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Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate

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Abstract:	Vacuum freeze dryer is able to remove some of the moisture content of the material. However, the drying rate is very slow because the sublimation process must propagate through the layers of material. Therefore, the aim of this study is to examine the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate. Drying was carried out at freezing temperature of -55 ºC and the drying time was 7 hours. The research parameters observed were water losses, water content, texture, color, weight losses, and total soluble solids. The results showed that the exhaust gas heat in a vacuum freeze dryer can be used to optimize the water sublimation process. As a result, the drying process will be faster. The exhaust gas heat has a significantly effect on changes in water losses, moisture content, texture, weight losses, and total soluble solids, but does not significantly effect on the sample color. An efficient drying system was found in the exhaust gas heat (EGH) method because the quality parameters measured have better characteristics than a vacuum freeze dryer (VFD) method.
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13 August 2021

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It is my great pleasure to submit our paper entitled "**Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate**" to be considered for publication in your journal.

Urgency of this paper:
Vacuum freeze dryer has been proven to be an effective drying method to produce freeze-dried products with the best quality compared to other drying methods. However, the drying rate is very slow because the sublimation process must propagate through the layers of material. Our results show that the exhaust gas heat from a condenser to increase the vacuum freeze dryer can be used to optimize the water sublimation process. As a result, the drying process will be faster.

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As a corresponding author, we stated that:
1. That the work has not been published before
2. That it is not under consideration for publication elsewhere
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Please contact me if you need further information regarding the paper.

Thank you in advance for your cooperation.
Sincerely,

The corresponding author:
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Department of Agricultural Engineering, Faculty of Food Technology and Agroindustry,
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Declaration of Interest Statement

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Highlight

- Vacuum freeze-dryer utilizing condenser waste heat can optimize the water sublimation.
- Utilization of condenser waste heat can speed up the drying process.
- The EGH is more optimal than the CFD because the drying process is faster.
- The water loss in the EGH method is higher than the VFD method.
- The EGH method produces a higher WL value than the VFD method.

Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate

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Abstract

Vacuum freeze dryer is able to remove some of the moisture content of the material. However, the drying rate is very slow because the sublimation process must propagate through the layers of material. Therefore, the aim of this study is to examine the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate. Drying was carried out at freezing temperature of -55 ºC and the drying time was 7 hours. The research parameters observed were water losses, water content, texture, color, weight losses, and total soluble solids. The results showed that the exhaust gas heat in a vacuum freeze dryer can be used to optimize the water sublimation process. As a result, the drying process will be faster. The exhaust gas heat has a significantly effect on changes in water losses, moisture content, texture, weight losses, and total soluble solids, but does not significantly effect on the sample color. An efficient drying system was found in the exhaust gas heat (EGH) method because the quality parameters measured have better characteristics than a vacuum freeze dryer (VFD) method.

Keywords:

Color losses; Moisture content; Quality parameters; Total soluble solids; Water losses

1. Introduction

Vacuum freeze drying has been proven to be an effective drying method to produce freeze-dried products with the best quality compared to other drying methods [1-3]. The advantages of freeze-drying products are the texture structure that does not shrink [4], thus allowing very fast rehydration, high flavor retention because drying takes place at low temperatures, and the reconstitution of living cells in freeze-dried products remains high [5-6]. It has been used to obtain high quality freeze-dried products [7-8].

Even though vacuum freeze drying is the best drying process [9], it has several drawbacks, including a slow drying rate because the heat used for the sublimation process must be propagated through the layer of material [10]. The porous structure of the material has a very low conductivity that the transfer of heat to the surface of the material is also very low [11-12].

Heating analysis to increase the efficiency of heat propagation to the material layer has been carried out by Reyes et al. [13], however, the use of exhaust gas heat a condenser has not been disclosed. Freeze drying using additional heating has been reported by Xu et al. [14] that the high drying temperature greatly affects the sublimation rate.

Freeze-drying kinetics are influenced by the freezing rate and heat and mass transfer rates during the sublimation process [15-16]. The freezing process is one of the stages of freeze drying which requires high energy [17-18]. Therefore, the search for a more appropriate method is one of the most needed efforts by the food processing industry today [19].

Research on the process of utilizing heat sources from the condenser has not been widely reported. Therefore, this research is very important to explain the efficiency of exhaust gas heat utilization that drying can take place quickly and produce hygienic frozen products. Therefore, the aim of this study was to examine the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate.

2. Materials and methods

2.1. Materials

The materials used in the study were fresh cut jackfruit with a harvest age of 3 months. This fruit was obtained from farmers' gardens in Mataram, West Nusa Tenggara Province, Indonesia. The jackfruit was split, then the skin was separated and the seeds are removed. Another material were refrigerant R134A was obtained from a minimarket in Mataram City, West Nusa Tenggara, Indonesia.

