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Kinetics of Color Changes During Pretreatment Blanching of Pineapple (*Ananas Comosus*) Fruit Variety 'MD2'

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ABSTRACT

Drying is an intensive unit operation used to preserve the pineapple fruit. In this study, the kinetics of color degradation in pineapple slices during blanching as pretreatment with combined microwave and convection drying at different temperatures (110, 120, 130, and 140°C) and drying times (5, 10, 20, 25, and 30 min) were determined. L*, b*, chroma, and total color difference (TCD) increased as the drying temperature and time increased. As for the a* parameter, it is not dependent on the drying temperature. In addition, blanching pretreatment prior to drying can affect and change the color of pineapple slices by increasing L*, a*, chroma, and TCD compared to no blanching. Nevertheless, it maintains the yellowness (b*) in pineapple slices. As for kinetic models, zero-order best described the changes of L*, a*, b*, chroma, and TCD, while first-order best pronounced the parameters L*, b*, chroma, and TCD. These findings would be useful in designing thermal processes and related calculations for the pineapple fruit.

Keywords: Blanching, color changes, kinetic models, MD2 variety, pineapple

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INTRODUCTION

Fresh pineapple fruit is extremely perishable and will go bad quickly if not handled properly due to the high water content (around 80%) of the fruit (Orsat et al., 2006). When extreme situations such as the

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COVID-19 pandemic broke out in 2020, instability in the food supply chain affected the availability of food in the market through prolonged lockdowns and restrictions on immigration (Shahidi, 2020). Therefore, preservation techniques such as drying have become necessary for extending the shelf life.

Drying is the common method to preserve the high moisture content like pineapple. Drying is one of the oldest processing methods. It refers to removing moisture from solid material upon applying heat (Agarry et al., 2013). While drying fruit is a process where water is removed to retard the growth of microorganisms, as well as stop the occurrence of enzymatic or nonenzymatic browning reactions in the material matrix (Fan et al., 2006). In addition, fruits and vegetables are dried to extend shelf-life, enhance storage stability, minimize packaging requirements, and reduce transport weight (Karam et al., 2016). Kingsly et al. (2007) stated that drying also greatly affected the sensory and nutritional characteristics of the end product. Numerous drying techniques have been used for fruits and vegetables (Ahmed, 2011), such as solar drying (Lahsasni et al., 2004), microwave (Izli et al., 2018), and freeze-drying (Ceballos et al., 2012). Microwave drying was chosen as the drying method because it does not show a significant change in physicochemical properties. According to Abd Rahman (2020), microwave drying only shows minimal changes in the physicochemical properties, such as vitamin C and carotenoid compounds in mandarin citrus peels. It contrasts with hot air drying, which showed significant changes during elevated temperatures.

Application of physical pre-drying treatments such as blanching of solid food materials had been used commonly (Dandamrongrak et al., 2003). Blanching is a thermal treatment used prior to the food process (Xiao et al., 2017) to enhance the taste or texture of fruits and vegetables (Abdul Halim, 2021). The blanched products will cool rapidly or continue with the next processes, such as drying, freezing, frying, and canning (Abdul Halim, 2022; Xiao et al., 2017). Generally, vegetables and fruit are blanched to a predetermined temperature, and the time between 1 min and less than 10 min depends on the time required for the inactivation of peroxidase and polyphenol oxidase enzymes (Xiao et al., 2017). While drying, the pineapple fruit plant's tissues can experience several physical and chemical changes that substantially impact the quality. It includes shrinkage, color changes, ascorbic acid breakdown, and loss of rehydration capacity (Radojčin et al., 2021; Ramallo & Mascheroni, 2012). However, the temperature and duration of the blanching procedure for pineapple fruits are not defined. Hence, it is important to study the effect of blanching and drying on the kinetic color changes of pineapple fruits to determine the most suitable blanching and drying conditions to produce a good quality dried pineapple. Hidayat and Setyadjit (2019) reported the effect of blanching pretreatment on the physicochemical characteristics of potato powder samples.

They reported that the pretreatment affected the yield, color, water, and protein content and did not significantly affect ash, fat, or carbohydrate content. Alam et al. (2013) reported that carrot pomace became darker, corresponding to a decrease in the 'L' values and loss in redness ('a*' value decreased) and yellowness ('b*' value decreased) irrespective of blanching. Akter et al. (2010) investigated the effects of blanching with hot water and hot-air drying temperatures on the physicochemical properties, dietary fiber compositions, antioxidant activity, and hydration properties of ripe and soft persimmon peels. They found that blanched peels dried at 50°C had the highest dietary fiber compositions, swelling capacity, and antioxidant activity compared with those at high drying temperatures (60 and 70°C).

Agarry et al. (2013) conducted a study regarding the effect of blanching temperature-time combinations treatment conditions on the drying behavior of pineapple slices. The results show that the blanching temperature-time combinations affected drying rates and drying times. Blanching at 60 to 80°C for a short period (3 to 5 min) prior to drying showed increased mass transfer activity during the oven-drying process of pineapple slices. While blanching at 70 and 80°C for 10 min showed increased drying time compared with the unblanched pineapple samples (control). It could result from carbohydrate gelatinization and high water uptake (Agarry et al., 2013). Garba et al. (2015) observed that the effects of the blanching that resulted in higher drying rates were significant at a high temperature (80°C) and only marginal at a lower temperature (50°C).

The quality changes of the dried and blanched pineapple fruits were examined, and the influencing elements will be researched. The study used a model that can be used to predict how the color of pineapple fruits will vary over time in response to various blanching and drying settings. The first-order model and zero-order model were the kinetic models suggested based on the research found.

MATERIAL AND METHODS

Plant Materials

The pineapple fruit variety MD2 was supplied from the local farm at Sg. Merab, Kajang, Selangor, Malaysia. The pineapple fruits were harvested and delivered to Universiti Putra Malaysia on the same day. The fruits were from indices 4 (riped and matured), free from damage and pests. The fruits were then stored in room conditions at 25°C until further used.

Blanching

Pineapple slices were sliced into 60 cubes (Figure 1) for three different blanching temperatures, which were 0, 50, and 60°C (Agarry et al., 2013), respectively. The pineapple slices were immersed in a beaker filled with distilled water and heated using a water bath (Laft Technologies, Australia). For all temperatures, samples were blanched for up to 3 min, with 1 min cooled in the ice water to stop the heating process and analyzed for color properties.

