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Slovak Journal of Food Sciences

Potravinarstvo Slovak Journal of Food Sciences
vol. 12, 2018, no. 1, p. 744-755
doi: https://doi.org/10.5219/985
Received: 23 October 2018. Accepted: 24 October 2018.
Available online: 14 December 2018 at www.potravinarstvo.com

ISSN 1337-0960 (online)

EFFECT OF INFRARED RADIATION ON CHEMICAL AND PHYSICAL PROPERTIES ON DUKU'S PEEL

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ABSTRACT

Infrared radiation has a potential for drying agricultural commodities such as the peel of duku. Drying of duku's peel in a whole duku using infrared radiation could become an effective method to eliminate the water on the peel but not in the flesh and could increase the shelf life of duku. The objective of this study was to investigate the potential of using infrared radiation for drying the peel of duku which would increase the shelf life of duku during storage. Duku's peel drying process was achieved by means of heating duku using a pairs of electric infrared emitters (IRE) facing each other with the emitter distance of 6 cm and 10 cm for a relatively short heating time of 50, 60, 70 and 80 seconds and after that stored at a cool room at the temperature of 15 °C for the length of one month. During storage, the physical and chemical changes of duku were then evaluated. It was found that the weight loss, fruit firmness, and total soluble solid of duku dried by means of exposing to Infra Red Emitter (IRE) were significantly affected by the distance of IRE, the temperature of IRE and the time exposed to IRE. However the titratable acidity only affected significantly by the distance of IRE. There were no significantly changes of browning index on duku during drying by exposing to IRE and while stored up to 25th day of storage. Drying duku by exposing it to IRE show a slightly better shelf life than the previous work.

Keywords: infrared radiation; duku; shelf life; drying

INTRODUCTION

Lansium domesticum corr. is a tropical fruit of South East Asia with its member known as langsat, longkong and duku. Duku is one of the most favourite fruit in Indonesia because the mature and ripe one has a unique aroma and pleasant taste. Duku has a thicker peel and no latex while langsat has a peel that contains a milky sticky sap. There are 4 to 12 fruits per bunches for duku and 15 to 25 fruits for langsat. Both of them have five separate segments, with one to five seeds in it **(Paull, 2014)**. The fruit is easily peeled from the stem end and the flesh is commonly eaten out-of-hand or served as a dessert. Peel color (green for the immature to yellow for the mature one) and the lack of latex could be used as an indicator for the level of fruit maturity. All the bunches of one tree could not be harvested at the same time because of the non-uniformity of the fruit maturity. The fresh peel contains 0.2% of a light yellow, volatile oil, a brown resin and reducing acids. A dark, semi-liquid oleoresin composed of 0.17% volatile oil and 22% resin could be extracted from the dried peel. The dried peel could be burned to create an aromatic smoke serving as a mosquito repellant **(Phantumas, 1998)**. The extract of *Lansium domesticum* fruit was found to have an antioxidant as evaluated by the DPPH free radical assay and the dried hydro-ethanol extract of *Lansium domesticum* fruit could be used as cosmetic **(Tilaar et al., 2008)**.

Duku, at room temperature, has a limited post-harvest life of about 3 – 7 days. The deterioration of quality which took place was in the form of pericarp browning, changes in texture, appearance and off-flavour after harvest **(Lichanporn et al., 2009; Venkatachalam and Meenune, 2012a)**. Post-harvest damage on duku could be controlled by several methods: chemical soaking, low temperature storing, modified atmosphere packaging and drying. The most commonly drying method is using hot air. This method is chosen because it is the easiest and the lowest cost **(Diamante et al., 2010)**. However, these treatments cause degradation of the product's components which leads to censorial loss of dry product. The food drying method that's commonly developed nowadays is using the low humidity-low temperature method **(Ondier et al., 2010)** and using high radiation frequency such as microwave, radio frequency, and infrared **(Contreras et al., 2008; Kassem, 2011)**.

The infrared radiation had been implemented in food processing to reduce the water content, lowering energy consumption and time spent in the process, securing and ensuring the quality of foodstuffs processed **(Pan et al., 2011)**. Infrared also has been used to predicted quality of foods and agricultural by near infrared radiation due to the simple and minimal sample preparation **(Liguori et al., 2016)**. Some drying studies had been performed using infrared radiation systems to dry banana **(Pan et al., 2008; Pekke et al., 2013)**, tomato peeling **(Li et al., 2014; Li and Pan, 2014a; Li and Pan, 2014b; Pan et al., 2009; Pan et al., 2011; Pan et al., 2015)**, apple **(Nowak and Lewicki, 2004; Togrul, 2005)**, longan **(Nathakaranakule et al., 2010)**, celery **(Jezek et al., 2008)**, carrot **(Botelho et al., 2011; Grdzelishvili and Hoffman, 2012; Kocabiyik and Tezer, 2009)**, onion **(Mongpraneet et al., 2002; Pathare and Sharma, 2006; Sharma et al., 2005)**, potato **(Afzal and Abe, 1998; Doymaz, 2012; Grdzelishvili and Hoffman, 2012)**, red pepper **(Nasiroglu and Kocabiyik, 2007)**, peach **(Jun and Sheng, 2006)**, and spices **(Rachmat et al., 2010)**. The use of radiation in the food sector is not entirely beneficial for the food process. The previous research has suggested that the use of UV-C radiation negatively affects the sensory properties of grape juice because it has a significant change in the smell and taste of wine **(Czako et al., 2018)**. Infrared radiation had been used to inactivate lipoxygenase, an enzyme in soybean, with the result of 95.5% inactivation within 60 seconds **(Kouzeh-Kanani et al., 1982)**. Certain enzyme reactions involving lipase and amylase might be affected by the infrared heating **(Kohashi et al., 1992; Sawai et al., 2003)**. Infrared radiation could also inactivate pathogens in the material. Infrared radiation could inactivate bacteria, spore, yeast, and mold by controlling some of the influential parameters such as power on infrared heater **(Hamanaka et al., 2000)**, sample temperature **(Sawai et al., 2003)**, wavelength and the target wave in a wide range **(Krishnamurthy et al., 2008)**, sample thickness **(Sawai et al., 2000)**, and sample water content **(Hamanaka et al., 2006)**. The increased supply of radiant heat coud also be the result of tools design **(Zverev and Sesikashvili, 2018)**. The unique characteristics possessed by infrared radiation was it could only heat up the surface of the material in a short time without raising the temperature of the inside material **(Li and Pan, 2014a)**.

