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Technical Paper

Detection of Chilling Injury Symptoms of Salak Pondoh Fruit during Cold Storage with Near Infrared Spectroscopy (NIRS)

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Abstract

One of the treatment methods that is suitable for maintaining the quality of salak pondoh fruit is cold storage. However, cold storage of salak pondoh fruit below its optimum storage temperature (15°C) can cause chilling injury (CI). This research aims to develop a non-destructive method of determining the CI symptoms of salak pondoh fruit during storage at 5°C with NIRS. Measurements were carried out for 14 days by measuring the CI parameters (pH and IL/ion leakage) and the NIR reflectance spectra. The best PLS method NIR calibration model for estimating pH was generated using the Savitzky-Golay Smoothing pretreatment with r_c*= 0.81,* r_v *=0.76, SEC= 0.12, SEP =0.12, CV= 2.97%, RPD= 1.66, and consistency =100.06%. The IL slope of salak pondoh fruit correlated with the pH in a linear pattern relationship with the equation y = 0.1735x - 0.4305. The highest IL slope value was obtained on the* 4^{th} *day of storage which means that IL has reached its peak, and CI was predicted to have occurred on the* 4^{th} *day of storage.*

Keywords: *chilling injury, ion leakage, NIR, pH, salak pondoh*

Diterima: 06 Januari 2022; disetujui: 02 Februari 2022

Introduction

Salak pondoh (*Salacca edulis* Reinw.) is one of the original Indonesian horticultural commodities that has great potential to be developed commercially. Salak pondoh is very popular with local people, who are known for their high-level consumption of salak fruit in Indonesia. According to BPS (2020), the production of salak fruit increased 28.18% from 955,763 tons in 2019 to 1 225,088 tons in 2020. Foreign demand for this fruit is also quite high, with demands coming from Asian countries, Australia, and Europe. However, salak exports from Indonesia remain relatively low, though the trend keeps increasing from year to year.

Similar to other horticultural products, salak pondoh fruit is perishable. Fresh salak fruit after harvesting can only last 6 to 7 days at room temperature (Santosa and Hulopi 2011). During distribution, storage, and marketing, salak pondoh fruit will experience a decrease in quality. This decrease in quality includes the skin of the fruit getting dry over time, making it difficult to peel. The flesh also turns brown, soft, watery, and rotten. The important characteristic of salak fruit after it is harvested is the ability to continue carrying out physiological activities, especially respiration which is a factor causing decreased quality and fruit damage. Ahmad (2013) revealed that all fruits after they are harvested will naturally experience internal and external quality changes leading to damage, namely; the ripening process which ends in the decay phase.

One of the treatments that can be applied to maintain the quality of salak fruit is cold storage. Storage of salak fruit in a cooling system must also demand attention to the optimum storage temperature to avoid chilling injury. The right optimum temperature for the storage of salak fruit is a cold temperature of 15°C (Titiek and Mudjisihono 1998). Storage below the optimum temperature can cause chilling injury (CI), resulting in membrane damage through lipid membrane oxidation, structural changes and increased membrane permeability (Zhao et al. 2006). Damage to the cell membrane on the plant cell wall can cause ions and contents in the cell to leak out and mix with water outside the cell, causing the fruit to be damaged. Marangoni et al. (1996) defined the incident as ion leakage (IL) in fruit cells and made it an objective parameter for measuring chilling injury in fruit. In addition, Purwanto et al. (2005) stated that changes in pH can also be used as an indicator of chilling injury.

The development of non-destructive detection of chilling injury symptoms is a method that currently needs to be applied. One of the methods developed is the Near-Infrared Spectroscopy (NIRS) method. Jimmy (2019) predicted chilling injury symptoms of crystal guava fruit during cold storage at a temperature of 5°C using NIR reflectance, the chilling injury occurred on the 5^{th} day of storage. The purpose of this study was to develop a non-destructive method for determining the symptoms of chilling injury in salak pondoh fruit during cold storage using NIRS.

Methodology

Materials and Equipment

The main materials used were salak pondoh fruit (aged 6 months after flowering with a uniform maturity level) obtained from a salak plantation in Wonokerto, Sleman Regency, Yogyakarta. Other materials used are aquadest and aquabidest. The tools used in this study were: (1) the NIRFlex N-500 spectrometer (fiber optic solids), used to retrieve the spectral data of the salak pondoh fruit, (2) the CR-300 DX-L rheometer to measure fruit firmness, (3) refractometer to measure total soluble solids, (4) pH/conductivity meter to measure pH of fruit juice and measure ion leakage, and (5) refrigerator to store salak pondoh fruit during the research.

