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OPTIMIZATION OF INFRARED DRYING CONDITION FOR WHOLE DUKU FRUIT USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Duku (*Lansium domesticum*), tropical exotic fruit, was successfully preserved by drying using exposure to infrared radiation emitters. Response surface methodology (RSM) is used to optimize independent variables (IRE distance of 6 cm and 10 cm, IRE temperature of 200 °C, 300 °C, 400 °C, and IRE exposure time of 50 s, 60 s, 70 s, and to produce response variables (weight loss, fruit firmness, titratable acidity, total soluble solid, and browning index). It could be concluded from the optimization performed that drying duku skin in a whole fruit by exposing the fruit to the infrared emitter resulted in a duku fruit with a relatively good physical and chemical conditions and still be consumable. The IRE distance of 6 cm gave a desirability value of 0.80 while the IRE distance of 10 cm gave a desirability value of 0.92 however the IRE distance of 6 cm gave a better storage time. The IRE distance of 6 cm has an optimum value of weight loss 2.2%; optimum value of fruit firmness of 40.92 N; optimum value of total soluble solid of 17.48 brix; optimum value of titratable acidity of 0.33%; and optimum value of browning index of 0.9. The fitting model base on RSM resulted from this research indicated that this study could be used as the basis for alternative process in food processing of duku but still need further research to increase the shelf life and a better result in the chemical and physical characteristics of duku.

Keywords: Duku; infrared; optimization; response surface methodology

INTRODUCTION

Food processing such as thermal and non-thermal processes could affect changes in structure and composition of the food **(Mercier et al., 2011)**. The process of food processing with a thermal method, could cause a chemical and organoleptic properties damage and reduce nutrition or nutritional bioavailability. An example of food processing technology with thermal is drying. Drying is one of the food processing method to prolong shelf life or preserve grains, fruits, vegetables and food in all varieties. The quality of dried fruits depends on the conditions of drying process. One type of drying processes is by using infrared radiation. Infrared drying has been widely implemented in the food process because of its several advantages including to reduce water content in food, low energy consumption, short time in processing and also maintain and ensure product quality conditions **(Pan et al., 2009)**. The advantages of infrared radiation could inhibit the pathogens in products which include mold, yeast, bacteria and spore by controlling some parameters such as power on the heater **(Hamanaka et al., 2000)**, temperature of sample **(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)**. As with other electro magnetics wavelengths such as microwaves and radio frequencies, infrared radiation has a unique characteristic in the design of its spectral distribution and energy intensity which could be be controlled by using optical filters. Furthermore, the unique characteristic of infrared radiation to the product is the heat energy from the emitter only affected the surface of food in a short time without raising the inside temperature of material **(Li and Pan, 2014a)**. Infrared radiation is divided into three different categories, namely near-IR (NIR) with a spectrum scale in the range of 0.75 – 1.4 μm, mid-IR (MIR) with a spectrum scale in the range of 1.4 – 3 μm, and far-IR with a spectrum scale in the range of 3 – 1000 μm (FIR) **(Sakai and Hanzawa, 1994)**. Infrared radiation has a longer wavelength than visible light, but is shorter than terahertz radiation and a microwave. The infrared radiation spectrum has a range of 750 nm up to 100 μm and widely used in food processing in several ways including food processes involving heating processes, spectroscopic measurements of chemical composition (food analytical applications), and measurement of non-contact food temperature.