The unique characteristics of infrared radiation could be used to dry the outside surface of duku peel which would result in a shell like that would protect duku flesh from the outside air and from the attack of microbes. The microorganisms could be originated from storage. The controlled storage (the refrigerator and the showcase) could kept the product still fresh and it most suitable for most of foods and fruits **(Bubelová et al., 2017)**. Currently, there was no previous report found on the literature about the usage of infrared radiation for drying the whole duku's peel. Therefore, the objective of this research was to develop a new drying method for the whole peel of duku by means of infrared radiation.

Scientific hypothesis

The hypothesis of this research was that the infra red radiation could dry the skin of duku which would extend its shelf life.

MATERIAL AND METHODOLOGY

Sample of duku

Duku (Lansium domesticum) used in this study were obtained from a local farm in South Sumatera, Indonesia. The diameter of duku was measure using a Vernier Calliper that has a precision of 0.01 mm to determine the size of duku. The weight of the fruit was measured with electronic balance with a precision of 0.001 g. Duku fruits with a diameter of 2.5 to 3.5 cm were selected, checked and visually inspected and a defected ones were eliminated before drying test.

Infrared radiation heating system

A laboratory scale of IR-emitter heating consisted of two ceramic emitters (245 mm x 60 mm size) which had capacity of 1000 W for each emitter were installed facing each other. The vertical distance between the infrared heaters in the heating position could be adjusted by tightening and loosening of the nut moving on the screws provided on the space bar and it has cover to prevent the loss of temperature. The heating chamber was placed inside an enclosure with a door that opens upward. The fruit basket was placed horizontally on a frame with the wall cover the same size as the wall of the heating chamber. The fruit basket would accomodate three dukus, horizontally, with the diameter of 2.5 to 3.5 cm. The fruit basket was connected by means of a horizontal shaft which would rotate automatically with the speed of 30 rpm upon operating by means of sliding it into the heating chamber.

Infrared heating procedure

Initially, before the heating process, the fruit basket with its frame system was placed outside of the heating chamber at a distance of 1 m. The distance of the infrared emitter was adjusted according the distance treatment of 6 cm and 10 cm (treatment A). The infrared emitters were then turned on and were let to reach the treatment temperature of 200 °C, 300 °C and 400 °C respectively (treatment B). The temperature was monitored by a laboratory thermostat ($\pm$10 °C) and was shown by the LED termperature display (Extech 445815: Hygro-Thermometer Humidity with basic accurancy ±4% RH; ±1.8 °F, ±1 °C). The temperature was also confirmed by means of using laser radiation thermometer (Wintact-WT900-EN00). Upon reaching the desired temperature the heating system was let idle for 5 minutes to stabilized the heating system. Then the covered door was open upward and the empty fruit basket system, which was rotating at the speed of 30 rpm, was pushed into the heating chamber and then the door was closed down. The empty basket system was let to work for 60 seconds and then it was pulled out and the heating system door was closed down. This simulation was performed to let the whole system to adjust to the operating temperature. The fruit basket system was then let to cool down for 5 minutes and then 3 dukus with the diameter size of about 3 cm, arranged parallel, was placed into the fruit basket and locked to make sure the fruit would stay inside the basket during the treatment. The basket was then let to rotate for 60 seconds and the heating chamber door was open upward and the fruit basket system was slide pushed into the heating chamber and the door closed down. The fruit basket was let inside the heating chamber for the lenght of 50, 60, 70 and 80 seconds according to the treatment length of exposure (treatment C). After the fruits exposed for the determined time the heating chamber door was open upward, fruit basket system was then slide pulled outward, the door closed down and the fruits were let to cool down to room temperature by means of placing it at room temperature for 30 minutes. After cooling down the fruits were stored in controlled temperature case of 15 °C ±2 °C and then the physical and chemical characteristics were measured every two days up to 20 days and everyday between the 20th to 30th day by means of destructive measurement. So there were time series of physical and chemical properties measurement. The determination of time series of duku were performed completely randomized. All the experiment was replicated three times.

The physical-chemical properties of the fruits that were measured periodically in this research were: weight of duku, fruit firmness, total soluble solids (TTS), titratable acidity (TA) and browning index.

At the initial of the experiment each duku was marked with a permanent marker and its weight measured. The initial physical and chemical properties of duku were measured by means of taking randomly 5 fruits and its physical and chemical properties measured and averaged and was determined as the initial physical and chemical properties of duku. The distance of the emitter was made fix until all the treatment of temperature and time exposed were completed; and then it was adjusted to other distance. The distance of the emitter was determined randomly and the temperature and time exposed treatment were completely randomized.

Physical quality changes

Physical quality changes measured were weight loss and fruit firmness. The weight loss (%) of duku were measured by taking the percentage ratio (%) of the different of initial weight to the measured weight of fruit at the deteremined time measured to the initial weight. Fruit firmness was measured by means of using a portable Penetrometer (Andilogs CNR-FT&V, precision of 0.25% FS) at room temperature (27 °C). The fruit firmness of duku were performed destructively at three point (Figure 1) which was at the top, middle and bottom of duku. The fruit firmness was digitally display in Newton and then the average of the three measurement was taken as the fruit firmness for one fruit.