Procedures

This research was conducted in two stages, namely stage I and stage II. Stage I aims to develop a calibration model, determine the pH regression equation on the slope of ion leakage from destructive measurements, and measure changes in fruit quality. This first stage procedure includes sample preparation, measurement of NIR reflectance, measurement of fruit quality parameters and chilling injury parameters, development of NIR calibration models using the PLS method, evaluation of calibration results and PLS validation to determine the pH regression equation on the slope of ion leakage. While in stage II aims to predict pH based on NIR reflectance and predict chilling injury symptoms based on changes in ion leakage slope.

The samples used were first sorted to separate defects and intact to uniform size. Sample sorting was carried out based on the following criteria: uniform weight, ranging from 50–65 grams, 80% maturity level, dark brown skin color, clean fruit skin surface, free of defects, free of disease, and free of fungal spots. Then the samples were separated into several destructive measurement groups based on the storage temperature at 5°C (T5), 15°C (T15), and room temperature (TR); 66 samples for the temperature of 5°C, 33 samples for the optimum temperature (15°C), 24 samples for room temperature, as well as several monitoring measurement groups. Five samples were allotted for the temperature of 5°C as samples for monitoring the measurement of NIR reflectance. Furthermore, the samples were put into the refrigerator and parameter measurements were carried out 11 times. In the first week, observations were carried out every day, and the following week, observations were made every two days. Parameters measured are reflectance spectra, firmness, total soluble solids, pH, and ion leakage.

The reflectance spectra were measured at 3 different points using NIRFlex N-500 spectrometer (fiber optic solids) with a wavelength of 1000-2500 nm and an interval of 0.4 nm. Measurement of firmness was carried out at 3 different points using a Rheometer CR-300 with a maximum load of 10 kg, a depth of 10 mm, a probe diameter of 5 mm, and a pressing speed of 30 mm/minute. Ion leakage measurements were carried out on 3 different samples with a size of 10 x 8 x 8 mm. Ion leakage is measured based on changes in the value of the electrical conductivity of the solution from immersing the sample with aquabidest and then measured with a conductivity meter. Meanwhile, the measurement of total soluble solids and pH value were observed according to the AOAC 2005.

The development of a calibration model and NIR validation were carried out on pH with ion leakage. NIR reflectance spectra data processing on calibration and validation were carried out on NIR reflectance data with the PLS method using the Unscrambler X 10.4 application. Pretreatment of Spectrum data was carried out to reduce the influence of wave interference and noises on the spectrum so that the calibration model is more accurate and stable. The spectrum data pretreatments used included Normalize, Savitzky-Golay Smoothing (SGs), Standard Normal Variate (SNV), and Multiplicative Scatter Correction (MSC). The calibration and validation models' performance was evaluated by comparing the pH predicted by the NIR with the measured pH. The evaluation was done based on correlation coefficient (r), standard error calibration (SEC), standard error prediction (SEP), coefficient of variation (CV), the ratio of prediction to deviation (RPD), and consistency.

Determination of the pH regression equation with ion leakage slope based on destructive data was done by testing regression analysis using the Microsoft Excel program. The equation obtained was used to determine the symptoms of chilling injury based on changes in the pH of the salak pondoh fruit. The best NIR calibration model obtained was used to predict the pH of the salak pondoh fruit based on the NIR reflectance of the monitoring sample measurement results. The reflectance data of five monitoring samples were transformed with the best pretreatment, then used to predict fruit pH during storage with the best NIR calibration model. The fruit pH data from the NIR prediction was used to predict the slope of ion leakage with the pH regression equation on the slope of ion leakage obtained in the previous stage. Chilling injury symptoms of salak pondoh fruit during cold storage were predicted based on the relationship between storage time and the predicted ion leakage slope.