The use of infrared has been carried out in previous research for drying the skin of fresh duku. The design of this research was a multi-variate process involving many factors that affected the efficiency and the effectiveness of drying process on duku fruit. Previously, classical method was used to determine the optimum condition by using one parameter and it was time-consuming, laborious and the result mostly could not be guaranteed **(Wernimont, 1985)**. On the other hand, experiments with many factorial combinations and variables were not effective and efficient because of the large number of experiments needed **(Haaland, 1989)**. To overcome this problem, a method that often used in optimization process is response surface methodology (RSM). RSM is a good statistical technique to optimise a complex processes with several factor variations simultaneously. This model have the advantages of reducing the number of trials, increasing statistical interpretation and efficient **(Gan and Latiff, 2011; Jiang et al., 2011)**. RSM has been used for more than 60 years since its development in 1951. Initially used in the area of Chemistry and chemical engineering, but since then has been used in many areas to optimize the variables used in an experiment **(Hill and Hunter, 1966)**. Some of the designs used in RSM are Full Factorial Design (FFD), Box-Behnken Cesign (BBD), and Central Composite Design (CCD). Box-Behnken design (BBD) is more efficient and easier to arrange and to interpret the result of experiment than other designs **(Ferreira et al., 2007)**. RSM is better than the elimination process on multiple variable and more informative in interpreting and analysing the result **(Ozdemir et al., 2008)**. RSM could help in determining and solving multivariate problems simultaneously which describe the effect of test variables and determine the correlation among variables and its combined effect **(Erbay and Icier, 2009)**. 3D RSM and 2 D contour plot could help in visualization the relationship among variables and type of interactions between variables. The shapes of the contour plots indicate the significant of interactions among variables **(Muralidhar et al., 2001)**. RSM is more useful than the artificial neural network because RSM is directly showing the interaction between different components and determining the relationship among variables. RSM could provide statistically acceptable result with fewer experiments **(Youssefi, Emam-Djomeh and Mousavi, 2009)**.

The use of the RSM method has been widely used in food processing in optimizing various processes such as extraction, drying, blanching, enzymatic hydrolysis and clarification, production of microbial metabolites. RSM also has been used in the formulation of food products such as the optimization of food drying process including spray drying of guava powder **(Vaibhav et al., 2014)**. The optimization of pink guava had been performed using central composite face-centred design to optimize the spray drying parameters of the inlet temperature, maltodextrin concentration (MDC) and feed flow (FF) **(Sishir et al., 2016)**; the optimization of the extraction of phenolic compounds and antioxidant potential of *Berberis asiatica* fruits **(Belwal et al., 2016)**, the optimization of the extract of flax seed oil **(Ondrejovič et al., 2011)**, and species determination of common carp **(Bajzík et al., 2011)**. The main goal of this study was to optimize the results of the drying process of the skin of whole duku fruit which was exposed to infrared radiation and to select the optimum combination of analytical response variables of the physical and chemical test results with the dependent variables of distance of emitter, exposure time and temperature of the emitter using RSM.

Scientific hypothesis
The hypothesis of this research was that the response surface methodology (RSM) could optimize the drying process of the skin of the whole of duku fruit.

MATERIAL AND METHODOLOGY
Sample of duku
The material used in this research was the local exotic fruit *Lansium domesticum cor*. or Duku. The sample of duku used in this study was taken from the area of South Sumatra. Sample selection includes physical (a diameter selection of fruit was 2.5 to 3.5 cm) and chemical (microbial attack) were selected and checked before the drying process.

Infrared Expose for Drying Process
The fruit was exposed using infrared radiation which has two emitters (245 mm x 60 mm size; 1000w for each). The emitter was adjusted for 6 cm and 10 cm (X1) and the temperature of infrared radiation was turned into 200 °C, 300 °C and 400 °C (X2), while the temperature of emitter was arranged to 50, 60, 70 and 80 seconds according to the exposure time (X3). After exposing time, the fruits were stored in controlled temperature (15 °C ±2 °C) and then the chemical and physical effects of infrared were analysed continuously (every two days). The chemical and physical properties have been discussed in previous research **(Rahmawati et al., 2018).**