2.2. Tools

The main equipment used were a vacuum freeze dryer (VFD) and a modified vacuum freeze dryer with the use of exhaust gas heat (EGH). The other equipment were a digital refractometer type DR301-95, moisture tester, color meter TES135 series, and texture analyzer Brookfield model CT3.

2.3. Drying procedure

The drying process was carried out with a freeze temperature of -55 ^{o}C and the drying time was 7 hours. Each treatment used a sample of 0.5 kg of fresh-cut jackfruit. The experiment was repeated 3 times.

2.4. Water Losses Analysis

Water losses (WL) describes the amount of water evaporated from the sample during the vacuum freeze drying process which can be calculated by equation (1) [20]:

$$WL = m_0 - m_t \frac{W_t}{W_0} \quad \text{(Eq. 1)}$$

Where, m_0 = sample moisture content at time 0 (%), m_t = sample moisture content at time t (%), W_0 = sample weight at time-0 (grams), W_t = sample weight at the time-t (gram).

2.5. Moisture content analysis

The moisture content of fresh-cut jackfruit was determined following the standard method of analysis [3]. Approximately 5 g of the sample was weighed into a can. The sample was heated to 50+1 °C until constant weight was reached, transferred to a desiccator, and was weighed soon after it had reached environment temperature. The moisture content was calculate by Equation (2):

$$M_c = \frac{a-b}{a} \times 100\% \quad \text{(Eq. 2)}$$

Where, M_c = moisture content (%), a = initial of moisture content (%), b = final of moisture content (%).

2.6. Texture analysis

The measurement of the sample texture of result from the vacuum freeze dryer was carried out using a texture analyzer. The result can be calculated using equation (3):

$$T = \frac{P}{A} \quad \text{(Eq. 3)}$$

Where, T = texture (N/mm^2), P = compressive force (N), and A = cross-sectional area (mm^2).

2.7. Color Analysis

The color of fresh-cut jackfruit was measurement using the Chroma meter type AT-13-04 Konica Minolta type CR-400. Color measurement using the Hunter L* a* b* color value system [21].

For lightness were defined as:

$$L* = L*_d - L*_f \quad \text{(Eq. 4)}$$

For redness were defined as:

$$a* = a*_d - a*_f \quad \text{(Eq. 5)}$$

For yellowness were defined as:

$$b* = b*_d - b*_f \quad \text{(Eq. 6)}$$

Where, L* = lightness (L* = 0 for black, L* = 100 for white), a* = green-red (a*<0 for green, a*>0 for red), b* = blue-yellow (b*<0 for blue, b*>0 for yellow), subscript 'f' refers to fresh samples and 'd' to the values of dried materials.

2.8. Weight losses analysis

The weight losses (WL) of the sample was measured before and after drying. Weight losses was calculated using the following equation (6) [22]:

$$WL = \frac{w_f - w_d}{w_f} 100\% \quad \text{(Eq. 7)}$$

Where, WL = weight losses (%), w_f = mass of sample before drying (grams), w_d = mass of sample after drying (gram).

2.9. Total soluble solids analysis

Total soluble solids (TSS) were measured using a digital refractometer type DR301-95. The TSS value is expressed in degrees of brix to indicate the dissolved sugar content in

the sample. Measurements were made by crushing 2 grams of jackfruit and then placing it on the refractometer sensor. Each treatment was repeated three times.

2.10. Data analysis

Analysis of variance (ANOVA) was used to determine the comparison of the results of the two types of dryers to the characteristics of frozen jackfruit. If the ANOVA table the F-count value is greater than F-crit, it means that there is a difference at the 5% significance level [23].

3. Results and discussions

3.1. Water losses

The data of WL in the sample during vacuum freeze-drying was shown in Figure 1. In this figure, it can be seen that the water losses in the EGH method is higher than that of the VFD method. This is due to the exhaust gas heat from the condenser as a heating source in the EGH method which can significantly accelerate the evaporation rate of water, whereas in the VFD method the water evaporation process only occurs because of the difference in pressure inside and outside the drying chamber. In line with this, Westerterp et al. [24] also stated that the process of evaporation of the water on the material during vacuum freeze drying occurs because there are difference in pressure on the surface of the material with environmental pressure and the longer the drying process, the more water was evaporated.