Results and Discussions

Changes in Salak Pondoh Fruits Quality Parameters

Parameters of salak pondoh fruit quality observed included firmness and total soluble solids. Fruit firmness is influenced by cell turgor pressure, structure, and cell wall polysaccharide composition (Marlina et al. 2014). One of the physical indicators of damage to the salak pondoh fruit that affects the level of fruit firmness is the shrinkage of the surface of the fruit flesh. This is due to the loss of water as the respiration and transpiration processes continue during storage, causing a decrease in cell turgor pressure, firmness, and fruit firmness. The graph of changes in the level of firmness during storage can be seen in Figure 1.

The results showed that the change in firmness was very fluctuating and tended to decrease during storage. The decrease in firmness level at room temperature storage was greater than at low-temperature storage. This is due to the influence of storage temperature where low-temperature storage can inhibit the fruit's metabolic processes, softening, and aging. The decrease in the level of firmness occurs due to the degradation of the composition of the cell wall, such as the change in insoluble pectin (protopectin) to soluble pectin, causing the bonding power between cells to weaken (Winarno 2002).

Changes in the level of fruit firmness correlated with the presence of chilling injury symptoms. Storage data for 14 days shows that the firmness level of the 5°C treatment sample is still hard because samples stored below the optimum temperature will experience a chilling injury which results in abnormal metabolic processes. This low-temperature storage for a long period of time resulted in the metabolic process in the sample not running properly so that there was no protopectin reshuffle.

Total soluble solids (TSS) describe the amount of macromolecular compounds such as carbohydrates, amino acids, and organic acids suspended in a solution in a material. The TSS value shows the percentage of suspended material left in the solution as a residue resulting from evaporation or heating. The value of TSS is related to the content in the material because it has carbohydrate reserves which are used as energy for the respiration process. The respiration process causes the conversion of carbohydrates into sugar (Winarno 2002). The graph of changes in TSS during storage can be seen in Figure 2.

The results of the above observations indicate that there are changes in TSS that vary and tend to increase during storage. TSS increase at low-temperature storage (5°C and 15°C) was slower than at room temperature storage. This is due to the influence of temperature, where the lower the temperature, the slower the TSS changes. Winarno (2002) explained that an increase in total sugar was due to the accumulation of sugar from starch degradation because during the ripening process, hydrolysis of polysaccharides occurred into simple sugars. A decrease in total sugar occurred because some of the sugar was used for the respiration process.

Changes in TSS correlate with chilling injury symptoms. This was influenced by temperature; the lower the temperature, the slower the total soluble solids change. This can be seen from the inhibition of the starch degradation process into glucose occurring at a temperature of 5°C. According to Pantastico (1986), the rate of degradation of starch into simple sugars is influenced by temperature and enzymes. The higher the temperature, the faster the degradation of starch will occur to a certain extent where the hydrolase enzyme activity will be inhibited.

Changes in Chilling Injury Parameter

The chilling injury parameters of salak pondoh fruit include pH and ion leakage. Changes in pH can be caused by the long storage period and the presence of microorganisms. These changes occur due to the inability of mitochondria to retain hydrogen ions and changes in the composition of proteins in the membrane as a result of chilling injury (Hutabarat 2008). Changes in the pH of salak pondoh fruit during storage can be seen in Figure 3.

The results of the above observations indicate that there is a change in the pH value that varies and tends to increase at the end of storage. The biggest change in pH value occurred at room temperature storage which was stored for 8 days where the sample had entered the decay phase. While in storage for 14 days, the lowest pH changes occurred at 5°C storage. The higher pH changes in salak fruit indicate the degradation of starch into simple sugars during the ripening process. According to Winarno (2002), measurement of pH can not be separated from the level of fruit maturity which is indicated by the ratio of sugar and acid.

Salak pondoh fruit stored at 5°C for 14 days had the highest pH value of 4.22 on the 12th day, the lowest pH

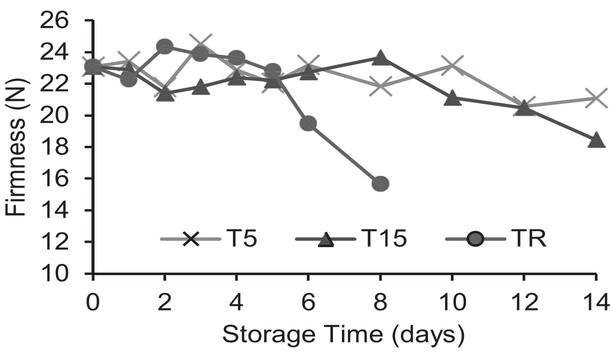

Figure 1. Changes in the firmness of salak pondoh fruit during storage.