Chemical quality changes

The chemical properties measured were the acidity by means of titratable acidity (TA), sugar content by means of total soluble solid (TSS) and browning index. The TA measurement was performed by means of titration method which is taking 5 gram of ground duku flesh into a beaker glass and then diluted with 100 mL distilled water by stirring it. The dilution was then filtered by using Whatman paper no. 42. The titration was performed by taking 20 mL of filtrate, adding two drop of the indicator PP and then titrated using standard solution (NaOH, 0.1 M).

The sugar content of duku on this experiment was measured by measuring the total soluble solid (TSS). The

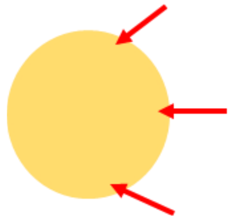

Figure 1 The Point of measurement for fruit firmness.

TSS was measured by grinding the duku flesh and then filtered by using the Whatman paper no. 42. The filtrate was then drop, by means of pippeting the filtrate, into a glass window of a digital refractometer and the TSS was shown on the display as a °brix (Atago Digital Refractometer Model DBX-55A range 0.0 – 55.0 brix, accuracy ±0.1%).

The Browning index was determined by means of spectrophotometric method **(Cohen et al., 1994)**.

The measurement was performed by initially making a standard solution to determine the wavelenght, λ_{max}, of duku solution. The λ_{max} for this measurement was found on 417 nm with absorbancy of 0.193 (Spectrophotometer Vis Thermo Scientific-Genesys 20; wavelength 325 – 1100 nm, accuracy 2.0 nm). The browning index was measured by taking 20 mL filtrate of duku as performed for the TA measurement and then putting it into a cuvette which was then inserted into the spectrometer. The browning index was then shown on the digital display of the spectrometer.

Statisic analysis

The statistical design used for this research was a split-split plot design with the main factor the distance of IR-emitter, while the sub factor was temperature of the IR-emitter, and the sub-sub factor was exposure time. The analysis of Variance (ANOVA) for the dependent variables were calculated with the help of Statistical Package (SAS version 9.4, 2014). The response of the dependent variables and its significancy were analysed by means of the F-value.

RESULTS AND DISCUSSION

Effect of parameters on physical and chemical properties on duku's peel

The effect of parameters on physical and chemical properties of duku's peel after exposing to IR-Emitter (IRE) was shown on Table 1. The IRE distance had a very significant effect (p <0.0001) to the weight loss, fruit firmness, titratable acidity, total soluble solid, and browning index. The IRE temperature of 200, 300 and 400 °C had a significant effect (p <0,05) to the weight loss, fruit firmness, TA and TSS but not to the browning index. While the exposure time of 50, 60, 70 and 80 second only significant (p <0.0001) to the weight loss, fruit firmness, TSS, and browning index. In general, the IRE treatment only had a significant effect to the weight loss, fruit firmness and TSS.

Table 1 Statistical Result of ANOVA.

Source	Weight loss		Fruit Firmness		Titratable Acidity		Total Soluble Solid		Browning Index	
	F Value	*p* >F	F Value	*p*>F	F Value	*p* >F	F Value	*p* >F	F Value	*p* >F
D	29.24	<.0001	605.25	<.0001	46.06	<.0001	151.81	<.0001	40.85	<.0001
T	57.89	<.0001	10.33	<.0001	4.00	0.0085	13.02	<.0001	2.01	0.79027
D*T	17.68	0.0004	17.65	<.0001	1.73	0.1631	5.83	0.0008	1.82	1.00555
E	19.98	<.0001	12.01	<.0001	1.90	0.1119	6.29	<.0001	11.44	<.0001
D*E	9.79	<.0001	41.92	<.0001	2.31	0.0591	2.43	0.0492	10.55	<.0001
T*E	0.000	1	4.07	0.0015	5.15	0.0002	0.96	0.4461	0.00	1
D*T*E	0.000	1	4.32	0.0009	2.31	0.0459	4.24	0.0011	0.31	6.28263

Note: D = distance of IR-emitter (cm), T = Temperature of IR-emitter (°C), E = exposure time to the IR-emitter (s).

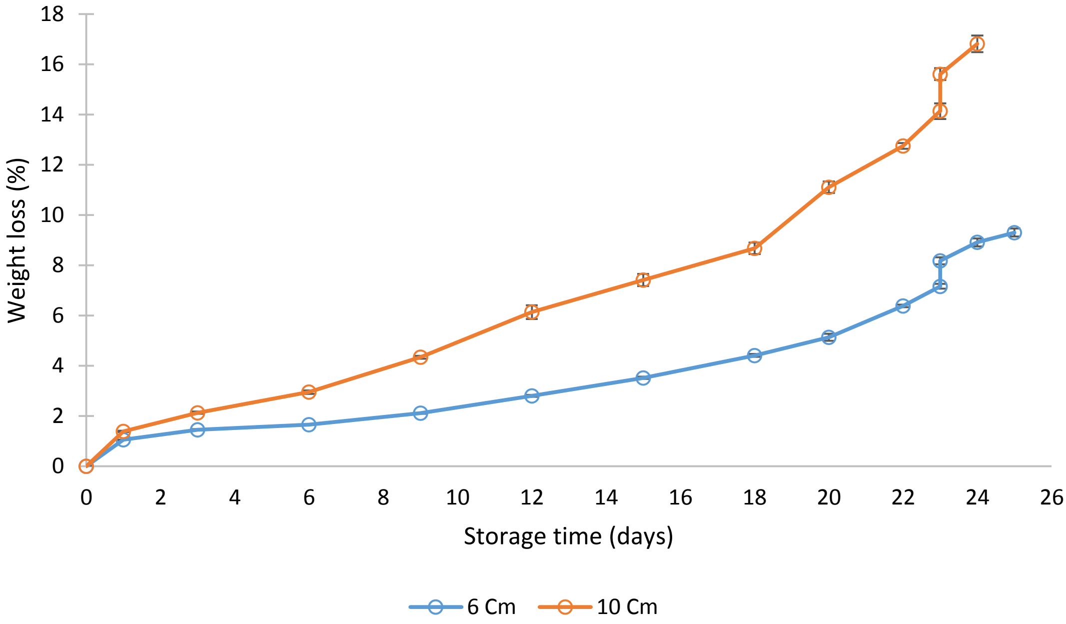

Figure 2 The weight loss of duku during storage time exposed to IRE distance of 6 cm and 10 cm.