Figure 1. Slices of pineapple fruit

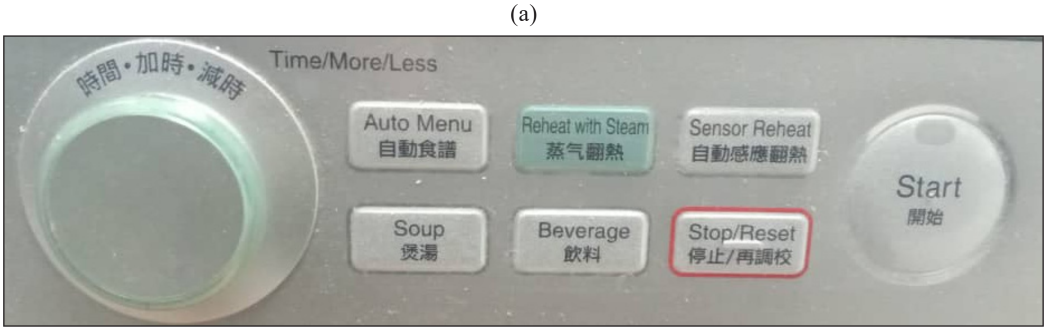
Combined Microwave and Convection Drying

The pre-blanched samples were then further dried using a microwave oven with 1,220 W power (NN-J993, Panasonic, Japan) (Figure 2) at four different temperatures: 110, 120, 130, and 140°C. The temperatures were set up accordingly using the microwave oven control panel. First, press the convection button on the control panel (Figure 2a). Then, turn the left knob clockwise to set the temperature (Figure 2a). The drying time was varied at 5, 10, 15, 20, 25, and 30 min for each temperature, respectively, by turning clockwise the right knob on the control panel (Figure 2b) (Izli et al., 2018; Maskan, 2001). For every 5 min, the dried pineapple sample color was taken using a portable colorimeter (WR-18, FRU, China).

Color Analysis

The effect of blanching and combined microwave and convection drying were observed through color analysis. A colorimeter (WR-18, FRU, China) determined the samples' color after blanching and drying. The quantitative attribute of colorfulness, also known as

(a)



(b)

Figure 2. The microwave oven (a) left and (b) right control panel (NN-J993, Panasonic, Japan)

chroma (C) and total color difference (TCD), was calculated using Equations 1 and 2 (Izli et al., 2018):

$$C = \sqrt{a*^2 + b*^2} \tag{1}$$

$$TCD = \sqrt{(L* - L_o*)^2 + (a* - a_o*)^2 + (b* - b_o*)^2} \tag{2}$$

where, a* = Redness or greenness of the sample; a_0* = Redness or greenness of the standard tile; b* = Yellowness or blueness of the sample; b_0* = Yellowness or blueness of the standard tile; L* = Whiteness or brightness of the sample; and L_0* = Whiteness or brightness of the standard tile.

Mathematical Models and Kinetic Analysis for Color of Blenched and Dried Pineapple Fruit

The parameter of L*, a*, b*, C*, and TCD is used to estimate the color changes of pineapple slices. The two models were chosen to study the effect of color changes due to blanching and drying: zero order and first order. Equation 3 below shows the zero-order model equation (Maskan, 2001):

$$P = P_O - kt \tag{3}$$

where, P is the parameter to be estimated, the subscript 0 indicates the parameter's initial value, t is the drying time, and k is the rate constant at temperature. The equation was then rearranged into Equation 4, as Gonçalves et al. (2010) proposed to plot the zero-order equation graph.

$$1 - \frac{P}{P_o} = kt \tag{4}$$

where, the y-axis is $\left(1 - \frac{P}{P_0}\right)$, the x-axis is the duration of drying in minutes (t), and the slope of the graph is determined as the kinetic reaction rate. Equation 5 shows the first-order equation model proposed by Gonçalves et al. (2010) and Maskan (2001):

$$\frac{P}{P_0} = e^{-kt} \tag{5}$$

Equation 5 is then converted into Equation 6 to plot the first-order graph:

$$\ln\left(\frac{P}{P_0}\right) = -kt \tag{6}$$

where, y-axis: $\ln\left(\frac{P}{P_0}\right)$; x-axis = duration of drying (t, min); and slope of the graph = kinetic reaction rate (-k).

Statistical Analysis

Using statistical tools SigmaPlot (version 18.0), data analysis and mass modeling prediction were carried out. The standard error of the estimate (SEE) and coefficient of determination (R^2) were chosen as the parameters to assess the applicability of the regression models. The models with higher R^2 and smaller SEE numbers were chosen as appropriate. The R^2 value near 1.00 for regression equations generally shows a good fit with the model (Shahbazi & Rahmati, 2012).

RESULT AND DISCUSSION

Color Characteristics of Pineapple Fruit

Pineapple fruits' flesh variety MD2 before blanching and drying was yellowish, translated in the color parameters shown in Table 1. Before blanching and drying, the pineapple fruits' flesh has a value of 39.2 for the L* parameter indication on the brightness. Furthermore, the positive value of a* parameter is 2.4, which indicates a shift towards redness. The redness of the pineapple was based on the sugar content of the fruit (Ding & Syazwani, 2016). On the other hand, the positive value of the b* parameter, which is 37.3, suggests a shift towards yellowness. This finding was similar to the study by Romli et al. (2019), which detected the b* value was 33.20±0.83 for MD2 pineapple with index 4 maturity. The combination of the a* parameter (2.4) and b* parameter (37.3) shows that the color of the flesh of pineapple fruit is light yellow based on the CIELAB color chart.

Table 1
Initial characteristics of pineapple fruit variety MD2

Parameter	Initial value
L*	39.2
a*	2.4
b*	37.3
Chroma (C)	37.3
Total color difference (TCD)	0.0

Effect of Microwave Drying on the Color of Pineapple Fruits without Blanching as Pretreatment

Based on Figure 3, the value of L* had a slight increase ($P<0.05$) as the duration time increased (5 to 30 min) for all the temperatures. After drying, the value of L* at 110°C (5 min) is 39.3 and increased to 47 (25 min). However, at a duration of 30 min, the value of L* had decreased to 44.8. The same trends are also shown at temperature 120°C, where the L*value increases from minute 5 (51.7) to minute 25 (52.6) but decreases to 52.2 in minute 30. As for temperatures 130 and 140°C, the L* values increased from minute 5 to minute 25. According to Ramallo and Mascheroni (2012), the variations of L* values were not significant during pineapple drying. This parameter was not affected by process temperature. Similar observations about L* values were reported by Krokida and Maroulis (1999) during apple, banana, carrot, and potato drying.

Figure 4 shows the a* value for the flesh of pineapple fruits. It can be observed that the a* value at the temperature 140°C was the lowest compared to the other drying temperature. Drying at a temperature of 110°C showed the most significant increase from 13.5 (5 min) to 40.9 (30 min) ($P<0.05$). While for temperature 120°C, the a* value increased from 9.2 (5 min) to 26.0 (10 min) before decreasing to 6.5 at minute 20. Then

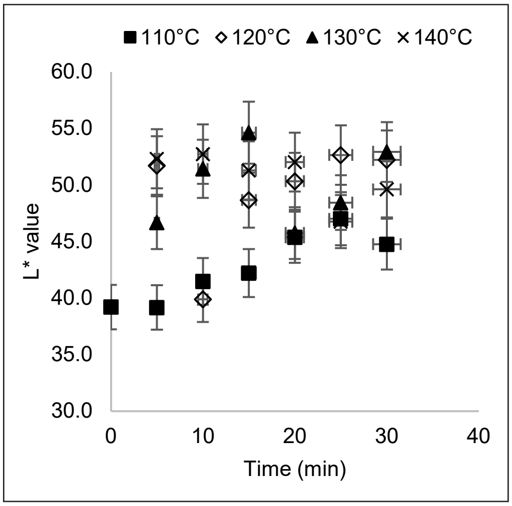


Figure 3. The effect of microwave drying (110, 120, 130, and 140°C) without blanching on the color parameters of pineapple fruits: Lightness (L*)

it increases again to 22.2 at minute 30. As for temperature 130°C, it was observed that a* value increased from 5.9 (5 min) to 14. 2 (30 min). The same increasing trend also shows at temperature 140°C. The increase in a* values as the drying temperatures increased, and the drying method lowered green pigmentation without increasing the yellow color (Ramallo & Mascheroni, 2012). Ramallo and Mascheroni (2012) reported that the increase of a* and b* parameters of pineapple fruit was independent of the drying temperature, where they found the relative visual yellow color (b* value) was slightly increased during drying at 45 and 60°C, and practically remained without changes during the drying at 75°C. The authors found that values of parameter b* remained constant during thermal processing at 70°C. Overall, the a* value is not dependent on the drying temperature as it does not show an increasing or decreasing trend, as Ramallo and Mascheroni (2012) stated.