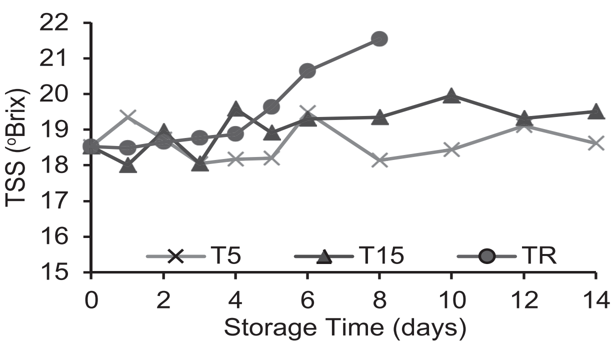

Figure 2. Changes in TSS of salak pondoh fruit during storage.

value of 3.78 on the 3rd day, and the largest increase in pH value on the 4th day. in the first week of storage. This suggests that the increase in pH on day 4 caused damage to the fruit. According to Naruke et al. (2003), changes in pH can be used as an indication of chilling injury. Therefore, an abnormal change in pH at 5°C storage indicates chilling injury symptoms.

Ion leakage has a close relationship with chilling injury and is often used as an objective measurement parameter (Marangoni et al. 1996). According to Saltveit (2002), an increase in the amount of ion leakage released from the cell membrane is one sign of chilling injury. The rate of ion leakage obtained from fruit tissue immersed in an isotonic aqueous solution was used to measure indices of chilling injury in membranes with increased permeability (Saltveit 2002).

Observations showed that during storage at 5°C there was a change in the rate of ion leakage. The biggest change in ion leakage rate occurred on the 4th day of storage, which was around 16.59% with a slope value of 0.2664. Ion leakage is caused by damage to cell membranes that occurs due to protein lipids as constituents of cell walls experiencing plastic tension due to cold temperatures. Nobel (1991) stated that the tension is caused by the pressure of the cell contents on the cell wall and depends on the permeability of the protoplasm, the elasticity of the cell wall, and the concentration of active osmotic substances in the vacuole.

Figure 4 shows the increase in the percentage of ion leakage. The increase was caused by the increased damage to the permeable membrane so that when removed from the cold storage room, the cell wall broke, and the cell fluid came out, which caused an increase in ion leakage. The rate of change of ion leakage during storage is obtained through the slope value or the slope of the graph of the total percentage of ion leakage from the linear equation.

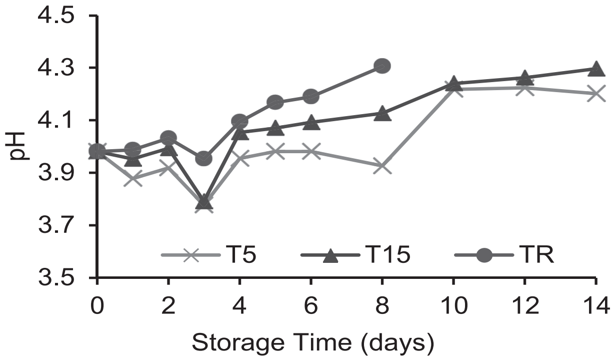

Figure 3. Changes in the pH of salak pondoh fruit during storage.

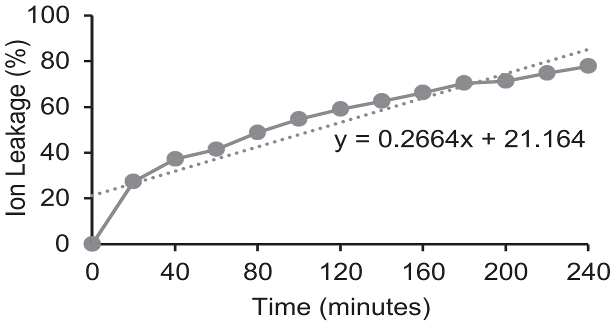

Figure 4. Changes in ion leakage on the 4th day of storage at 5°C.

Table 1. The rate of change of ion leakage at storage temperature of 5°C.