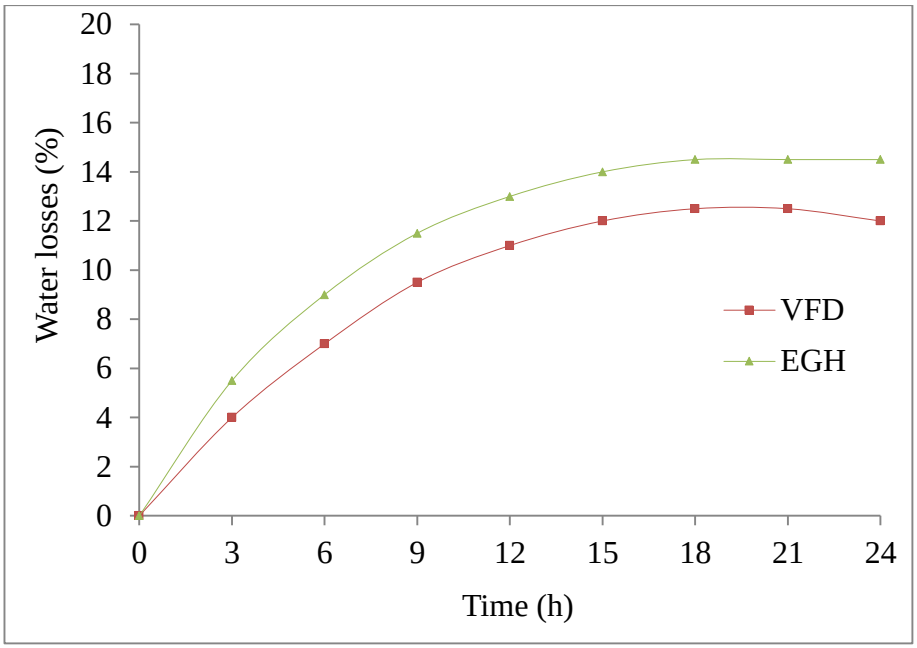

Figure 1. The water loss profile of fresh cut jackfruit during vacuum freeze drying

Based on the results of the analysis of variance, it was known that the use of different drying methods provides different WL data. The EGH method produces a higher WL value than the VFD method. This shows that the use of additional heat energy from the exhaust gas heat of the condenser has a significant effect on the WL value.

Other factors that influence water losses during drying are temperature and drying time. This result in line with the opinion of Mello et al. [25] that many factors influence to the water losses in the drying process, including drying temperature, air humidity, and air flow velocity. The greater the temperature difference between the heating medium and the drying material, the faster the heat transfer into the material, the rate faster of water losses from the dried material. The air humidity was inversely related to drying time. The higher the humidity, the longer the drying process will be. Meanwhile, the air flow rate was directly proportional to the drying time. The higher the air flow rate, the faster the drying process.

3.2. Moisture content

Figure 2 presents the curves of the reduction in moisture content of the two different drying methods used in this study. To reach the moisture content of the frozen product, these two methods have different times. The final moisture content in the EGH method is much lower than the VFD method. This indicates that the use of exhaust gas heat from a condenser as a heating source can significantly accelerate the rate of decreasing moisture content. These data indicate that one of the important characteristics of vacuum freeze-dryers was the efficient use of energy to reduce moisture content compared to other drying methods.

In Figure 2 it can also be seen that the final water content of the sample in the VFD method is higher, namely 15.95% than the final water content in the EGH method which is only 9.45%. This happens because there are additional heat energy from the condenser that the water sublimation process in the EGH method takes place faster than the VFD method. The same study have been described by Zhang et al. [26] that by utilizing secondary drying in a freeze dryer can optimize the sublimation process of water that the drying process takes place very quickly.

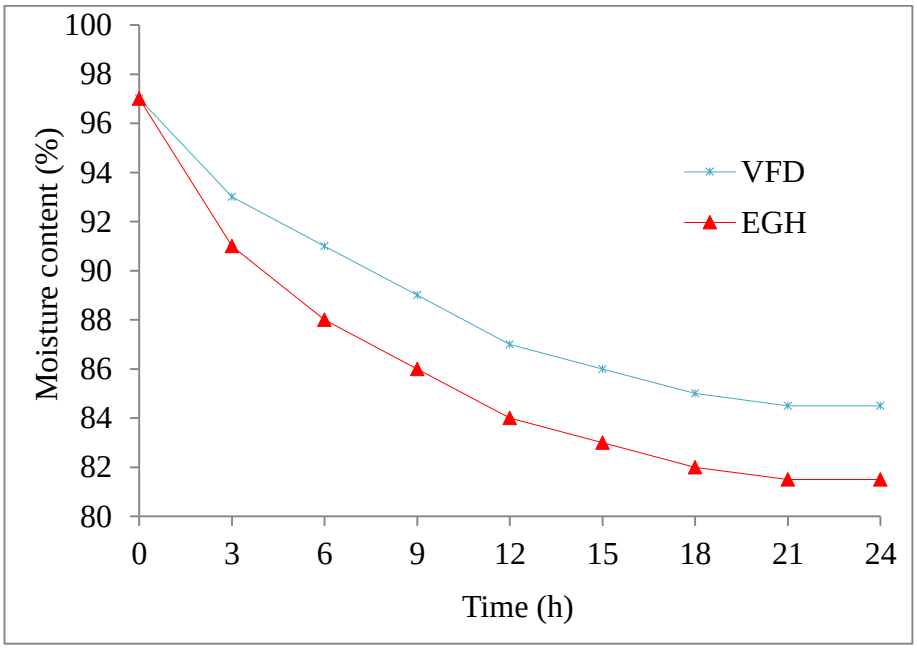

Figure 2. Curve of the rate of reduction in moisture content during vacuum freeze drying