Figure 5 shows that the value of b* after drying at 110°C at 5 min is 51.5 and increased to 86.0 at 30 min. A similar trend can also be seen in temperatures 120 and 130°C. The result shows that the b* value increased significantly as temperature and duration time increased. Overall, it can be concluded that as the temperature and time of drying increases, the b* parameter also increases, resulting in the yellowness of fruit after drying.

Based on Figure 6, the value of chroma after drying at 110°C at 5 min is 53.5 and increased to 95.2 at 30 min. For 120°C, the value of chroma at 5 min, that is 54.8, increases to 79.5 at 30 min. The same increasing trend also showed for temperature 130°C. While for temperature 140°C, the chroma's value decreases slightly from 37.3 (5 min) to 36.9 (30 min). This result is similar to the findings by Guine et al. (2012), where they stated that the chroma of dried pumpkin decreased significantly with freeze

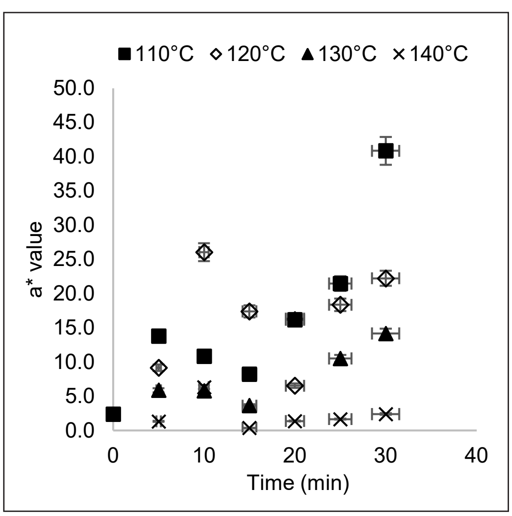


Figure 4. The effect of microwave drying (110, 120, 130, and 140°C) without blanching on the color parameters of pineapple fruits: Redness (a*)

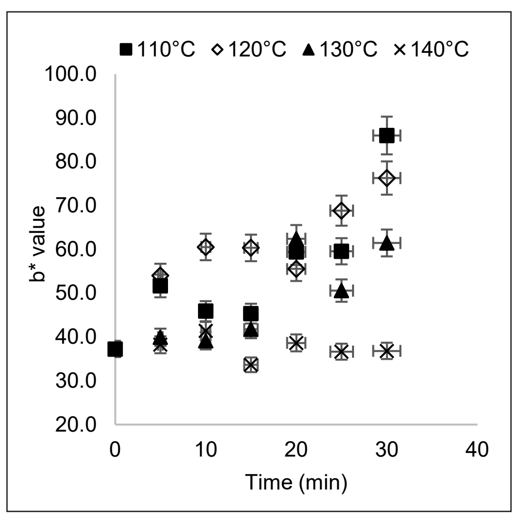


Figure 5. The effect of microwave drying (110, 120, 130, and 140°C) without blanching on the color parameters of pineapple fruits: Yellowness (b*)

drying. Since the chroma value was observed to increase for temperatures 110, 120, and 130°C and only decrease at temperature 140°C, it can be concluded that the effect of drying on the chroma color of the pineapple fruit is as the temperature and time of drying increases, the chroma value increases. The proportion of the grey component that defines a color is connected to the chroma parameter (Shamsudin et al., 2022). The intensity of the hue increased as the chroma rose.

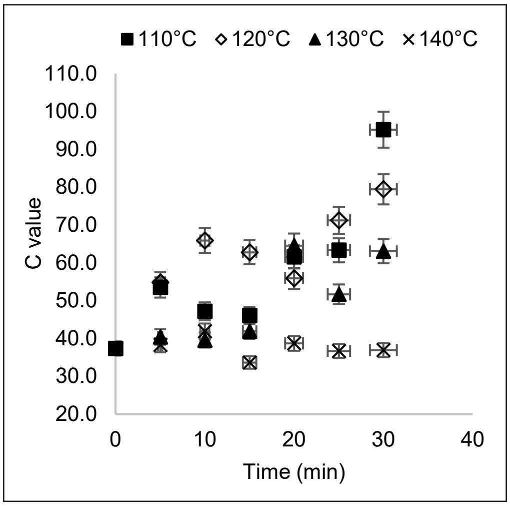


Figure 6. The effect of microwave drying (110, 120, 130, and 140°C) without blanching on the color parameters of pineapple fruits: Chroma value (C)

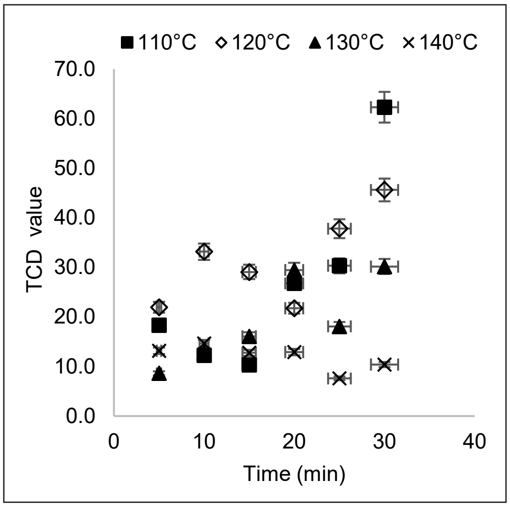


Figure 7. The effect of microwave drying (110, 120, 130, and 140°C) without blanching on the color parameters of pineapple fruits: Total color difference (TCD)

Based on Figure 7, the TCD value after drying increases as the time duration increases. At a temperature of 110°C, TCD increased from 18.4 at 5 min to 62.3 at 30 min. The same trend was observed at temperatures 110, 120, 130, and 140°C. A study by Mohammadi et al. (2008) also showed the same trend for TCD, stating that TCD increased as the air temperature increased.