Storage (days)	Slope Ion Leakage
1	0.2396
2	0.2408
3	0.2285
4*	**0.2664**
5	0.2501
6	0.2440
8	0.2731
10	0.3035
12	0.3497
14	0.2509

**Prediction of occurrence days of destructive chilling injury symptoms*

The slope of ion leakage is the rate of change of ion leakage during storage where the higher the slope of ion leakage value, the higher the membrane leakage, which indicates the fruit is getting damaged. The results showed an increase in the percentage of ion leakage in the salak pondoh fruit samples stored at 5°C. The increase in ion leakage slope was seen since the 4th day of storage, which was 0.2664. It is suspected that chilling injury had occurred on that day, and the sample ion leakage slope experienced some fluctuating changes (Table 1).

Symptoms of chilling injury of salak pondoh fruit stored at a temperature of 5°C can be seen visually, such as brown spots on the flesh that begin to appear on the 6th day. In addition, another symptom that was seen was that the sample meat was browning on the 8th day. The symptoms of chilling injury are more obvious and numerous as the sample storage period increases.

Wave Pattern of NIR Spectra on Pondoh Salak Fruit

The content of ingredients in salak pondoh fruit is closely related to the absorption of NIR radiation. Estimation of the chemical composition of salak pondoh fruit understudy is pH or acidity. The device used is NIRFlex N-500 solid fiber optic with a wavelength of 1000–2500 nm. The data generated from the device is in the form of reflectance data containing information from a material. In general, the shape of the reflectance spectrum shows several spectral peaks and valleys. According to Blanco and Villarroya (2002), the peaks and valleys of this spectrum are influenced by differences in the chemical content of the material and the physical characteristics of the material. The difference in chemical content in the peaks and valleys can be adjusted to the chemical structure of water, acids, simple sugars, and starch. The NIR reflectance spectrum of salak pondoh fruit during storage for 14 days (original spectrum) can be seen in Figure 5.

The results of the observations showed an increase in the value of the spectrum, which means that there was a decrease in the absorbance value of the physicochemical content of the salak pondoh fruit. Absorption valleys occur at 1180 nm, 1450 nm, and 1940 nm waves, indicating water content. This absorption valley occurs because there are O-H bonds (O-H. *str first overtone*) at that wavelength (Osborne et al. 1993). Chilling injury is also indicated by the wavelength in which this O-H bond is present. This is because the chilling injury is a disease that occurs due to damage to cell membranes and increased cell permeability which is characterized by H^+ ion leakage or ion leakage (Suci et al. 2015).

The wavelength of 1215–1395 nm where there are C-H atomic bonds in the wave indicates the presence of CH_2 which is also indicated as a constituent structure of the acid. Organic acids commonly found in fruits are formic, acetic, fumaric, malic, citric, succinic, oxaloacetic, quinic, shikimate, oxalic, etc. Meanwhile, the dominant acid in salak pondoh fruit is malic acid (Lestari et al. 2013). Other components such as starch content were detected at wavelengths of 2250 nm and 2500 nm, while alkanes were detected at wavelengths of 1900 nm and 1950 nm.

The storage process for 14 days also affects the value of the reflectance spectrum. The reflectance spectrum value of salak pondoh fruit continued to increase during storage. This is due to physicochemical changes that occur due to metabolic processes during storage. Some of these changes include an increase in the value of TSS and pH, as well as a decrease in firmness.

Calibration and Validation of NIR Spectra on the pH of Salak Pondoh Fruit with PLS Method

Calibration and validation of NIR spectra in predicting the pH of salak pondoh fruit at a storage temperature of 5°C was developed based on the correlation of NIR reflectance spectra data with destructive pH measurement data. The calibration model was developed using the PLS algorithm method based on pre-treatment with accurate and precise calibration model results (Andasuryani et al. 2013). The data analyzed were collected from 33 samples which were stored at 5°C for 14 days. The total data used were 99 data, where 2/3 parts were used for calibration and 1/3 parts were used for validation. The characteristics of the sample pH data for calibration and validation can be seen in Table 2.

The selection of data was done based on the magnitude of the pH value. The values were obtained by taking values that were close to the maximum and minimum for calibration, and values that were close to the average value for validation, making it possible to get the best results. Yan et al. (2009) stated that the highest and lowest values in NIRS processing data are intended as calibration data sets in building a calibration model.

Table 2. Characteristics of the pH data of salak pondoh fruit for calibration and validation.