Experimental design
A Box and Behnken design (BBD) on Design Expert Program (DEP)TM Version 11 (Stat-Ease, Inc., Minneapolis, US) with three variables was used in this research to obtain the optimum IR heating to maximize the process. The independent variables in this design were the Infrared emitter distance (X_1, cm), the temperature of infrared emitter (X_2, °C), exposure time (X_3, s), storage time (X_4, days), while the response variables were weight loss (Y_1, g), fruit firmness (Y_2, N), total soluble solid (Y_3, %), titratable acidity (Y_4, °brix), and browning index (Y_5). The preliminary single factor test was used to determine the range for each variable. To analyse the response pattern and to establish the models for this research, seventeen experiments was conducted randomly. A second-order polynominal and regression coefficients were calculated for the experimental data. The quadratic equation to predict the optimum point of this research was explained as follows (Eq. 1):

$$Y = a_0 + \sum_{i=1}^{4} a_i X_i + \sum_{i=1}^{4} a_{ii} X_i^2 + \sum_{i=1}^{3} \sum_{j=i+1}^{4} a_{ij} X_i X_j \quad (1)$$

where Y is the dependent variable; a_o, a_i, a_{ii} and a_{ij} are coefficients estimated by the model, X_i, X_j are levels of the independent variables. They represent the linear, quadratic and cross product effects of the X_1, X_2, X_3, and X_4 factors on the response, respectively. **Design Expert Program Version 11 (2018)** (DEP)™ software was used to determine the response of the independent variables and to plot the response surface graphs. The result of the fitted equation was expressed in three-dimensional and two-dimensional surface graphs in order to illustrate the relation between the response variables and independent variables.

Determination of the response variable goals.

The point of optimization in this research was employed in order to optimize the independent variables to maximize the result of the response variables. The goals of the response variables were chosen from the sensory test of consumers (Table 1). The optimum combination of response variables would also be the optimum point of storage times of duku fruit after exposure using infrared radiation.

Statistic analysis

The statistical analysis of the optimation were analysed statistically by analysis of variance (ANOVA) for each response and significance was judge by P-value on model which calculated from the data by (DEP)™ software.

RESULTS AND DISCUSSION

Statistical analysis and Fitting of response surface model

RSM is a collection of statistical and mathematical methods used to improve, develop and optimize a process with multivariable data simultaneously. The result of ANOVA is shown in Table 2. The model adequacy were obtained by calculating the parameters including *R-square*, and Adequate precision. The model *p*-value from Table 2 shows that all of the response variables were less than 0.05 except fruit firmness and index browning on Infrared emiter (IRE) distance of 10 cm, and titratable acidity on IRE distance of 6 cm.

A small P value shows that the data is significant **(Guo et al., 2010)**. The time of exposure, temperature, and IRE distance had a significant effect ($p < 0.05$) on all response variables except fruit firmness and browning index on IRE distance of 10 cm and also the titratable acidity on IRE distance of 6 cm. The insignificant effect means that the interaction between the different factors did not influence the response variables (fruit firmness and browning index). The fit of the model was checked by determination of the coefficient *R-square* which was calculated from 0.54 to 0.98. The high value of *R-square* was an indication that the model is well adapted to the response variables.

High stability and insignificant variability of the model were implied by low value of *C.V.* All the *PRESS* value on Table 2 show that the model used could predict the independent variable quite well. The precision of the model used also shown by the relatively low value of adequate precision. Those values indicate a good signal to-noise ratio. The signal-to-noise ratio greater than 4 of adequate precision is desirable (**Myers and Montgomery, 2002**). It was concluded that by the ANOVA shown on Table 2 that the models could be used for optimization and navigating the design space of the research.

Table 1 The goals of the response variable of duku's quality.

Name	Goals	Lower Limit	Upper Limit
A:Temperature	in the range of	200	400
B:Exposure Time	in the range of	50	80
C:Storage Time	in the range of	1	25
Weight loss	minimize	6.97	19.41
Texture	maximize	19.26	56.25
Titratable Soluble Solid	maximize	8.9	20.2
Total Acidity	minimize	0.35	0.67
Index Browning	minimize	0.06	0.26

Table 2 Result of the model design on the response variables Weight loss (Y_1), Fruit firmness (Y_2), Titratable acidity (Y_3), Total soluble solid (Y_4), and Browning index (Y_5).