Effect of Blanching Pretreatment and Drying on the Color of Pineapple Fruits

Figure 8 shows the effect of blanching on the color parameter L* of dried pineapple fruits. Based on the figure, the L* parameter for no blanched, blanched at 50°C, and blanched at 60°C shows the increasing trend as the time increased. Comparing no blanched

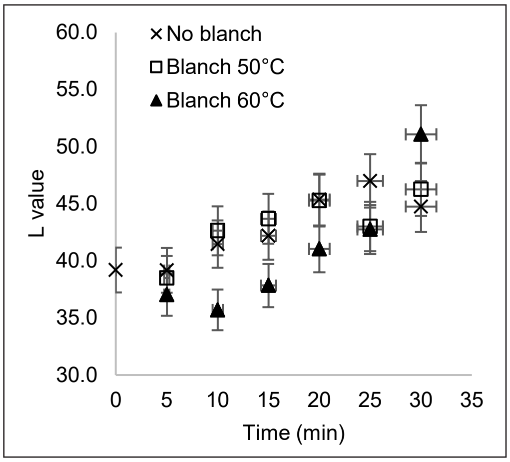


Figure 8. The effect of blanching (50 and 60°C) and microwave drying (110°C) on the color parameters of pineapple fruits: Lightness (L*)

and blanched at 50 and 60°C, the L* value at 60°C is lower than no blanch and blanch at 50°C at minute 5 to minute 25. While the L* value, when subjected to no blanched and blanched at 50°C, is nearly the same and does not show much difference. It may occur due to the lower temperature of blanching that does not affect the color of the pineapple slices. To conclude, blanching can affect the L* value by lowering it when the subject blanches at 60°C. The lower value of L* indicates the samples turn darker. A similar result was also observed by Deylami et al. (2016), where they discovered a significant (*P*<0.05) decrease in hunter L∗ value as the temperature of thermal treatment increased from temperature 60 to 100°C indicating that the mangosteen pericarp extracts became darker at higher temperatures.

Figure 9 shows the effect of blanching on color parameter a* of dried pineapple fruits. Based on Figure 9, the a* parameter, when blanched at a temperature of 60°C, has the highest a* value at minute 5 (20.3) until minute 20 (28.8) compared when no blanch and when blanched at 50°C. After minute 20, a* parameter for pineapple slices that blanch at 60°C decreases to 13.5 and then increases again to 16 at minute 30. While for conditions with no blanch and blanch at 50°C, their a* value does not show a significant difference (*P*>0.05) and is nearly the same. It may be due to the lower temperature of blanching that does not affect the color changes in pineapple slices. It has been proven by Verlinden et al. (2000) that a lower blanching temperature of 55°C reduces the physical breakdown of the fruit. The graph shows that the temperature of blanching pretreatment at 60°C increases the a* parameter, indicating the color of pineapples to shift to the redness.

Figure 10 shows the effect of blanching on color parameter b* of dried pineapple fruits. The different conditions of pretreatment, either no blanched, blanched 50°C, and

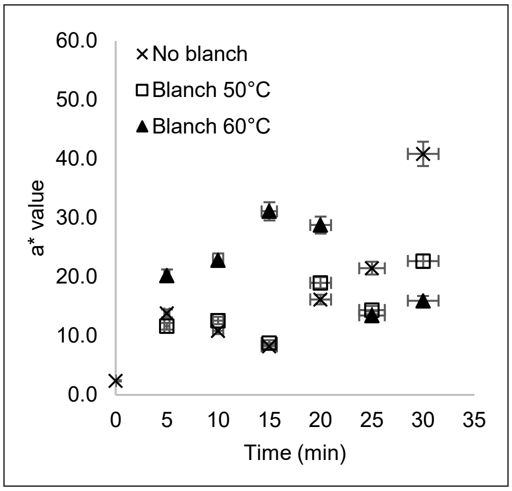


Figure 9. The effect of blanching (50 and 60°C) and microwave drying (110°C) on the color parameters of pineapple fruits: Redness (a*)

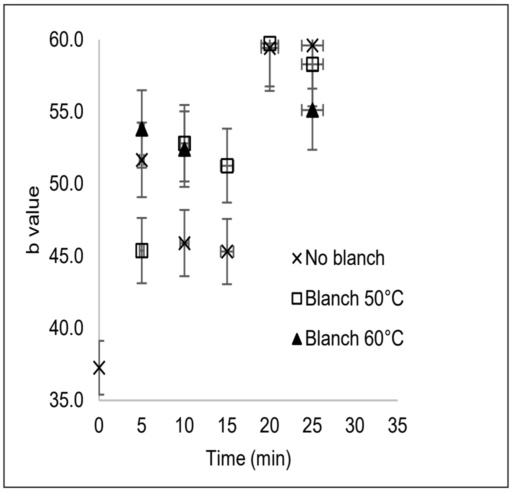


Figure 10. The effect of blanching (50 and 60°C) and microwave drying (110°C) on the color parameters of pineapple fruits: Yellowness (b*)

blanched 60°C independent of different pretreatment conditions. Figure 9 shows that the b* value for all three conditions is inconsistent with the presence of blanching or without blanching, making it independent of all three different pretreatment conditions.

Figure 11 shows the effect of blanching on the color parameter chroma of dried pineapple fruits. The chroma value for all conditions shows an increasing trend as time increases. Pineapple slices subjected to blanching at 60°C show the highest chroma value from minute 5 until minute 20. Then, the chroma value decreases to 56.8 (minute 25) and increases to 72.5 at minute 30. Pineapple slices subjected to no blanch and blanch at 50°C also show an increasing trend in chroma value, indicating an increase in intensity or saturation of the color. The vividness or saturation of color does change as the temperature and time of blanching increase (Demirhan & Özbek, 2015; Manjunatha et al., 2019; Onwude et al., 2016; Shamsudin et al., 2022).

Figure 12 shows the effect of blanching on the TCD parameter of dried pineapple fruits. Based on the figure, the TCD value for all conditions shows an increasing trend as the time increases from minute 5 to minute 30. Pineapple slices subjected to blanching at 60°C showed the highest TCD value compared to the other pretreatment conditions from minute 5 until minute 20. Then, the chroma value decreases to 21.3 (minute 25) and increases to 37.9 (minute 30). As for no blanch pineapple slices, it showed the lowest TCD value at minute 25. To conclude, the blanching pretreatment can affect the TCD value. As the temperature of blanching increases, the TCD value also increases. Overall, blanching pretreatment prior to drying can change the color of pineapple slices, turning the lightness of the pineapple darker and turning the color to redness when compared to no blanching. Nevertheless, it maintains the yellowness in the pineapple slice. Thus, in terms of color parameters, blanching pretreatment

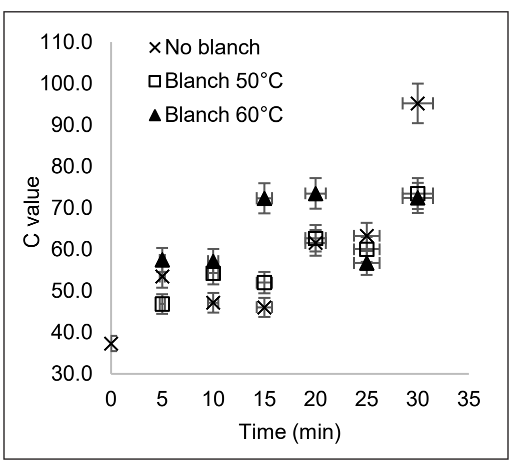


Figure 11. The effect of blanching (50 and 60°C) and microwave drying (110°C) on the color parameters of pineapple fruits: Chroma value (C)