Statistical Description	Temperature of 5°C	
	Calibration	Validation
Number of Data	66	33
Minimum Value	3.60	3.64
Maximum Value	4.44	4.40
Average Value	4.01	3.99
Standard Deviation	0.205	0.182

The PLS (Partial Least Square) method was used to statistically test the correlation between the predictor variable (reflectance spectra) and the response variable (pH value). The calibration and validation results obtained were then evaluated based on the value of r_c, r_v, SEC-SEP, CV, RPD and consistency. The results of calibration and validation of NIR on sample pH can be seen in Table 3.

A good calibration model has a high r value, the difference between SEC and SEP is low, a low CV value, a high RPD value, and a consistency value between 80-110%. Table 3 shows the results of the calibration and validation data processing on the estimation of the pH of the salak pondoh fruit. Based on the table, it can be seen that the best data treatment is in the pre-treatment of data using Savitzky-Golay Smoothing (SGs) with a factor of 9. The resulting model has a calibration correlation coefficient (r_c) of 0.81, a validation correlation coefficient (r_v) of 0,76, SEC is 0.12, SEP is 0.12, CV is 2.97%, RPD is 1.66 and consistency is 100.06%. The resulting model had a correlation coefficient (r_c and r_v) which is quite good because it is close to a value of 1. The difference between the SEC and SEP values is also very good because it is close to 0 with a consistency value that is between 80-110%, and a CV value <5%, which means the accuracy and stability of the model are good. While the resulting RPD value is between 1.5–2.0 where the estimation is still rough but can be used to predict. The

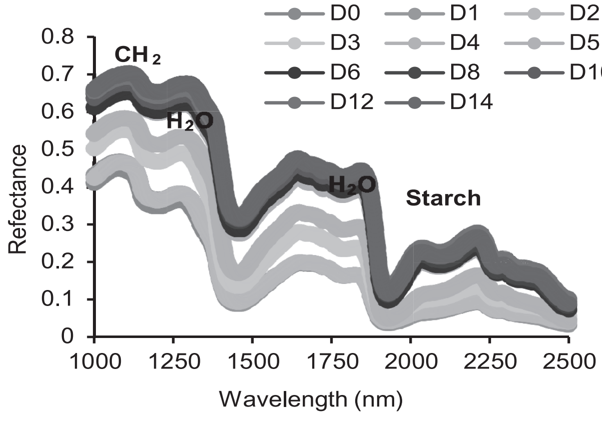

Figure 5. NIR reflectance spectrum of salak pondoh fruit during storage.

Table 3. Results of calibration and validation of NIR spectra on the pH of salak pondoh fruit at 5°C storage using the PLS method.

Pre treatment	Factor PLS	Set Calibration		Set Validation		CV (%)	RPD	Consistensy (%)
		r_c	SEC	r_v	SEP			
Original	9	0.81	0.12	0.76	0.12	2.99	1.65	98.65
Normalize	8	0.81	0.12	0.75	0.12	3.10	1.59	96.15
SGs	**9**	**0.81**	**0.12**	**0.76**	**0.12**	**2.97**	**1.66**	**100.06**
SNV	8	0.83	0.11	0.71	0.13	3.27	1.51	87.51
MSC	8	0.83	0.11	0.74	0.12	3.05	1.62	94.02

distribution of the best regression model data can be seen in Figure 6.

The results of the SNV and MSC processing have a correlation coefficient value of the calibration set which is greater than that obtained by using SGs processing. However, these treatments have RPD values that are smaller than SGs and CV values that are greater than SGs. Thus, the best treatment for predicting the pH of salak pondoh fruit during storage at 5°C was using SGs.

PH Regression Equation of Ion Leakage Slope

The slope of ion leakage is the rate of change of ion leakage caused by various factors, one of which is low-temperature storage. Meanwhile, NIRS produces qualitative and quantitative information originating from the interaction between NIR waves and organic chemical compounds that make up commodities such as water, protein, fat, starch and acid. Measurement of NIR waves cannot detect ion leakage directly, so the parameter of change in ion leakage slope used in this study is pH (degree of acidity). The relationship between pH and slope of ion leakage was determined by regression analysis based on destructive measurement data, namely daily average pH data and daily average ion leakage slope data (Figure 7). The results of the regression analysis show that pH is quite well correlated with the slope of ion leakage. The relationship between pH and the slope of ion leakage is in the form of a linear pattern and can be determined by the following equation:

$$y = 0.1735x - 0.4305$$

The value of y is the slope of ion leakage and x is the pH. Based on regression analysis, the results of the Anova table show a significance level or probability of 0.0156, meaning that the p-value is < 5%, so that the equation can be used to predict the slope of ion leakage based on changes in the pH of the salak fruit in the monitoring sample.