The moisture content is a very important characteristic of freeze-dried food products because the moisture content can affect the appearance, texture, and taste of the product [27]. The moisture content also affects the freshness and shelf life of the product. The high water content can make bacteria, molds, and yeast easy to reproduce there will be changes in foodstuffs [28]. The vacuum freeze drying process can remove moisture content from the sample. The moisture content produced from the vacuum freeze dryer in this study has met the quality requirements of freeze-dried fruit products a maximum of 15% [5].

3.3. Texture

Vacuum freeze drying is a drying method that causes sublimation of the water vapor in the material that the structure of the material expands. The results showed that along with the drying time, the sample structure was changed from solid and chewy to a crunchy and porous texture. It can be seen clearly in Figure 3 that the samples dried using the EGH method produced a crunchier texture compared to the VFD method. It shows that the water vapor sublimation process that occurs in the EGH method causes the sample texture to be crunchy and easy to break. The factors causing the crisp texture of the sample are due to the low pressure in the drying chamber and the relatively high internal vapor pressure during the vacuum freeze drying process.

In the EGH method, the sample structure changes due to the effect of additional heating energy from the exhaust gas heat of the condenser, after which the sample ice crystals turn into gas and then evaporate. Compared to the EGH method, the sublimation process in the VFD method was a heating process with low temperatures that the sample ice crystals evaporate more slowly. It was what causes the shrinkage of the sample. The results of the same paper have been described by Liu et al. [29] that the shocking effect of the

freezing process then heated to a higher temperature is the change of ice to vapor that the texture of the sample is crispier and more porous.

The changing process of the sample texture has occurred shortly after drying, then evaporation of the water occurs and air bubbles form. Previous studies have reported by Zielinska et al. [30] that the vacuum freeze drying process can cause water evaporation, then the product expands and forms air cavities. The high and low texture value of a material according to Bozkir et al. [31] depending on the characteristics of the material, such as thickness, homogenization, and composition.

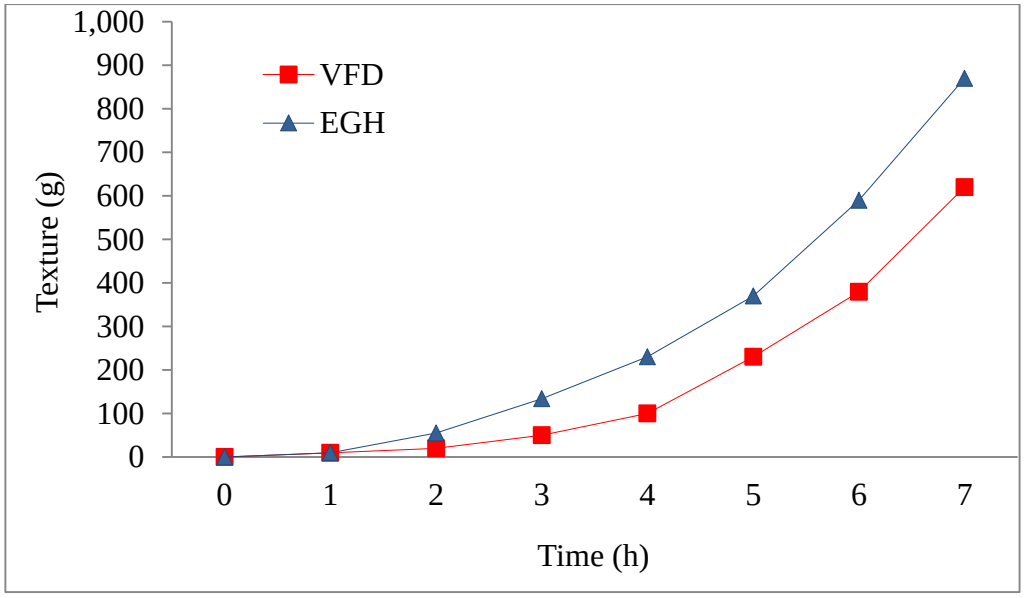

Figure 3. The texture profile of cut jackfruit during vacuum freeze dryer

The samples dried using the EGH method caused the water to come out of the fruit cell walls faster than the VFD method. This difference in the evaporation of high water content causes the texture structure of the sample to become more brittle and expand. This result in line with the study reported by Sobaszek et al. [32] that the vacuum freeze drying process resulted in water evaporation that the texture of the fruit would become hard.