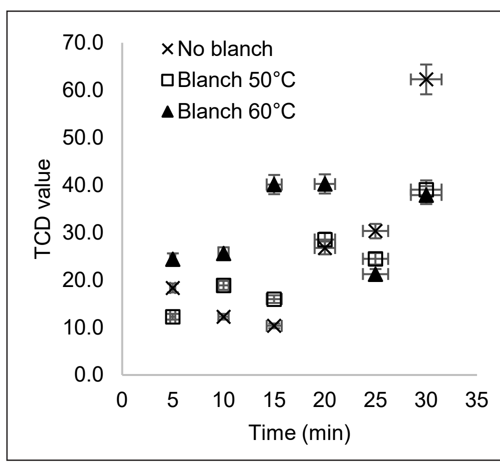


Figure 12. The effect of blanching (50 and 60°C) and microwave drying (110°C) on the color parameters of pineapple fruits: Total color difference (TCD)

is not suggested prior to drying since it can cause color degradation in pineapple slices compared to no blanching.

Modeling of Color Changes

Figure 13 shows L* values data fitted mn in the zero-order kinetic model. Based on Table 2, the k values for the L* parameter at 110, 120, 130, and 140°C for the zero-order model are -0.0066, -0.0097, -0.0117, and -0.0116, respectively. These values show the increasing trend, which also can be observed in the graph as in Figure 13 from temperature 110 to 130°C but decreased at temperature 140°C. As the slope of the graph becomes steeper with time, the k value also increases, which indicates the changes in the L* parameter. A similar trend was also observed for the first-order kinetic model. Based on Table 2, the k values for the L* parameter at 110, 120, 130, and 140°C for the first-order model are 0.0061, 0.0082, 0.0097, and 0.0061, respectively. Based on the tabulated data in Figure 14, it shows L*

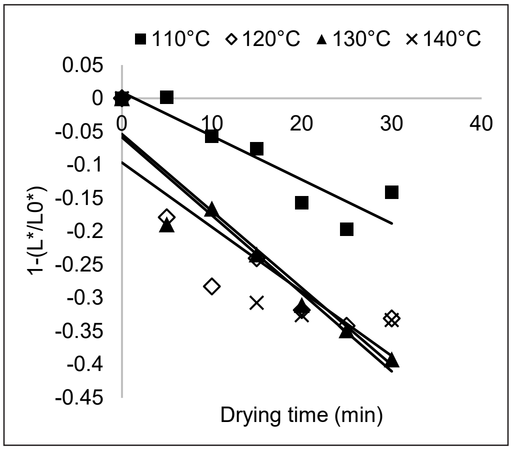


Figure 13. Zero-order kinetic model of the effect of microwave drying (110, 120, 130, and 140°C) on the color parameters of pineapple fruits: Lightness (L)

Table 2
The reaction rate (k) and coefficient of determination (R^2) for the first- and zero-order kinetic model of color parameter variations (L, a*, b*, C, and TCD) in dried pineapple fruit*

Parameter	Kinetic model	Temperature (°C)	k	R^2
L	Zero-order	110	-0.0066	0.8327
		120	-0.0097	0.7454
		130	-0.0117	0.9110
		140	-0.0116	0.8017
	First-order	110	0.0061	0.8408
		120	0.0082	0.7203
		130	0.0097	0.8857
		140	0.0061	0.8408
a	Zero-order	110	-0.4046	0.7152
		120	-0.2497	0.9107
		130	-0.1643	0.7429
		140	-0.0647	0.8586
	First-order	110	-0.0699	0.7293
		120	0.0621	0.7543
		130	0.0486	0.7391
		140	0.0483	0.5454
b	Zero-order	110	-0.0336	0.7320
		120	-0.0272	0.7888
		130	-0.0225	0.7091
		140	-0.0111	0.9147
	First-order	110	0.0218	0.7722
		120	0.0182	0.7469
		130	0.0174	0.7469
		140	0.0105	0.9203
C	Zero-order	110	-0.0406	0.7221
		120	-0.0292	0.7098
		130	-0.0252	0.7364
		140	-0.0109	0.8950
	First-order	110	0.0247	0.7699
		120	0.0208	0.8002
		130	0.0190	0.7726
		140	0.0103	0.9004
TDC	Zero-order	110	-0.0804	0.7114
		120	-0.0373	0.8445
		130	-0.0546	0.8256
		140	-0.0456	0.9839
	First-order	110	0.0472	0.8098
		120	0.0282	0.7041
		130	0.0356	0.8600
		140	0.0376	0.9693

data fitted in the first-order kinetic model. The zero-order and first-order kinetic models adequately described the degradation of L* values of pineapple slices over the entire temperature range. The coefficient of determination values (R^2) ranged between 0.7454 and 0.9110 for zero-order and 0.7203 and 0.8857 for the first-order kinetic model. This finding is supported by Chutintrasri and Noomhorm (2007), who discovered that the L* parameter followed the first-order kinetic reaction. In addition, Ansari et al. (2015) also found the same result where both models can be used adequately.

Based on Table 2, the value of k for a* parameter for zero order at temperatures 110, 120, 130, and 140°C were -0.4046, -0.2497, -0.1643, and -0.0647, respectively. These k value increase as the drying temperature increase from 110 to 140°C, which indicates the changes in a* parameter as the temperature change. Figure 15 shows that the slope (k) is steeper as temperature increases. The value of k for a* parameter for first order at temperatures 110, 120, 130, and 140°C were -0.0699, 0.0621, 0.0486, and 0.0483, respectively. These k value shows decreasing trends as the drying temperature increases, indicating the changes in a* parameter as the temperature increases. The data a* parameter was observed to be the best fit with zero order with the highest R^2 value (between 0.7152 to 0.9107) compared with the first order with a range between 0.5454 to 0.7543. The first-order kinetic model is presented in Figure 16. This result is agreed with Mohammadi et al. (2008), where they found that a* parameter followed the first-order model for color changes of kiwi fruit due to hot air drying.

