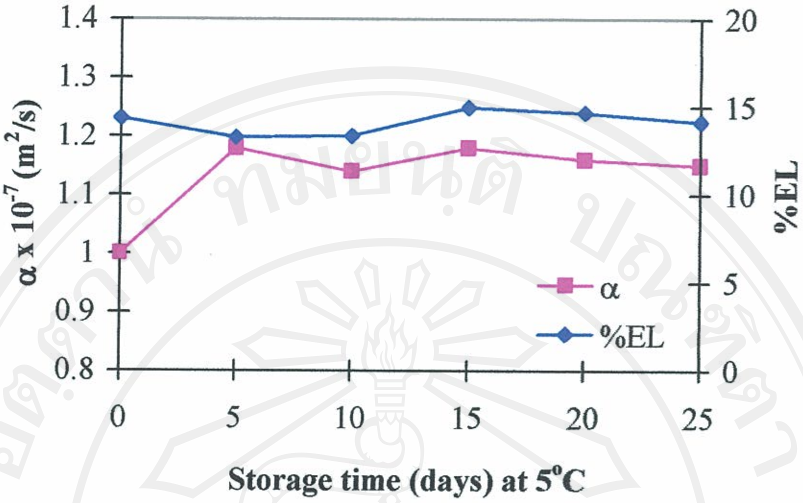

Figure 4.150 The relationship between the thermal diffusivity and electrolyte leakage of Nam Dok Mai Si Thong mango flesh being stored at 5°C.

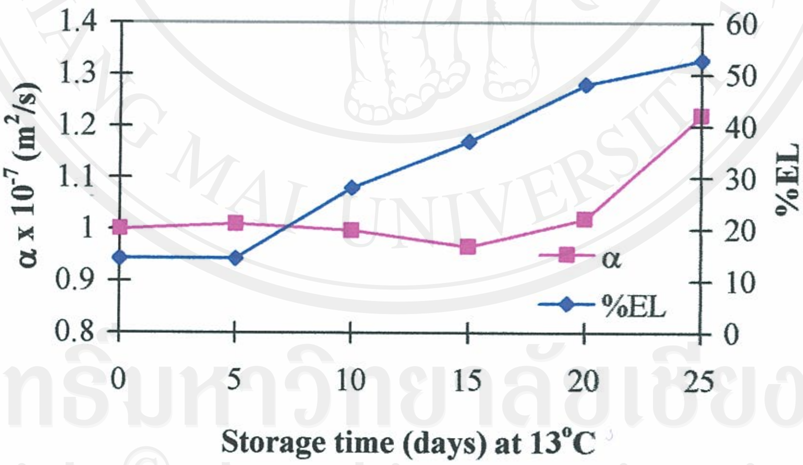

Figure 4.151 The relationship between the thermal diffusivity and electrolyte leakage of Nam Dok Mai Si Thong mango flesh being stored at 13°C.

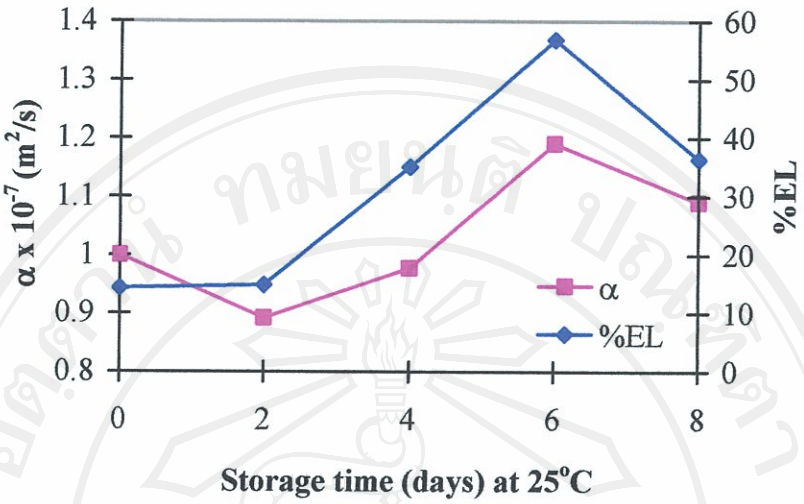

Figure 4.152 The relationship between the thermal diffusivity and electrolyte leakage of Nam Dok Mai Si Thong mango flesh being stored at 25°C.