In general, the texture of the jackfruit from vacuum freeze drying depends on the cell wall tissue. The texture change occurs in the vacuum freeze drying process because the sample has lost some of its moisture content. This view is supported by Pei et al. [33] who writes that the texture structure of the fruit depends on the cell wall tissue that in the vacuum freeze dryer there is a hardening on the surface of the material accompanied by changes in the size of the product texture.

3.4. Color

The graph of the color change of the fresh-cut jackfruit during vacuum freeze drying can be seen from the data in Table 1. From the Table 1 we can see that the type of dryer has no significant effect on lightness (L*), redness (a*), and yellowness (b*).

Table 1. Value of lightness (L*), redness (a*), and yellowness (b*) of the fresh-cut jackfruit during vacuum freeze drying.

Drying methods	**Color**		
	L*	a*	b*
Control	58.62 ± 0.55 [a]	5.75 ± 0.78 [a]	67.23 ± 0.14 [a]
EGH	57.23 ± 0.21 [a]	5.92 ± 0.14 [a]	68.37 ± 0.42 [a]
VFD	57.12 ± 0.34 [a]	5.42 ± 0.56 [a]	69.63 ± 0.12 [a]

Note: numbers followed by different letter notations in the same column show significant differences at the 0.05 significance level ($P<0.05$).

Based the data in Table 1, it is apparent that the change in the lightness color of the freeze-dried jackfruit tended to decrease during the drying process. The sample color

changes from shiny yellow become opaque yellow in both types of drying methods. The lightness value in the VFD method was lower (57.12) than the EGH method (57.23) although it was not significantly different. The lightness color shows a decreasing trend during drying in both methods. This is caused by a biological reaction, resulting in an enzymatic process that causes the color of the sample to decrease in brightness. This result is in accordance with Keutgen and Pawelzik [34] have reported that low temperatures in the vacuum freeze drying process have not been able to activate the polyphenolic enzymes in the sample and the enzymes can still be active at temperatures as low as -73 ºC, although with very low reaction rates.

The redness and yellowness color intensity did not change during the vacuum freeze drying process. The sample color before and after drying did not change significantly. Several investigators have also reported that the use of a vacuum freeze dryer did not result in color changes in the samples [35]. Sample color change usually occurs at high drying temperatures [36]. The same analogy has been explained by Falah et al. [37] that a significant change in sample color during high temperature drying can occur, but the change is not significant at cold temperature.

3.5. Weight losses (WL)

The results of the WL calculation of fresh-cut jackfruit during vacuum freeze drying are shown in Table 2. At the beginning of the drying process, the WL occurs very rapidly until 6th hour, then slowly until the end of drying. After reaching the saturated condition, the sample WL no longer changes. Table 2 also shows that the WL is higher in the EGH method compared to the VFD method.

Table 2. Average of WL value of fresh cut jackfruit from vacuum freeze drying

Drying time (hour)	Weight losses (g)

	EGH	VFD
1	0.00 [a]	0.00 [a]
2	7.29 [b]	6.53 [b]
3	10.12 [c]	9.41 [c]
4	15.13 [d]	13.75 [d]
5	23.14 [e]	18.65 [e]
6	35.67 [f]	29.42 [f]
7	37.32 [f]	31.82 [g]

Note: numbers followed by different letter notations in the same column show significant differences at the 0.05 significance level ($P < 0.05$).

From the table above we can see that the samples dried in the EGH method had a final WL of 37.32 g, while those dried in the VFD method had a final WL of 31.82 g. These data indicate that the use of exhaust gas heat form a condenser in the EGH method has a significant effect on reducing WL of fresh-cut jackfruit

The duration of the drying process also has a significant effect on the WL of fresh-cut jackfruit. The long drying process can trigger an increase in the percentage of WL in the sample. The same it cases has been reported by Singh and Khan [38] that WL is generally affected by the evaporation of moisture during drying due to the breakdown of organic compounds into inorganic compounds, namely compounds are oxidized to CO_2 and absorb O_2, then reduced to H_2O.

3.6. Total Soluble Solids (TSS)

The results of measuring the TSS value of fresh-cut jackfruit from vacuum freeze drying are shown in Table 3.

Table 3. Average TSS value of fresh-cut jackfruit from vacuum freeze drying

Drying time (hour)	Total soluble solids (°Brix)	
	EGH	VFD
1	8.04 [a]	8.04 [a]
2	10.19 [b]	09.83 [b]
3	11.23 [c]	10.31 [c]
4	12.33 [d]	11.67 [d]
5	14.46 [e]	13.55 [e]
6	15.67 [f]	14.92 [f]
7	17.32 [g]	16.22 [g]

Note: numbers followed by different letter notations in the same column show significant differences at the 0.05 significance level ($P<0.05$).