Based on Table 2, the value of k for the b* parameter for zero order at temperatures 110, 120, 130, and 140°C were -0.0336, -0.0272, -0.0225, and -0.0111, respectively. Figure 17 shows that the slope indicating the k value decreases as temperature increases, which translates to lower k as temperature increases. A similar decreasing trend was also observed in the first-order kinetic model

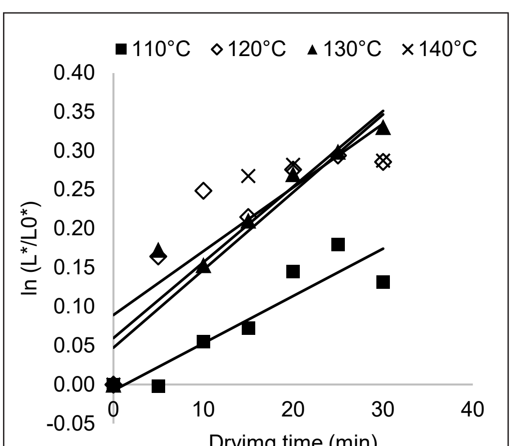


Figure 14. First-order kinetic model of the effect of microwave drying (110, 120, 130, and 140°C) on the color parameters of pineapple fruits: Lightness (L*)

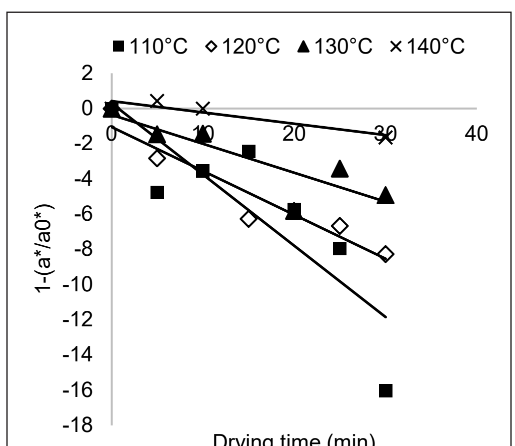


Figure 15. Zero order kinetic model of the effect of microwave drying (110, 120, 130, and 140°C) on the color parameters of pineapple fruits: Redness (a*)

where the k values were 0.0218 (110°C), 0.0182 (120°C), 0.0174 (130°C), and 0.0105 (140°C). Figure 18 shows the first-order graph for the b* parameter. The value R^2 for zero and first order is 0.7091-0.9147 and 0.7468-0.9147, respectively. High coefficient determination (R^2) for these models proves that the b* parameter changes best fit both models. Mohammadi et al. (2008) also observed the same result where first-order kinetic fits best. In addition, Ansari et al. (2015) also found the same result, where both models can be used adequately.

The values of k for the chroma parameter for zero order at temperatures 110, 120, 130, and 140°C were -0.0406, -0.0292, -0.0252, and -0.0109, respectively, as demonstrated in Table 2. The value of k is increasing as temperature increases. Figure 19 shows chroma values fitted with the zero-order kinetic model where the slope increases as the drying temperature increases, indicating the increase in the k value. A decreasing trend was observed in the first-order kinetic model where the k values were decreased from 0.0247 (110°C), 0.0208 (120°C), 0.0190 (130°C), and 0.0103 (140°C). Figure 20 shows the experimental data of chroma that fitted with the first model. Table 2 shows that the zero and first-order kinetic model best fits the chroma parameter with R^2 value

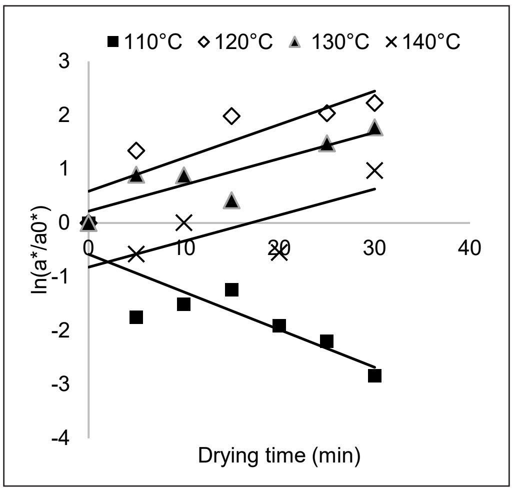


Figure 16. First-order kinetic model of the effect of microwave drying (110, 120, 130, and 140°C) on the color parameters of pineapple fruits: Redness (a*)

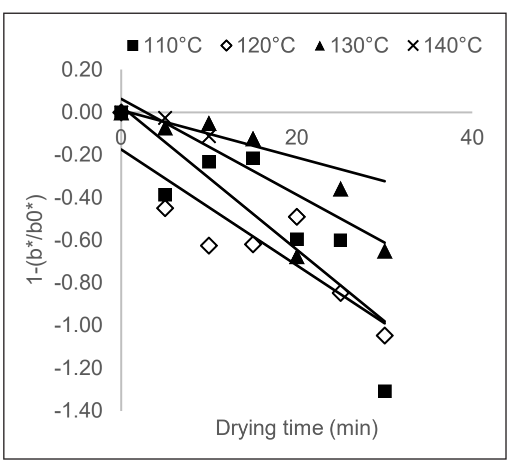


Figure 17. Zero order kinetic model of the effect of microwave drying (110, 120, 130, and 140°C) on the color parameters of pineapple fruits: Yellowness (b*)

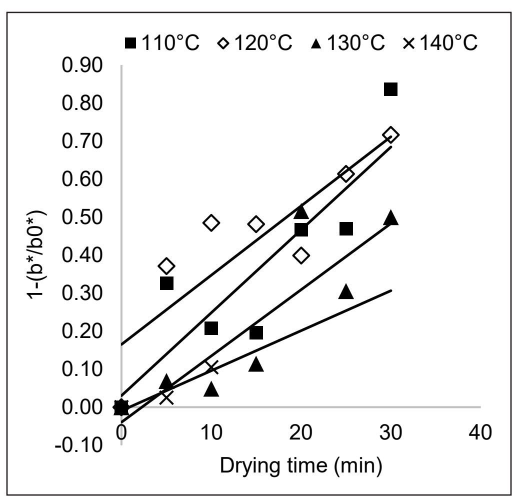


Figure 18. First-order kinetic model of the effect of microwave drying (110, 120, 130, and 140°C) on the color parameters of pineapple fruits: Yellowness (b*)

of 0.7098 to 0.8950 and 0.7699 to 0.9004, respectively. This finding agreed with the result of Demirhan and Özbek (2015), who found that the chroma best fits the first order for microwave drying the tea leaves.

Based on Table 2, the values of k for TCD for zero order at temperatures 110, 120, 130, and 140℃ were -0.0804, -0.0373, -0.0546, and -0.0456, respectively. These k values show inconsistent trends as the drying temperature increases, making it independent of drying time. Figure 21 shows the TCD values fitted in the zero-order kinetic model. A similar result was also observed for first-order kinetic, where the k value for TCD at temperatures 110, 120, 130, and 140℃ were 0.0472, 0.0282, 0.0356, and 0.0376. Figure 22 shows the

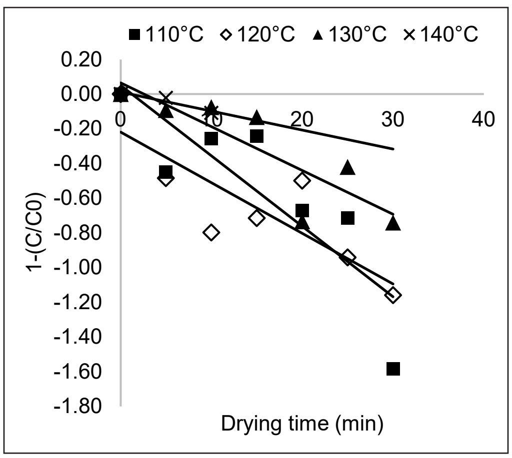


Figure 19. Zero-order kinetic model of the effect of microwave drying (110, 120, 130, and 140°C) on the color parameters of pineapple fruits: Chroma value (C)