Weight Loss

The weight loss of duku during storage occurs due to the influence of IRE distance, temperature and exposure time. The IRE distance of 6 cm and 10 cm has has a significant effect (*p* <0.0001) on weight loss during storage (Figure 2). The largest weight loss occurs in duku exposed to IRE radiation with a distance of 10 cm. This result was paralled to the results of fruit firmness at a distance of 10 cm. This condition could happen because the skin of duku was not receiving energy as much as the IRE distance of 6 cm which make duku's skin of 10 cm distance was not as dried as the 6 cm distance. The drier the duku's skin the firmer the skin and the more the skin would protect the duku's flesh and the less moisture could evaporate from the duku which would make the moisture loss of the duku exposed to IRE distance of 10 cm consistently had higher weight loss than the 6 cm distance (Figure 2).

The temperature of the IRE also had a significant effect (*p* <0.0001) on the weight loss during the storage time. Figure 3 shows that at a temperature of 400 °C (IRE distance of 6 cm) had the greatest weight loss compared to the temperatures of 200 °C and 300 °C. The higher the IRE temperature, the greater the heat energy radiated from the IRE which would cause the difference between the heating medium and the fruit layer. The temperature difference between the heating medium and the material causes transfer of heat into the material and the faster the transfer of water vapor from the material to the environment. The faster the vapor evaporates from the material the higher the weight loss **(Brackmann et al., 2014)**. Some studies reported that the higher the weight loss or mass loss on fruit skin the higher the postharvest quality due to the the gas exchange **(Brackmann et al., 2007)**. This also might be attributed to the fact that the

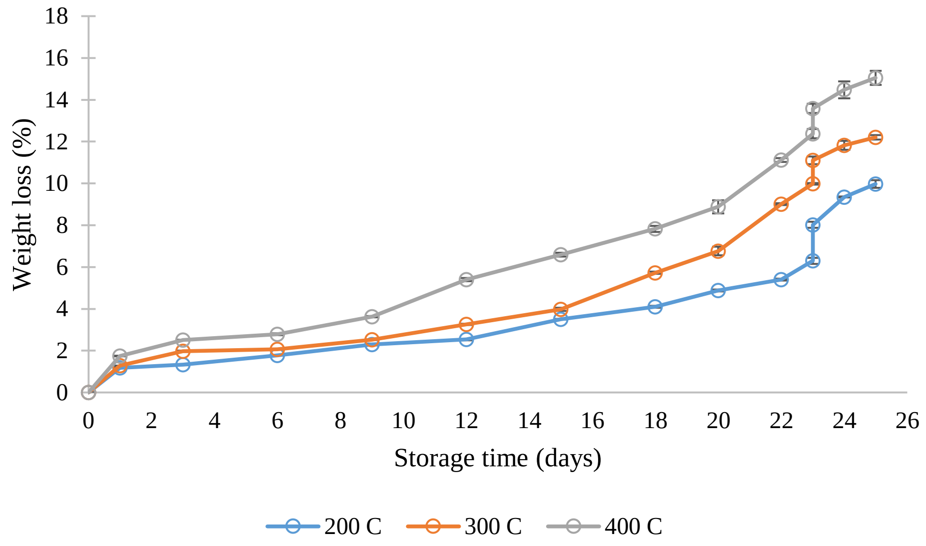

Figure 3 The weight loss of duku during storage time exposed to the IRE distance of 6 cm and temperatur of 200 °C, 300 °C and 400 °C.

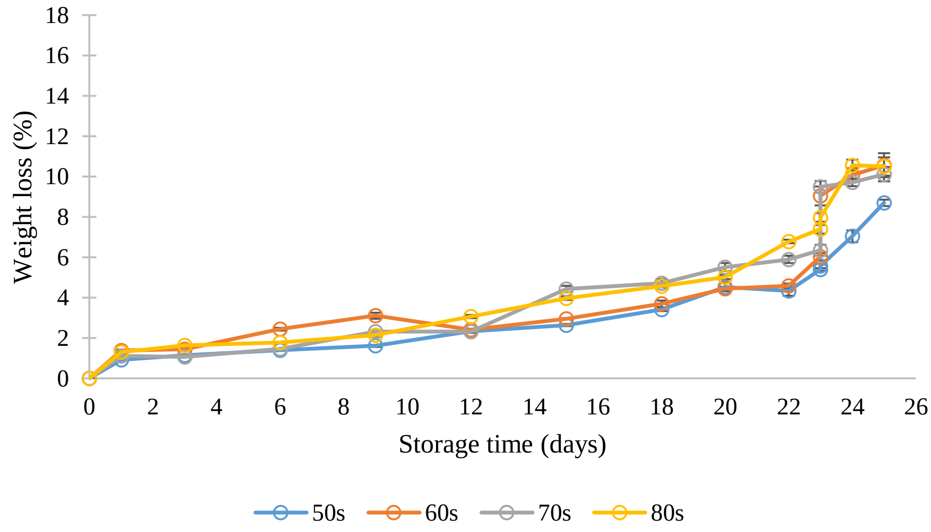

Figure 4 The weight loss of duku during storage time exposed to temperature IRE of 400 %or exposure time of 50, 60, 70 and 80 seconds.

increase of exposure time and temperature of IRE may increase the weight loss because of the accumulation of heat and evaporation of water vapor on fruit surface and flesh fruit during the process **(Li and Pan, 2014a)**, which is in agreement with the significant result shown on Table 1 that the exposure time was significant (p <0.0001) to the weight loss of fruit (Figure 4). The temperature of duku surface immediately rose up when the IR drying time was increase, which was mainly due to the enhanced radiative heat transfer to the fruit surface **(Ding et al., 2015)**.