The data in Table 3 shows that during drying, there was an increase in the TSS value in the sample due to the respiration and transpiration processes that were still ongoing even though the fruit had been harvested. The increase in TSS value is also accelerated by vacuum freeze drying. The TSS value was higher in the EGH method than the VFD method. This is thought to be due to the influence of the exhaust gas heat from a condenser which triggers the carbohydrate content to become sugar levels. A similar thing has been reported by [39] that immature fruit stores a lot of carbohydrates in the form of starch and during the process towards maturity the content will turn into sugar [40]. According to Nguyen and Chuyen

[41], fruits at advanced maturity levels have the highest TSS content, due to hydrolysis of starch to sugar.

Total soluble solids are the combination of all inorganic and organic substances present in food. Based on the data in Table 3, it can be seen that at the beginning of drying the TSS value is still low. With the length of drying time, the TSS value tended to be higher in the two methods, but had different values. The difference in TSS value is thought to be due to the difference in temperature used between the EGH and VFD methods. The driving force of the exhaust gas heat from condenser in the EGH method causes some of the water to evaporate faster. In addition, the faster sublimation process can open larger pores of the sample surface. When the pores of the sample surface as the permeability membrane opens wider, the amount of water evaporating from the material will also increase.

4. Conclusions

The exhaust gas heat from a condenser can be used to accelerate the sublimation process during the vacuum freeze drying process, the drying process can take place faster. The results of this study have proven that the use of exhaust gas heat from a condenser has a significant effect on the parameters of water losses, moisture content, texture, weight losses, and total dissolved solids, but it does not affect the sample color.

The new findings provide a better scientific understanding of the vacuum freeze drying process. This is relevant for better process understanding of vacuum freeze drying and application design for food products. Further research is needed to study the effect of freeze drying time on the quality of materials sensitive to changes in physiological activity.

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Conflicts of Interest

The authors declared no conflict of interest.

References

[1] Z. Shaozhi, L. Jielin, C. Guangming and W. Qin, "Thermodynamic analysis of a freeze-dryer utilizing hygroscopic solution," *Drying Technology*, 2017.

[2] W. M. Obeidat, E. Sahni, W. Kessler and M. Pikal, "Development of a Mini-Freeze Dryer for Material-Sparing Laboratory Processing with Representative Product Temperature History," *AAPS PharmSciTech,* vol. 19, no. 12, pp. 599-609, 2017.

[3] Ansar, Nazaruddin and A. D. Azis, "Effect of vacuum freeze-drying condition and maltodextrin on the physical and sensory characteristics of passion fruit (Passiflora edulis sims) extract," in *IOP Conference Series: Earth and Environmental Science*, Makassar, 2019.

[4] H. T. Ngo, S. Tojo, T. Ban and T. Chosa, "Effects of Prior Freezing Conditions on the Quality of Blueberries in a Freeze-Drying Process," *Transactions of the ASABE,* vol. 60, no. 4, pp. 1369-1377, 2017.

[5] Ansar, Nazaruddin and A. D. Azis, "New frozen product development from strawberries (Fragaria Ananassa Duch.)," *Heliyon,* vol. 6, no. 9, p. e05118, 2020.

[6] V. B. Nguyen, D. H. Nguyen and H. V. Nguyen, "Combination effects of calcium chloride and nano-chitosan on the postharvest quality of strawberry (Fragaria x ananassa Duch.)," *Postharvest Biology and Technology*, vol. 162, no. 111103, 2020.

[7] B. Schulze, E. M. Hubbermann and K. Schwarz, "Stability of quercetin derivatives in vacuum impregnated apple slices after drying (microwave vacuum drying, air drying, freeze drying) and storage," *LWT-Food Science and Technology,* vol. 57, no. 1, pp. 426-433, 2014.

[8] K. Sun, R. Li, W. Jiang, Y. Sun and H. Li, "Comparison of three-dimensional printing and vacuum freeze-dried techniques for fabricating composite scaffolds," *Biochemical and Biophysical Research Communications,* vol. 477, no. 4, pp. 1085-1091, 2016.

[9] Y. M. Chew and V. E. King, "Microwave Drying of Pitaya (Hylocereus) Peel and the Effects Compared with Hot-Air and Freeze-drying," *Transactions of the ASABE,* vol. 62, no. 4, pp. 919-928, 2019.

[10] A. Khampakool, S. Soisungwan and S. H. Park, "Potential application of infrared assisted freeze drying (IRAFD) for banana snacks: Drying kinetics, energy consumption, and texture," *LWT-Food Science and Technology,* 2018.