	Response Variables									
Sources	Y_1 Weight loss (gram)		Y_2 Fruit firmness (N)		Y_3 Titratable acidity (TA) (%)		Y_4 Total soluble solid (TSS) (brix)		Y_5 Browning index (BI)	
	6cm	10cm	6cm	10cm	6cm	10cm	6cm	10cm	6cm	10cm
Model (*P*-Value)	0.0002*	<0.0001*	<0.0001*	0.15	0.10	0.005*	0.0002*	0.0006*	0.0098*	0.14
R-Squared	0.99	0.98	0.82	0.54	0.73	0.91	0.97	0.96	0.90	0.75
Adjust R-Square	0.99	0.97	0.78	0.27	0.38	0.80	0.93	0.90	0.76	0.43
C.V %	5.41	12.25	13.99	28.81	11.69	13.48	4.2	11.44	16.86	97.37
PRESS	8.74	103.38	751.88	2515.2	0.45	2.84	56.22	262.80	0.08	10.32
Adequate precision	66.35	23.91	15.53	5.67	5.35	11.24	18.48	12.45	9.35	6.35

Note: (*) Significant effect ($p < 0.01$).

Adjust R-Square, Coefficient of Variation (*C.V*), PRESS

Table 3 Optimization result of independent variables and response variables on duku with design expert program.

IRE distance (cm)	Independent variables		Response variables[1]					Desirability
	Temperature of IRE (°C)	Exposure time of IRE (s)	ML	FF	TSS	TA	BI	
6	400	80	2.2	40.9	17.4	0.3	0.09	0.80
10	300	80	1.3	31.8	16.8	0.6	0.30	0.92

Note: [1]ML = Weight Loss (%); FF= fruit firmnes (N); TSS = Total Soluble Solid, (°Brix); TA = Titratable Acidity (%); BI = Browning Index (Abs).