Fruit Firmness

The fruit firmness was affected significantly by the IRE distance, temperature, and exposure time ($p < 0.0001$). Duku exposed to the IRE distance of 6 cm showing the increase of skin texture with the storage time which was parallel the weight loss shown on the Figure 2. Duku's skin exposed to the IRE with the distance of 10 cm was not as dried as the distance of 6 cm which make duku's skin less firmer and had a tendency of higher moisture content. The effect of IRE distance of 6 cm and 10 cm had the intensity of the emission on the surface of the fruit skin which is inversely proportional to the square of the distance from the radiation source. The closer the emitter is to the object (duku fruit), the greater the amount of radiation to the object (duku fruit) the harder the skin of duku with the storage time (Figure 5).

The changes in fruit firmness were also significant (p <0.0001) due to temperature and exposure time (Table 1). The higher the temperature used in the drying process, the drier the duku's skin and the firmer the skin which make the fruit firmnes increasing with storage time (Figure 6). During the exposure of duku to the IRE, the infra-red

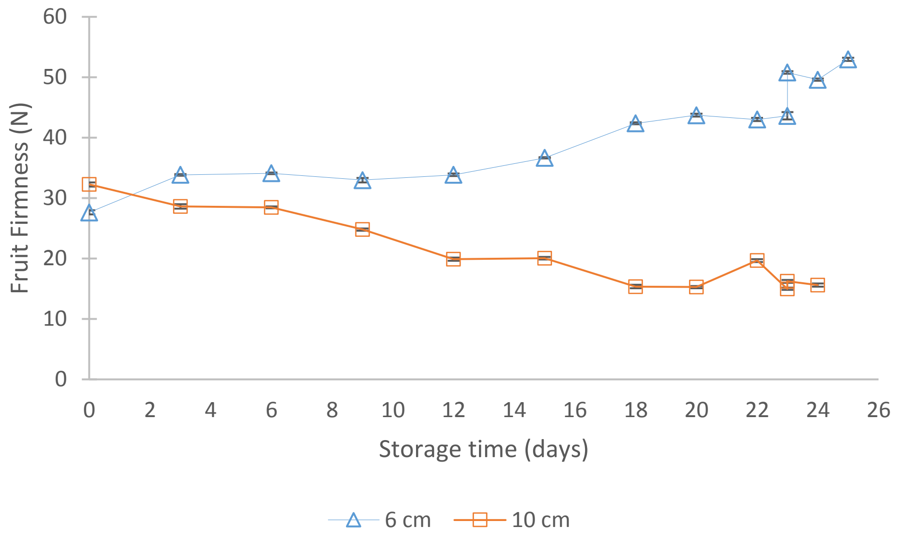

Figure 5 Fruit firmness during storage time in 6 cm and 10 cm distance of IRE.

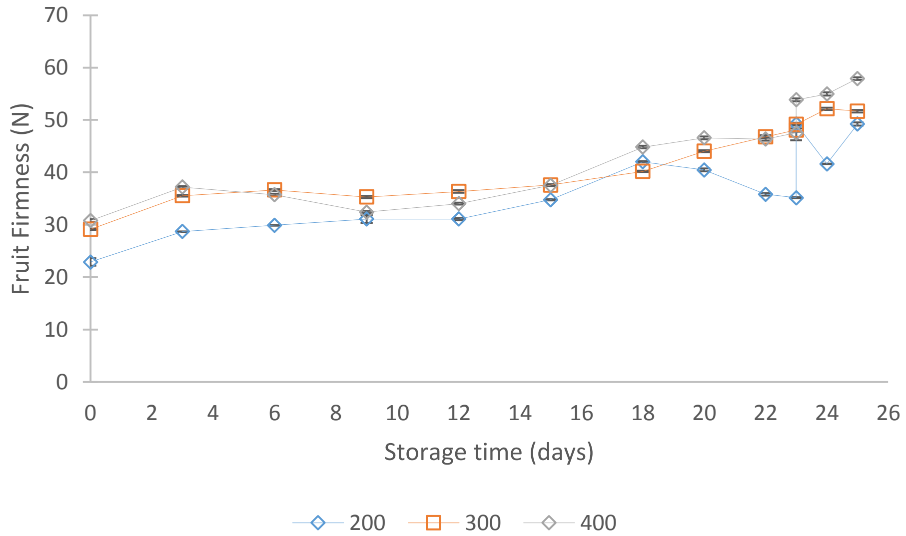

Figure 6 Fruit firmness during storage time at 200 °C, 300 °C and 400 °C in 6 cm distance of IRE.

beaming would hit the skin of duku then the heat would penetrate the inner tissue through radiation heat transfer. This thermal energy would cause sudden temperature increase which would cause cell wall damage, cell's water vapor evaporation, pectin breaks, mid-lamella cell damage, and polysaccharides cell wall degradation. The changes of firmness on duku also affected by the duration of radiation exposure and storage time after drying. A longer exposure time of infra red might result in the degradation of tissue's skin and the reduction of adhesiveness to the fruit flesh **(Li and Pan, 2014b)**. It could be seen from statistical analyze that exposure time has significant effect (p <0.0001) to the firmness of duku skin (Figure 7). Further analysis show that there is no significancy found on the firmness of skin between the duku exposure time of 50 and 60 second; and also between the 70 and 80 second exposure time. However there was a significancy occurs between the groups of 50, 60 second exposure with the groups of 70 and 80 second exposure time. The fruit firmness also reduced gradually during storage might be caused by polygalacturonase (PG) and pectin methyl esterase (PME). PG is a texture related fruit enzyme that catalyzes the hydrolysis of the linear α-1, 4, D-galacturonan backbone of pectic polysaccharides **(Poovaiah and Nukuya, 1979)**, and PME is one of the enzyme types that could hidrolyze pectin.