[11] L. J. Wang and W. Sun, "Numerical analysis of the three–dimensional mass and heat transfer with inner moisture evaporation in porous cooked meat joints during vacuum cooling," *Transactions of the ASAE,* vol. 46, no. 1, pp. 107-115, 2003.

[12] A. Lakatos, A. Csik and I. Csarnovics, "Experimental verification of thermal properties of the aerogel blanket," *Case Studies in Thermal Engineering,* vol. 21, p. 100966, 2021.

[13] V. Reyes, R. Bubnovich, M. Bustos, R. Vásquez, R. Vega and E. Scheuermann , "Comparative study of different process conditions of freeze drying of ‘Murtilla’ berry," *Drying Technology: An International Journal, 28:12, 1416-1425,* vol. 28, no. 12, pp. 1416-1425, 2010.

[14] Y. Xu, M. Zhang, A. S. Mujumdar, X. Duan and S. Jin-cai, "A two-stage vacuum freeze and convective air drying method for strawberries," *Drying Technology: An International Journal,* vol. 24, no. 8, pp. 1019-1023, 2006.

[15] X. F. Wu, M. Zhang, Y. Ye and D. Yu, "Influence of ultrasonic pretreatments on drying kinetics and quality attributes of sweet potato slices in infrared freeze drying (IRFD)," *LWT,* vol. 131, p. 109801, 2020.

[16] H. Selvnes, Y. Allouche, R. I. Manescu and A. Hafner, "Review on cold thermal energy storage applied to refrigeration systems using phase change materials," *Thermal Science and Engineering Progress,* vol. 22, p. 100807, 2021.

[17] G. Assegehegn, E. B. Fuente, J. M. Franco and C. Gallegos, "The Importance of Understanding the Freezing Step and Its Impact on Freeze-Drying Process Performance," *Journal of Pharmaceutical Sciences,* vol. 108, no. 4, pp. 1378-1395, 2019.

[18] M. Shehadi, "Optimizing solar cooling systems," *Case Studies in Thermal Engineering,* vol. 21, p. 100663, 2020.

[19] A. U. Shingisov and R. S. Alibekov, "Analysis of the moisture evaporation process during vacuum freeze-drying of koumiss and shubat," *Heat and Mass Transfer,* vol. 53, no. 5, p. 1571–1578, 2017.

[20] J. S. Souza, M. D. Medeiros, M. A. Magalhaes and F. N. Fernandes, "Optimization of osmotic dehydration of tomatoes in a ternary system followed by air-drying," *Journal of Food Engineering,* vol. 83, no. 1, pp. 501-509, 2007.

[21] J. Chapman, A. Elbourne, V. K. Truong, L. Newman, S. Gangadoo, P. Rajapaksha Pathirannahalage and D. Cozzolino, "Sensomics - from conventional to functional NIR spectroscopy-shining light over the aroma and taste of foods," *Trends in Food Science & Technology,* 2019.

[22] S. M. Goni and V. O. Salvadori, "Prediction of cooking times and weight losses during meat roasting," *Journal of Food Engineering,* vol. 100, no. 1, pp. 1-11, 2010.

[23] Ansar, Nazaruddin and A. D. Azis, "Caking mechanisms of passion fruit powder during storage," *International Journal of Innovation, Creatifity, and Change,* vol. 13, no. 2, pp. 618-628, 2020.

[24] K. Westerterp, G. Plasqui and A. Goris, "Water loss as a function of energy intake, physical activity and season," *British Journal of Nutrition,* vol. 93, no. 2, pp. 199-203, 2005.

[25] R. E. Mello, A. Fontana, A. Mulet, J. Luiz, G. Correa and J. A. Cárcel, "Ultrasound-assisted drying of orange peel in atmospheric freeze-dryer and convective dryer operated at moderate temperature," *Drying Technology,* vol. 38, no. 1, pp. 259-267, 2020.

[26] C. Zhang, X. Bu, J. He, C. Liu, G. Lin and J. Miao, "Simulation of evaporation and sublimation process in porous plate water sublimator based on a reduced CFD model," *International Journal of Heat and Mass Transfer,* vol. 154, p. 119787, 2020.

[27] X. Xu, Q. Li, Y. Lai, W. Pang and R. Zhang, "Effect of moisture content on mechanical and damage behavior of frozen loess under triaxial condition along with different confining pressures," *Cold Regions Science and Technology,* vol. 157, pp. 110-118, 2019.

[28] V. I. Aksenov, S. G. Gevorkyan and V. V. Doroshin, "Dependence of Strength and Physical Properties of Frozen Sands on Moisture Content," *Soil Mechanics and Foundation Engineering,* vol. 54, p. 420–424, 2018.