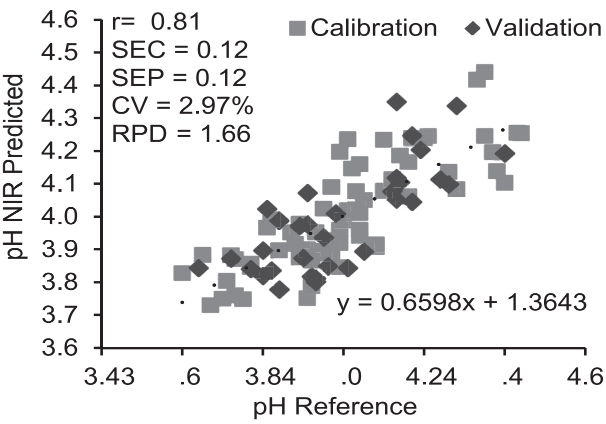

Figure 6. Results of calibration and validation of NIR on pH with Savitzky-Golay Smoothing (SGs) pretreatment at 5°C storage temperature.

pH Prediction Based on NIR Reflectance

The pH of salak pondoh fruit in the monitoring sample was predicted non-destructively with the best PLS calibration model method obtained through the data processing program (Unscrambler X 10.4). The monitoring sample used was 5 units. The results of NIR predictions for monitoring samples showed fluctuating changes in pH during storage and had a pattern that tended to be the same as the results of destructive

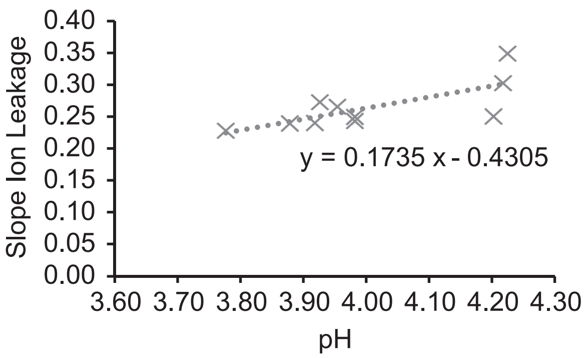

Figure 7. The relationship between pH and slope of ion leakage in salak pondoh fruit at 5°C storage.

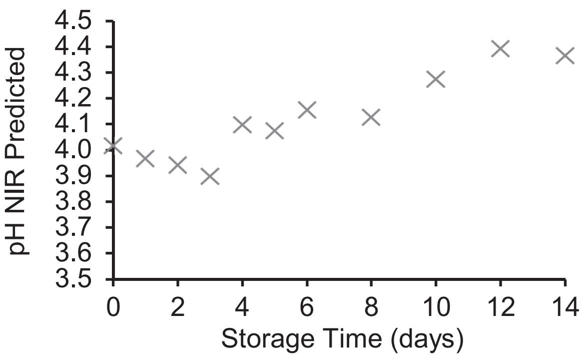

Figure 8. pH prediction of the average NIR of salak pondoh fruit monitoring samples at 5°C storage.

Table 5. Condition of salak pondoh fruit on the 4th day stored at 5°C.

Measurement Method	Parameter of Chilling Injury	Value	Parameter of Quality	Value	Unit
Destructive	pH	3.95	Firmness	23.3	Kgf
	Ion leakage	0.2664	TSS	18.2	Brix
Non-Destructive (Prediction by NIR)	pH	4.10			
	Ion leakage	0.2808			

Table 4. Prediction of ion leakage slope ion leakage of salak pondoh fruit based on the average pH of NIR prediction results at a storage temperature of 5°C.

Storage (days)	pH Predicted by NIR	*Ion Leakage Predicted*
1	3.9689	0.2581
2	3.9437	0.2537
3	3.8987	0.2459
4*	**4.0995**	**0.2808**
5	4.0749	0.2765
6	4.1558	0.2905
8	4.1280	0.2857
10	4.2741	0.3111
12	4.3930	0.3317
14	4.3655	0.3269

**Prediction of days of chilling injury symptoms*

measurements of the pH of salak pondoh fruit. The predicted pH of the average NIR of salak pondoh fruit can be seen in Figure 8.