Titratable Acidity

Although the sweetness in one of the important component of fruit but organic acid is also has a role in the overall fruit flavor. The acid-sugar balance on fruit is essential for producing a pleasant taste in fruit, especially in duku. The IRE distance on this experiment as shown on Table 1 has a significant effect to the titratable acidity of duku (p <0,0001). The titratable acidity of duku exposed to the IR-emitter distance of 6 cm and 10 cm were going

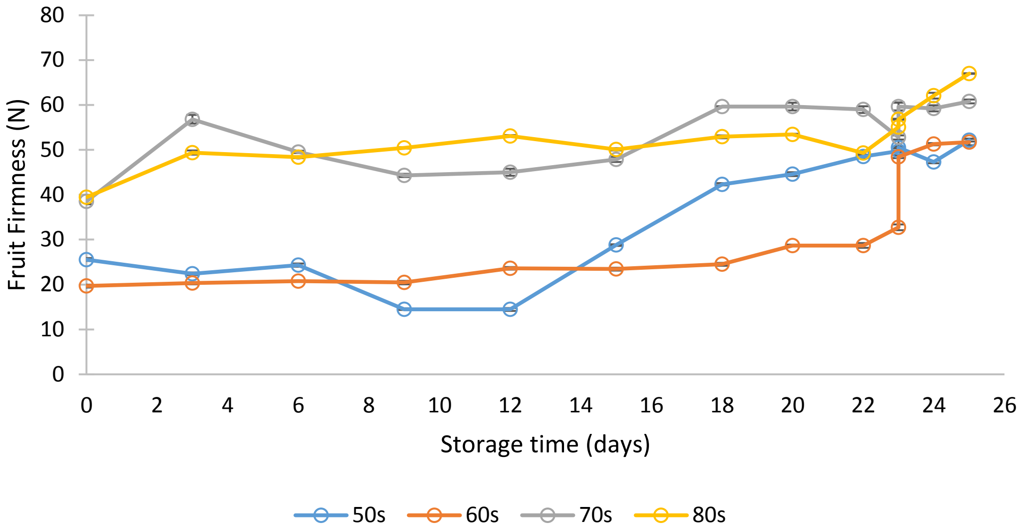

Figure 7 Fruit firmness during storage time at 50 s, 60 s, 70 s and 80 s in 400 °C temperature of IRE.

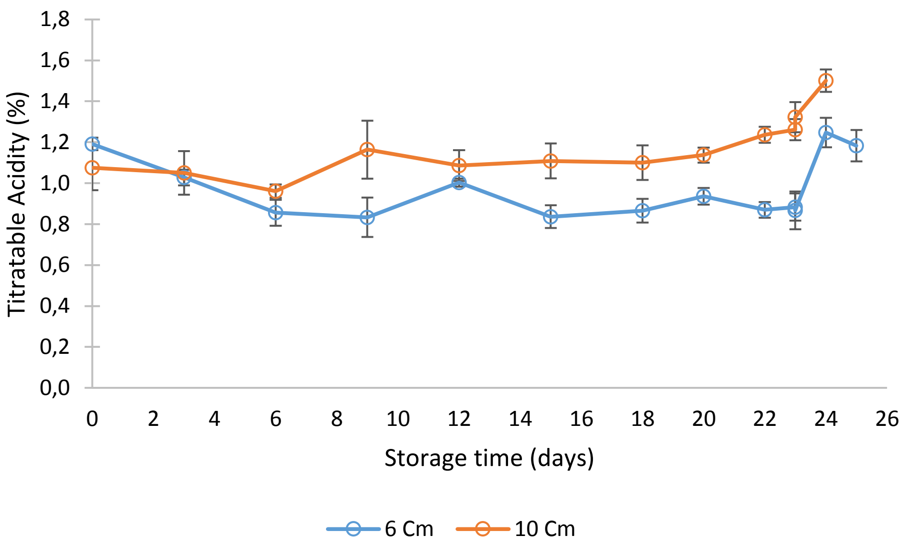

Figure 8 Titratable acidity (%) during storage time in 6 cm and 10 cm distance of IRE.

down slight up to the 6th days of storage and then split up. Duku exposed to the IRE distance of 6 cm stayed relatively the same around the 0.8% while the IRE distance of 10 cm went up and stayed relatively the same around the 1.15% until the end of the observation.

The changes of titratable acidity up to the 10th storage day affected by the IRE distance paralel to the increase and also the decrease of sugar (total soluble solid) which indicates that the changes of titratable acidity was the result of sugar changes. The organic acid would degrade into fructose and glucose (Figure 9) until the 10th storage days which then slowly increases until the last day of storage. The titratable acidity of duku after the 10th day of storage was relatively flat but the titratable acidity of duku exposed to IRE with the distance of 10 cm is always higher than duku exposed to IR-emitter distance of 6 cm. Duku's skin, after exposing to the IRE, had a tendency to have a firmer texture and a lower moisture content that would make the duku skin to have a shell like skin. This condition would create an armor to the fruit flesh that result in a semi-modified atmosphere to the duku's flesh which reduce the transport of CO_2 and O_2 from the duku's flesh to the environment. This semi-modified atmosphere condition would prevent the conversion of acid into sugar and would make duku flesh fell into a slower metabolism and respiration which would reduce the usage of energy. This phenomenon was shown by duku exposed to the IR-emitter with the distance of 6 cm but not for the one exposed to the 10 cm distance. Duku´s exposed to IRE of 10 cm has a softer skin compare to the 6 cm (Figure 5) which make its skin would transfer more O_2 to the flesh and produce more acid compare to the duku exposed to the IRE of 6 cm.