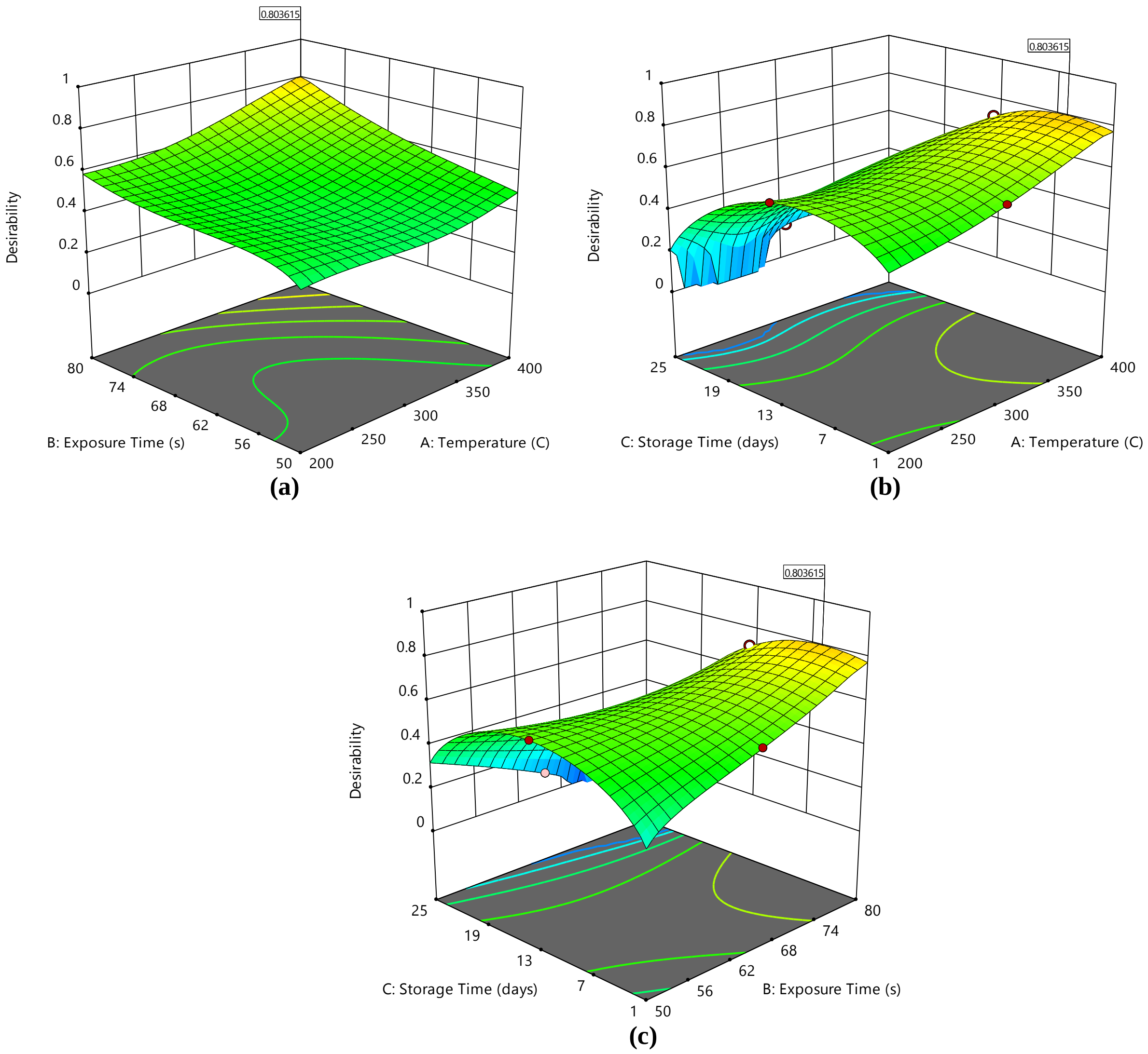

Figure 1 Response surfaces (3D) showing the desirability at an IRE distance of 6 cm. Note: The correlation between exposure time and IRE temperature (a), storage time and IRE temperature (b), and storage time and exposure time (c), respectively.

Optimization of drying condition for whole duku fruit using infrared emitter radiation

The determination of the optimum value of response variables on the drying process by exposing to IRE is performed by plotting the response surface of variables against the independent variables. The purposes of the optimization process in this research are selected based on the consumers and seller point of view. For the consumers, the most important sequence in choosing fruit is a visual appearance (good texture), a minimum browning colour, a relatively high sweetness (TSS) and a relatively low sour taste (TA). For the seller, in order to get high profit, the fruit with a relatively low in weight loss is more desirable.

The desirability value for the optimization process were in the range of 0.80 at an IRE distance of 6 cm and 0.92 at an IRE distance of 10 cm (Table 3). The range of desirability value usually in the range of zero to one. The desirability value equal to one, represents an ideal case, which is the optimization selection results according to the goals specified, while the zero value represents that the value of one or several variable responses was not in accordance with the goals. Table 3 shows that the desirability produced have a significant difference (*p* <0.05).

The response surface had an optimum point within the experimental range of the independent variables. The coordinates of the three independent variables were obtained by numerical optimization analysis.

By using the second-order polynominal shown on equation (1) with the response variables of weight loss (Y1, gr), fruit firmness (Y2, N), total soluble solid (Y3, %), titratable acidity (Y4, °brix) and browning index (Y5), with the independent variables of IRE distance, temperature

$$Y_1 = 14.1665 + 1.27X_1 + 0.48X_2 + 5.49X_3 + 0.688X_1^2 + 0.161X_2^2 + 3.22X_3^2 - 0.188X_1X_2 + 1.091X_1X_3 + 0.804X_2X_3 \quad (2)$$