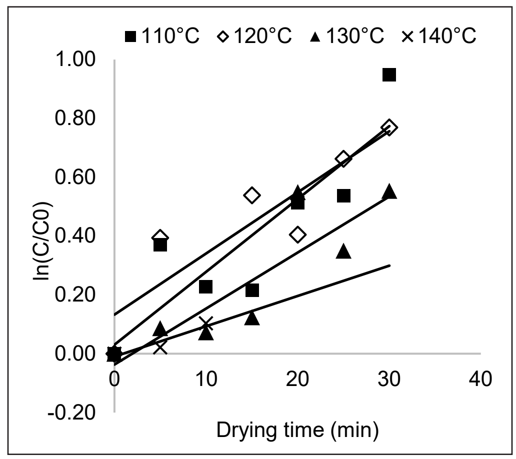


Figure 20. First-order kinetic model of the effect of microwave drying (110, 120, 130, and 140°C) on the color parameters of pineapple fruits: Chroma value (C)

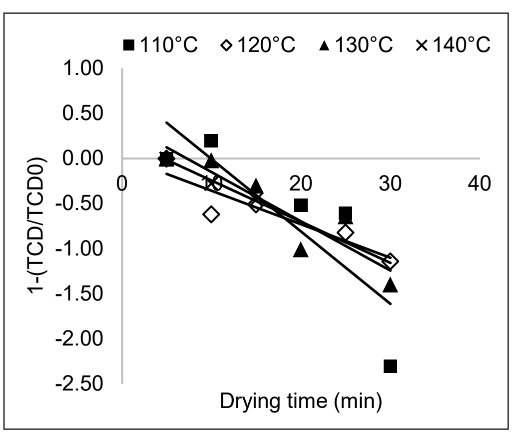


Figure 21. Zero-order kinetic model of the effect of microwave drying (110, 120, 130, and 140°C) on the color parameters of pineapple fruits: Total color difference (TCD)

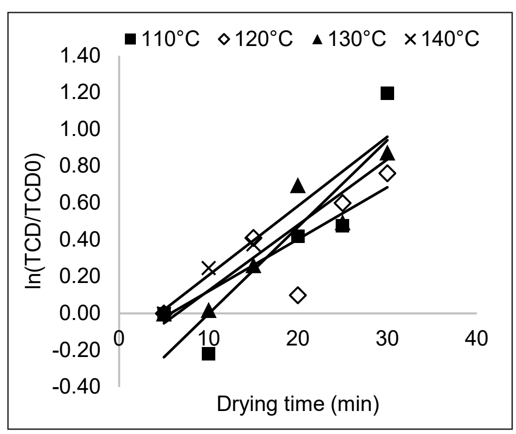


Figure 22. First-order kinetic model of the effect of microwave drying (110, 120, 130, and 140°C) on the color parameters of pineapple fruits: Total color difference (TC)

TCD data that fitted with the first model. Table 2 shows that the zero and first-order kinetic model best fits the TCD parameter with the R^2 value of 0.7114 to 0.9839 and 0.7041 to 0.9693, respectively. Chutintrasri and Noomhorm (2007) also found that the zero-order kinetic model fitted well to TCD.

CONCLUSION

Pre-blanching prior to drying affects the color of the pineapple as the L* value moves toward darker, reduces the a* value, and maintains the b* value by comparing it with the unblanched pineapple. Hence, pre-blanching is not suggested as it causes color degradation. During drying using the microwave technique, the L* values increased as the temperature as well as time increased. Meanwhile, the a* value showed no effect on the different temperatures or times of drying. Furthermore, the drying pineapple tended to gain yellowness and became saturated as the drying time and temperature increased. The kinetic modeling of color changes gives the result of L* b*, C, and TCD were all fitted with zero (R^2: 0.7091–0.9839) and first order (R^2: 0.7041–0.9693). As for the a* parameter, the kinetic modeling only fitted with zero order (R^2: 0.7152–0.9107). In conclusion, different drying time and temperature does give significant changes.

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REFERENCES

Abd Rahman, N. F. (2020). *Physicochemical and antioxidant properties of pamelo residues using different drying methods and kinetic models of naringin degradation* [Doctoral's thesis, Maejo University]. Maejo University Publications. http://ir.mju.ac.th/dspace/bitstream/123456789/454/1/6003507002.pdf

Abdul Halim, A. A. (2021). *Physical characteristics and effects of blanching treatment on the color and textural properties of dabai fruit (*Canarium odontophyllum *miq.)* variety "ngemah" [Unpublished Bachelor's dissertation]. Universiti Putra Malaysia.

Abdul Halim, A. A., Shamsudin, R., Ariffin, S. H., Zainol @ Abdullah, W. N. Z., & Azmi, N. S. (2022). Kinetic models on quality changes during heat blanching of some fruit and vegetables. *Advances in Agricultural and Food Research Journal*, *3*(1), a0000265. https://doi.org/10.36877/aafrj.a0000265

Agarry, S. E., Ajani, A. O., & Aremu, M. O. (2013). Thin layer drying kinetics of pineapple: Effect of blanching temperature – Time combination. *Nigerian Journal of Basic and Applied Sciences*, *21*(1), 1-10. https://doi.org/10.4314/njbas.v21i1.1

Ahmed, J. (2011). Drying of vegetables: Principles and dryer design. In N. K. Sinha (Ed.), *Handbook of vegetables and vegetable processing* (pp. 279–298). Blackwell Publishing Ltd. https://doi.org/10.1002/9780470958346.ch13

Akter, M. S., Ahmed, M., & Eun, J.-B. (2010). Effect of blanching and drying temperatures on the physicochemical characteristics, dietary fiber composition and antioxidant-related parameters of dried persimmons peel powder. *International Journal of Food Sciences* *and Nutrition*, *61*(7), 702–712. https://doi.org/10.3109/09637481003757852

Alam, M. S., Gupta, K., Khaira, H., & Javed, M. (2013). Quality of dried carrot pomace powder as affected by pretreatments and methods of drying. *Agricultural Engineering International: CIGR Journal*, *15*(4), 236–243.

Ansari, S., Maftoonazad, N., Hossein, S. E., Farahnaky, A., & Asadi, G. H. (2015). Kinetic of color and texture changes in rehydrated figs. *Tarım Bilimleri Dergisi*, *21*(1), 108–122. https://doi.org/10.15832/tbd.47774

Ceballos, A. M., Giraldo, G. I., & Orrego, C. E. (2012). Effect of freezing rate on quality parameters of freeze dried soursop fruit pulp. *Journal of Food Engineering*, *111*(2), 360–365. https://doi.org/10.1016/j.jfoodeng.2012.02.010

Chutintrasri, B., & Noomhorm, A. (2007). Color degradation kinetics of pineapple puree during thermal processing. *LWT - Food Science and Technology*, *40*(2), 300–306. https://doi.org/10.1016/j.lwt.2005.11.003

Dandamrongrak, R., Mason, R., & Young, G. (2003). The effect of pretreatments on the drying rate and quality of dried bananas. *International Journal of Food Science and Technology*, *38*(8), 877–882. https://doi.org/10.1046/j.0950-5423.2003.00753.x

Demirhan, E., & Özbek, B. (2015). Color change kinetics of tea leaves during microwave drying. *International Journal of Food Engineering*, *11*(2), 255–263. https://doi.org/10.1515/ijfe-2014-0276

Deylami, M. Z., Rahman, R. A., Tan, C. P., Bakar, J., & Olusegun, L. (2016). Effect of blanching on enzyme activity, color changes, anthocyanin stability and extractability of mangosteen pericarp: A kinetic study. *Journal of Food Engineering*, *178*, 12–19. https://doi.org/10.1016/j.jfoodeng.2016.01.001

Ding, P., & Syazwani, S. (2016). Physicochemical quality, antioxidant compounds and activity of MD-2 pineapple fruit at five ripening stages. *International Food Research Journal*, *23*(2), 549-555.