The reduction of O_2 and CO_2 on the 12th to the 22nd storage days impaired the function of Krebs cycle **(Davies, 1980)**. The reduction of O_2 resulting in pyruvate would undergo homolactic fermentation or alcohol fermentation. The experiment conducted for duku did not resulting in the alcohol fermentation but resulting in relatively the same level of titratable acidity (Figure 8) and only increase significantly after the 22nd day due to the decaying of duku.

Contrary to the effect of the effect of IR-emitter distance which have a very significant effect to the titratable acidity, the temperature of the IR-emitter only have a significant difference in the level of 5% (p =0.0085) while the exposure time to the IR-emitter did not have a significant effect to the titratable acidity. This result show that the IRE distance has a more significant effect to the shell like skin which preventing the organic acid of fruit converted to other substance due to the semi-modified atmosphere condition within the duku.

Total Soluble Solid

The sugar content of duku on this experiment was measured by means of using refractometer and shown as a total soluble solid (TSS). TSS in duku was significantly affected by the IRE distance (Table 1). TSS in duku exposed to the IRE radiation, for the first 10th day of storage were influenced by the changing of titratable acidity (TA) but after that decrease gradually because it was converted to monosaccharide due to the respiration process (Figure 9). The increase of TSS after the infrared radiation exposure and storage was due to the conversion of carbohydrate to glucose. The carbohydrate conversion to glucose could be caused by the respiration in storing period. Starch can be converted back to glucose by the least three different enzymes namely, α-amylase, β-amylase and starch phosphorylase **(Suárez-Dieguez et al., 2009)**. In non-climacteric fruit, the accumulation of sugar is associated with the development of optimum eating quality, although the sugar may be derived from sap imported into the fruit rather than from the fruit breakdown of starch reserves **(Nascimento et al., 2006)**.

Duku's skin which became firmer for the IRE distance of 6 cm after the 10th day of storage preventing the transport

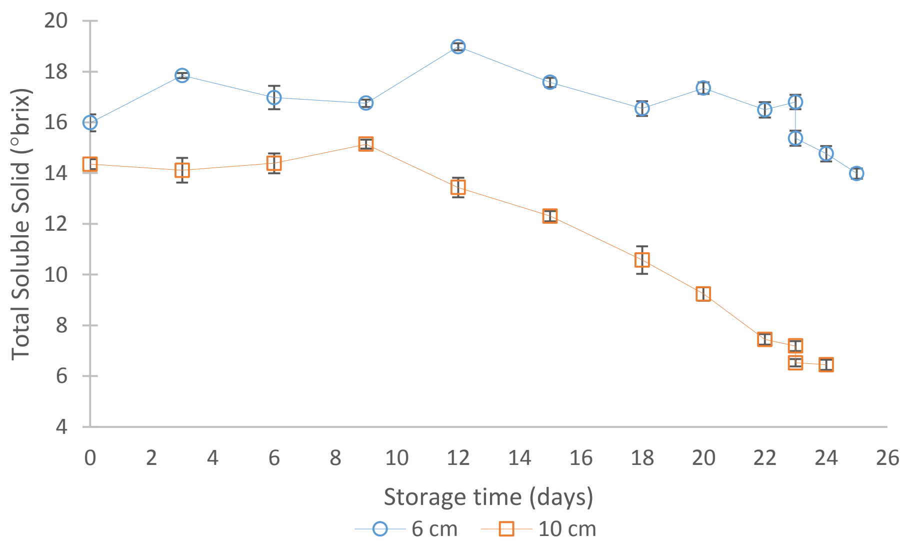

Figure 9 Total soluble solid (brix) during storage time in 6 cm and 10 cm distance of IRE.

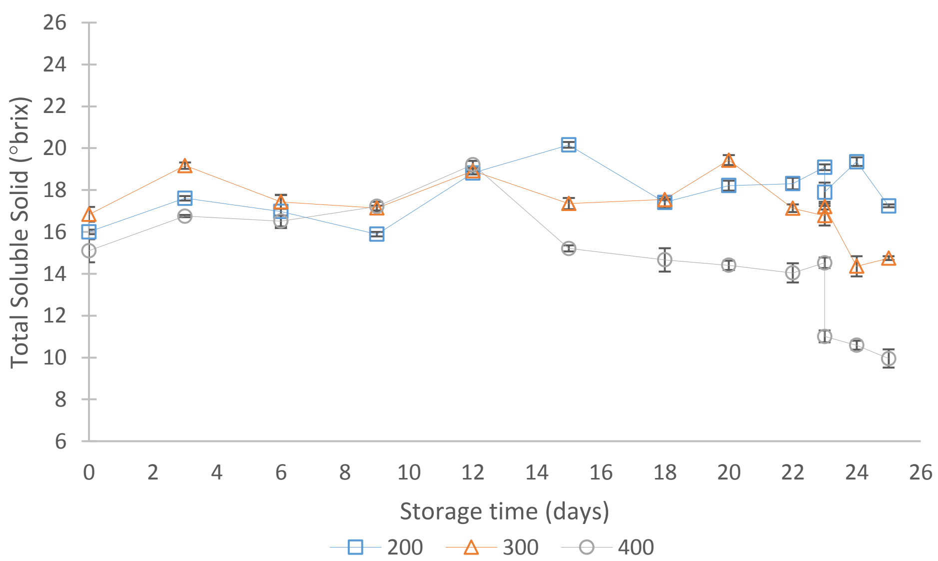

Figure 10 Total soluble solid (brix) during storage time at 200 °C, 300 °C and 400 °C in 6 cm IRE distance.