$$Y_2 = 36.165 + 2.05X_1 + 8.26X_2 + 11.7X_3 \quad (3)$$

$$Y_3 = 17.33 - 0.023X_1 - 0.007X_2 + 0.027X_3 - 0.0091X_1^2 - 0.0337X_2^2 + 0.0113X_3^2 - 0.068X_1X_2 - 0.0065X_1X_3 + 0.039X_2X_3 \quad (4)$$

$$Y_4 = 0.51 - 0.704X_1 - 1.0713X_2 - 1.17X_3 - 0.79X_1^2 + 1.41X_2^2 - 1.557X_3^2 - 0.85X_1X_2 - 2.27X_1X_3 - 2.257X_2X_3 \quad (5)$$

$$Y_5 = 0.1455 - 0.0083X_1 + 0.028X_2 + 0.0269X_3 + 0.44X_1^2 + 0.045X_2^2 + 0.0008X_3^2 + 0.7X_1X_2 + 0.07X_1X_3 + 0.72X_2X_3 \quad (6)$$

Where:
Y_1 = Weight loss,
Y_2 = Fruit firmness,
Y_3 = Total soluble solid,
Y_4 = Titratable acidity, and
Y_5 = Browning index.

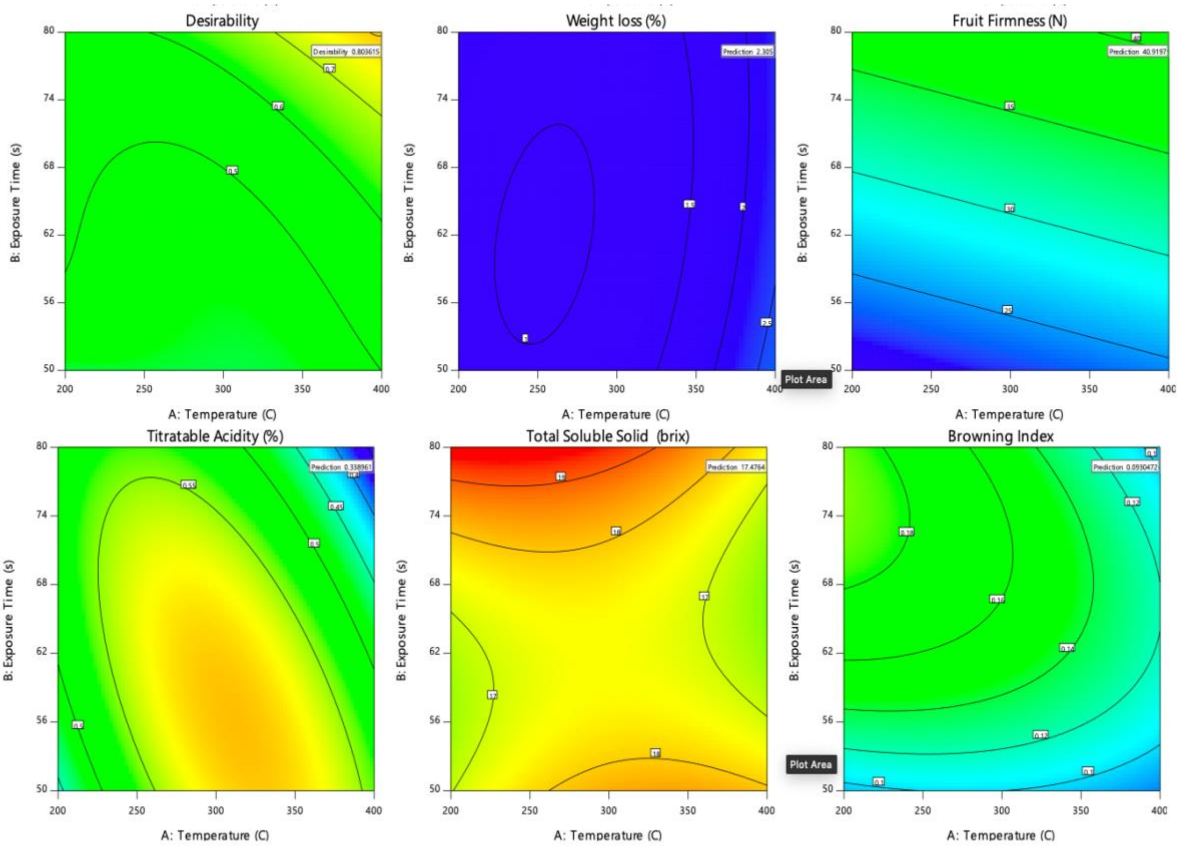

Figure 2 Response surfaces (2D) at 6 cm distance of emitter infrared for the optimization points of exposure time, and temperature on response variables.

(X1, °C), exposure time (X2, s), the RSM was performed to find the optimum point (maximum) of the fitted model as shown on Equation (2), (3), (4), and (5).

The results of the above equation were derived from equation (1) by calculating the optimization on drying with the IRE distance of 6 cm. The equations (2), (3), (4), and (5) show that the results of the model in the response variable could be used to determine the correlation between each factor.

All the equation (2) to (5) except equation (2) which represent the fruit firmness show that all the dependent variable was affected by the three independent variables linearly, quadratically, and its interactions which were the hypotheses RMS using A Box and Behnken design (BBD). However, the fruit firmness only affected by independent variable linearly or the quadratic and its interaction have no significant contribution to the fruit firmness. Nevertheless, the model could be used for the calculation on the optimization of the drying process, especially on duku (exotic fruit) although the optimal shelf life produced was not significantly different from previous research using modified atmosphere **(Saputra and Pratama, 2013)**.

Based on the equation and Figure 1 for the IRE distance of 6 cm show that the cross of IRE temperature (400 °C) and exposure time (80 seconds) gave a desirability value of 0.8; IRE temperature of 400 °C and storage time 7 days gave a desirability of 0.8; and storage time of 7 days with the exposure time of 80 second gave a desirability of 0.8. The IRE distance of 10 cm show that the IRE