Fan, L., Zhang, M., & Mujumdar, A. S. (2006). Effect of various pretreatments on the quality of vacuum-fried carrot chips. *Drying Technology*, *24*(11), 1481–1486. https://doi.org/10.1080/07373930600952826

Garba, U., Kaur, S., Gurumayum, S., & Rasane, P. (2015). Effect of hot water blanching time and drying temperature on the thin layer drying kinetics and anthocyanin degradation of black carrot (*Daucus carota* L.) shreds. *Food Technology and Biotechnology*, *53*(3), 324-330. https://doi.org/10.17113/ftb.53.03.15.3830

Gonçalves, E. M., Pinheiro, J., Abreu, M., Brandão, T. R. S., & Silva, C. L. M. (2010). Carrot (*Daucus carota* L.) peroxidase inactivation, phenolic content and physical changes kinetics due to blanching. *Journal of Food Engineering*, *97*(4), 574–581. https://doi.org/10.1016/j.jfoodeng.2009.12.005

Hidayat, T., & Setyadjit. (2019). Effect of pre-treatment on the physicochemical characteristics of potato powder dried by drum dryer. In *IOP Conference Series: Earth and Environmental Science* (Vol. 309, No. 1, p. 012056). IOP Publishing. https://doi.org/10.1088/1755-1315/309/1/012056

Izli, N., Izli, G., & Taskin, O. (2018). Impact of different drying methods on the drying kinetics, color, total phenolic content and antioxidant capacity of pineapple. *CyTA - Journal of Food*, *16*(1), 213–221. https://doi.org/10.1080/19476337.2017.1381174

Karam, M. C., Petit, J., Zimmer, D., Djantou, E. B., & Scher, J. (2016). Effects of drying and grinding in production of fruit and vegetable powders: A review. *Journal of*

Food Engineering, *188*, 32–49. https://doi.org/10.1016/j.jfoodeng.2016.05.001

Kingsly, R. P., Goyal, R. K., Manikantan, M. R., & Ilyas, S. M. (2007). Effects of pretreatments and drying air temperature on drying behaviour of peach slice. *International Journal of Food Science and Technology*, *42*(1), 65–69. https://doi.org/10.1111/j.1365-2621.2006.01210.x

Krokida, M. K., & Maroulis, Z. B. (1999). Effect of microwave drying on some quality properties of dehydrated products. *Drying Technology*, *17*(3), 449–466. https://doi.org/10.1080/07373939908917545

Lahsasni, S., Kouhila, M., Mahrouz, M., Mohamed, L. A., & Agorram, B. (2004). Characteristic drying curve and mathematical modeling of thin-layer solar drying of prickly pear cladode (*Opuntia ficus-indica*). *Journal of Food Process Engineering*, *27*(2), 103–117. https://doi.org/10.1111/j.1745-4530.2004.tb00625.x

Manjunatha, S. S., Mathews, A. T., & Patki, P. E. (2019). Modelling the kinetics of mass transfer and change in colour during deep fat frying of green peas (*Pisum sativum* L.) at different frying temperatures. *Heat Mass Transfer*, *55*, 3087–3102. https://doi.org/10.1007/s00231-019-02637-7

Maskan, M. (2001). Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal of Food Engineering*, *48*(2), 169–175. https://doi.org/10.1016/s0260-8774(00)00154-0

Mohammadi, A., Rafiee, S., Emam-Djomeh, Z., & Keyhani, A. (2008). Kinetic models for colour changes in kiwifruit slices during hot air drying. *World Journal of Agricultural Sciences*, *4*(3), 376–383.

Onwude, D. I., Hashim, N., Janius, R., Nawi, N. M., & Abdan, K. (2016). Color change kinetics and total carotenoid content of pumpkin as affected by drying temperature. *Italian Food Science*, *29*(1), 1-18.

Orsat, V., Changrue, V., & Vijaya Raghavan, G. S. (2006). Microwave drying of fruits and vegetables. *Stewart Postharvest Review*, *2*(6), 1–7. https://doi.org/10.2212/spr.2006.6.4

Radojčin, M., Pavkov, I., Bursać Kovačević, D., Putnik, P., Wiktor, A., Stamenković, Z., Kešelj, K., & Gere, A. (2021). Effect of selected drying methods and emerging drying intensification technologies on the quality of dried fruit: A review. *Processes*, *9*(1), 132. https://doi.org/10.3390/pr9010132

Ramallo, L. A., & Mascheroni, R. H. (2012). Quality evaluation of pineapple fruit during drying process. *Food and Bioproducts Processing*, *90*(2), 275–283. https://doi.org/10.1016/j.fbp.2011.06.001

Romli, R., Murad, M., Wan Nur Hafzan, W. M., & Haris, H. (2019). Physicochemical properties and sensory acceptability of pineapples of different varities and stages of maturity. *Food Research*, *3*(5), 491-500. https://doi.org/10.26656/fr.2017.3(5).060

Shahbazi, F., & Rahmati, S. (2012). Mass modeling of fig (*Ficus carica* L.) fruit with some physical characteristics. *Food Science and Nutrition*, *1*(2), 125–129. https://doi.org/10.1002/fsn3.20

Shahidi, F. (2020). Does COVID-19 affect food safety and security? *Journal of Food Bioactives*, *9*, 1-3. https://doi.org/10.31665/jfb.2020.9212

Shamsudin, R., Ariffin, S. H., Zainol @ Abdullah, W. N. Z., Azmi, N. S., & Abdul Halim, A. A. (2022). Quality evaluation of color and texture of the dabai fruit (*Canarium odontophyllum* Miq.) at different temperatures and times of blanching. *Pertanika Journal of Science and Technology*, *30*(4), 2427-2438. https://doi.org/10.47836/pjst.30.4.07

Verlinden, B. E., yuksel, D., Baheri, M., Baerdemaeker, J. D., & Dijk, C. V. (2000). Low temperature blanching effect on the changes in mechanical properties during subsequent cooking of three potato cultivars. *International Journal of Food Science and Technology*, *35*(3), 331-340. https://doi.org/10.1046/j.1365-2621.2000.00391.x

Xiao, H.-W., Pan, Z., Deng, L.-Z., El-Mashad, H. M., Yang, X.-H., Mujumdar, A. S., Gao, Z.-J., & Zhang, Q. (2017). Recent developments and trends in thermal blanching – A comprehensive review. *Information Processing in Agriculture*, *4*(2), 101–127. https://doi.org/10.1016/j.inpa.2017.02.001