of O_2 and CO_2. However this condition was different for the TSS exposed to IRE distance of 10 cm which was softer than the 6 cm distance that would facilitate the gas exchange. The gas exhange would facilitate the conversion of acid into sugar which was happen to duku exposed to the IRE distance of 10 cm, however, since the requirement of energy for metabolism and respirtion relatively higher for duku with less modified atmosphere would consume the sugar in the flesh and resulted in lower concentration of TSS for duku exposed to IRE distance of 10 cm. However, when TA had decreased (Figure 8), TSS has increased significantly during storage. The increase in TSS was probably due to the solubilization of neutral sugar from carbohydrate polymer and resulted in the TSS/TA ratio and led to the sweetness of duku **(Sapii et al., 2000).**

The temperature and expose time of IRE, both had the significant effect to the TSS but the significancy mostly happened after the 10th day storage. This differences were affected by the IRE distance to the TSS which was very significantly different after the 10th day of storage. The TSS of duku after that time period significantly lower for the one exposed to the IRE distance of 10 cm. In this condition, the effect and the interaction between IR radiation (temperature and exposure time) and component of TSS (Fructose, Glucose, and Sucrose) should be further investigated.

Browning Index

Many tropical fruits are susceptible to browning and therefore might cause the economic losses to the agriculturist. The browning on fruit caused by browning enzyme was catalized by the polyphenol oxidase (PPO) enzyme and peroxidase enzyme. Peroxidase and phenylalanine ammonia lyase could also increase the activity of browning **(Kincal et al., 2006; Zocca et al., 2008)**. Browning might happened due to the membrane damage that was caused by the heating process using infrared radiation. The membrane damage would also damage the cell and in turn resulted in the lysis of plasma from the cell and increase the permeability of fruit cells and facilitated the mixing of enzyme and substrate which produce the browning reaction on the fruit **(Lichanporn et al., 2008; Venkatachalam and Meenune, 2012b)**. Browning reactions on duku could also occur due to fruit storage condition. The lipoxygenase, polyphenol oxidase, phenylalanine ammonia lyase, peroxidase enzymes are activated if the chilling injury occurs on storage time. The operating conditions such as IRE distance had a significant effect to the Browning index while temperature, and exposure time had no-significant effect to the Browning index of this research (Table 1). The browning index measurement for this research was found, for almost all the measurement performed on this research, to have value under or around the sensitivity of the instrument used (0.2 Abs) except after the 20th day of storage which was caused by the decaying duku (Figure 11). Due to the value of Browning index very close to the sensitivity of the instrument it was decided that the IRE treatment did not have a significant effect to the Browning index of duku after exposing duku to IRE and during storage.

Shelf life

The effect of infra red drying to the shelf life of duku by considering the weight loss, fruit firmness, titratable acidity, total soluble solid, and browning index during storage show a slightly better result than the previous work **(Saputra and Pratama, 2013; Saputra et al., 2014)**. This conculsion was drawn by considering the limiting factor which is the fruit firmness and total soluble solid. The fruit firmnes of duku expose to the IRE distance of 10 cm after 14 days of storage had came to the level of 50% of the fruit firmnes of day zero which was to low for a good duku. Besides that the level of total soluble solid for duku exposed to IRE distance of 10 cm after 14 days of storage also had came to a low concentration which eventhough still acceptable but its firmness made it un-acceptable.

Different from the result found for the duku exposed to the IRE distance of 10 cm, the one exposed to IRE distance of 6 cm show a different result. Eventhough the weight loss, fruit firmness, titratable acidity, and total soluble solid did not show a significant changes compare to the original value but from visual inspection it was found that some mold had been growing on duku's skin on some of the duku at the 20th day of storage which would be

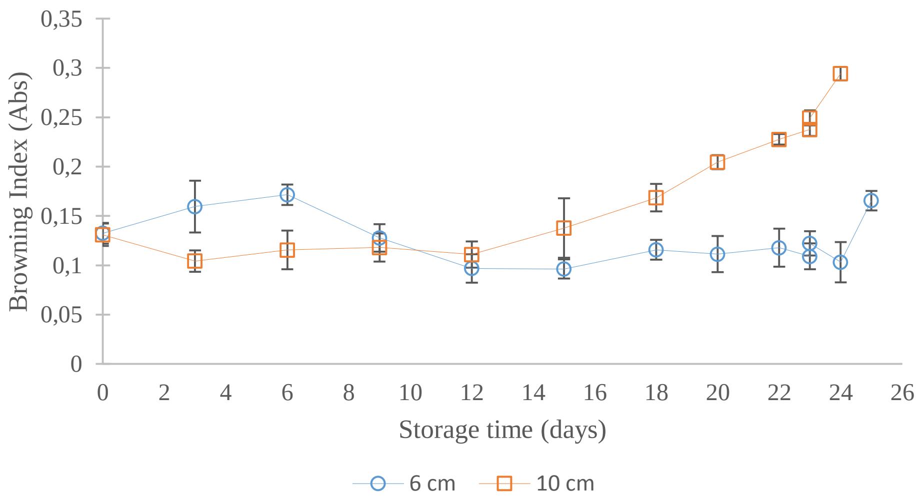

Figure 11 Browning index during storage of duku which was affected by the distance of IRE.

un-acceptable to the consumer. Based on that the shelf life of duku at the 20th storage day and the safety of consumer it was decided that the shelf of duku exposed to the IRE was 16 days.

CONCLUSION

It was found that the weight loss, fruit firmness, and total soluble solid of duku dried by means of exposing to Infra Red Emitter (IRE) were significantly affected by the distance of IRE, the temperature of IRE and the time exposed to IRE. However the titratable acidity only affected significantly by the distance of IRE. There were no significantly changes of browing index on duku during drying by exposing to IRE and while stored up to 25th day of storage. Drying duku by exposing it to IRE show a slightly better shelf life than the previous work.

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Acknowledgments:

The authors would like to express their gratitude to the Ministry of Research, Technology and Higher Education, Indonesia through the PMDSU Project Batch-II.

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