Based on the results of NIR predictions, salak pondoh fruit at a storage temperature of 5°C had the largest pH value of 4.39 on the 12th day and the lowest pH value of 3.90 on the 3rd day. Meanwhile, the largest increase in pH occurred on the 4th day, which was 4.10. The results of the NIR prediction on pH are in accordance with the results of destructive measurements where the destructive measurements obtained the largest pH value, the lowest pH, and the largest increase in pH, respectively, on the 12th day, 3rd day, and 4th day. This strengthens the notion that the increase in pH on day 4 has caused damage to the fruit. Naruke et al. (2003) revealed that changes in pH can be used as an indication of chilling injury. Therefore, an abnormal change in pH on day 4 indicates the onset of chilling injury symptoms.

Prediction of Ion Leakage Slope Based on Changes in pH

The pH data of salak pondoh fruit as predicted by NIR was used to predict the slope of the ion leakage of the fruit during storage at 5°C using Equation 7. The data used was the average predicted pH value of 5 monitoring samples. The prediction results show a change in the slope of the ion leakage which is fluctuating and has a pattern that is almost the same as the change in the slope of the ion leakage from the destructive measurement. The highest predicted change in slope of ion leakage occurred on the 4th day of storage, which was around 14.17% with a slope value of 0.2808. This indicates that the membrane leakage has reached its peak and chilling injury is predicted to have occurred on the 4th day of storage (Table 4).

Meanwhile, visual observations on monitoring samples stored at 5°C did not show chilling injury symptoms on the 4th day. Symptoms of chilling injury began to appear on the 6th day where on the surface of the peel of salak pondoh the color changed to a dark black or brownish. In addition, observations on the flesh samples were carried out at the end of storage, namely on the 14th day. Symptoms of chilling injury that can be seen were many brown spots and widespread browning.

Detection of Chilling Injury on Pondoh Salak Fruit Using NIRS

Chilling injury detection using NIRS is based on chilling injury symptoms that can be observed in salak pondoh fruit such as abnormal changes in pH during cold storage and ion leakage in cell membranes. NIRS is used to predict pH because NIR can interact with H^+ where H^+ is an ion associated with pH and this H^+ ion comes from bonds with CH_2 compounds. The CH_2 compound bond is a bond to organic acids where normally during storage there is a change of organic acids which causes the pH of the fruit to increase. Storage of fruit at a temperature that is too low causes the membrane to be damaged and ion leakage occurs. This ion leakage is related to the release of H^+ ions which causes a change in pH. The condition of the salak pondoh fruit which is suspected of having chilling injury symptoms during destructive and non-destructive measurements can be seen in Table 5.

The occurrence of chilling injury symptoms in salak pondoh fruit stored at a temperature of 5°C can be detected properly. It can be seen in Table 5 that the value of the chilling injury symptom parameter does not have much difference, both using destructive and non-destructive methods. This difference may occur due to the difference in the value of the NIR reflectance in the two measurement methods. In addition, by using destructive and NIR methods, chilling injury can be detected on the 4th day. Therefore, the detection of chilling injury symptoms based on the relationship between changes in pH and the rate of ion leakage during storage at 5°C can be done using NIR.

Conclusions

Storage of salak pondoh fruit at low temperatures can maintain the internal quality of the fruit (firmness, total soluble solids, and pH) compared to storage at room temperature. Non-destructive estimation of the pH of salak pondoh fruit at 5°C storage can be done using NIR reflectance spectra data. The best calibration model generated by the PLS method was obtained using Savitzky-Golay Smoothing data pretreatment (SGs factor 9) with value of r_c = 0.81, r_v = 0.76, SEC = 0.12, SEP = 0.12, CV = 2.97%, RPD = 1.66, and consistency = 100.06%. The ion leakage slope of salak pondoh fruit at 5°C storage can be predicted based on the pH value of the fruit with the equation y = 0.1735x – 0.4305. The highest ion leakage slope value occurred on the 4th day of storage, which was 0.2808, which means that the membrane leakage had reached its peak and chilling injury was predicted to occur on the 4th day of storage. The occurrence of chilling injury symptoms in salak pondoh fruit stored at a temperature of 5°C can be detected properly and can be predicted by using NIRS methods.

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