temperature of 300 °C and exposure time of 80 seconds gave a desirability value of 0.92; IRE temperature of 350 °C and storage time of 5 days gave a desirability value of 0.92; and the exposure time of 80 seconds and storage time of 1 days gave the desirability value of 0.92. Although the IRE distance of 10 cm gave a higher desirability value than the IRE distance of 6 cm, the IRE distance of 6 cm gave a better shelf life value of 7 days.

A response surface could also shown on a 2D contour plot (Figure 2) which were a graphical representations of the model equation. The contour plot was an interaction between independent variables **(Muralidhar et al., 2001)** and the prediction of the maximum value presented in the smallest ellipse in the contour **(Tanyildizi et al., 2005)**. The main purpose of the plot was to determine the optimal value of the response variable so that the response was maximized. The design plot was a function of two factors at a time. The results of a 2D plot graph show that the weight loss on duku fruit after being exposed to infrared and stored for 25 days has an optimum value 2.2% at IRE distance of 6 cm. The weight loss would increase with not significantly different from previous research using modified atmosphere **(Saputra and Pratama, 2013**).

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CONCLUSION

It could be concluded from the optimization performed that drying duku skin a whole fruit by exposing the fruit to the infrared emitter resulted in a duku fruit with a relatively good physical and chemical conditions and still be consumable. The IRE distance of 6 cm gave a desirability value of 0.80 while the IRE distance of 10 cm gave a desirability value of 0.92 however the IRE distance of 6 cm gave a better storage time. The IRE distance of 6 cm has an optimum value of weight loss 2.2%; optimum value of fruit firmness of 40.92 N; optimum value of total soluble solid of 17.48 brix; optimum value of titratable acidity of 0.33%; and optimum value of browning index of 0.9. The fitting model base on RSM resulted from this research indicated that this study could be used as the basis for alternative process in food processing of duku but still need further research to increase the shelf life and a better result in the chemical and physical characteristics of duku.

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