[29] B. Liu, Y. Zhao, Y. Jia and J. Liu, "Heating Drives DNA to Hydrophobic Regions While Freezing Drives DNA to Hydrophilic Regions of Graphene Oxide for Highly

Robust Biosensors," *Journal of the American Chemical Society,* vol. 142, no. 34, pp. 14702-14709, 2020.

[30] M. Zielinska, M. Markowski and D. Zielinska, "The effect of freezing on the hot air and microwave vacuum drying kinetics and texture of whole cranberries," *Drying Technology,* vol. 37, no. 13, pp. 1714-1730, 2019.

[31] H. Bozkir, Y. Tekgül and E. S. Erten, "Effects of tray drying, vacuum infrared drying, and vacuum microwave drying techniques on quality characteristics and aroma profile of orange peels," *Journal of Food Process Engineering,* vol. 44, no. 1, p. e13611, 2021.

[32] P. Sobaszek, R. Różyło, L. Dziki, U. Gawlik-Dziki, B. Biernacka and M. Panasiewicz, "Evaluation of Color, Texture, Sensory and Antioxidant Properties of Gels Composed of Freeze-Dried Maqui Berries and Agave Sugar," *Processes,* vol. 8, no. 10, p. 1294, 2020.

[33] F. Pei, W. Yang, Y. Shi, Y. Sun, A. M. Mariga, L. Y. Zhao, Y. Fang, N. Ma, X. An and Q. Hu, "Comparison of Freeze-Drying with Three Different Combinations of Drying Methods and Their Influence on Colour, Texture, Microstructure and Nutrient Retention of Button Mushroom (Agaricus bisporus) Slices," *Technology,* vol. 7, p. 702–710, 2014.

[34] A. J. Keutgen and E. Pawelzik, "Qualit yand nutrition value of strawberry fruit under longterm salt stress," *Journal Food Chemistry,* vol. 107, no. 2, pp. 1413-1420, 2007.

[35] X. Q. Yue, Z. Y. Shang, J. Y. Yang, L. Huang and Y. Q. Wang, "A smart data-driven rapid method to recognize the strawberry maturity," *Information Processing in Agriculture,* 2019.

[36] Y. Zhang and S. Barringe, "Effect of hydrocolloids, sugar, and citric acid on strawberry volatiles in a gummy candy," *J Food Process Preserv,* p. 00:e13327., 2017.

[37] M. A. Falah, P. Yuliastuti, R. Hanifah, P. Saroyo and Jumeri, "Quality of fresh strawberry (fragaria sp cv. holibert) from Ketep Magelang Central Java and its storage in tropical environment," *Jurnal Agro Industri,* vol. 8, no. 1, pp. 1-10, 2018.

[38] Z. Singh and A. S. Khan, "Physiology of plum fruit ripening," *Stewart Postharvest Rev.,* vol. 2, no. 1, pp. 3-12, 2010.

[39] L. Rydzak, Z. Kobus, R. Nadulski, K. Wilczyński, A. Pecyna, F. Santoro, A. Sagan, A. Starek-Wójcick and M. Krzywicka, "Analysis of Selected Physicochemical Properties of Commercial Apple Juices," *Processes,* vol. 8, p. 1457, 2020.

[40] M. Yusufe, A. Mohammed and N. Satheesh, "Effect of duration and drying temperature on characteristics of dried tomato (Lycopersicon esculentum L.) cochoro variety," *Journal of Food Technology*, vol. 21, no. 1, pp. 41-50, 2017.

[41] Q. V. Nguyen and H. V. Chuyen, "Processing of Herbal Tea from Roselle (Hibiscus sabdariffa L.): Effects of Drying Temperature and Brewing Conditions on Total Soluble Solid, Phenolic Content, Antioxidant Capacity and Sensory Quality," *Beverages*, vol. 6, no. 1, pp. 1-11, 2020.

320

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Ansar - <ansar72@unram.ac.id>

Submission Confirmation for Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate

1 pesan

Results in Engineering <em@editorialmanager.com> 13 Agustus 2021 21.43
Balas Ke: Results in Engineering <support@elsevier.com>
Kepada: Ansar Ansar <ansar72@unram.ac.id>

Dear Dr. Ansar,

Your submission entitled "Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate" has been received by journal Results in Engineering

You will be able to check on the progress of your paper by logging on to Editorial Manager as an author. The URL is https://www.editorialmanager.com/rineng/.

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Thank you for submitting your work to this journal.

Kind regards,

Results in Engineering

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Submission Confirmation for RINENG-D-21-00242R1

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Results in Engineering <em@editorialmanager.com> 15 November 2021 07.37
Balas Ke: Results in Engineering <support@elsevier.com>
Kepada: Ansar Ansar <ansar72@unram.ac.id>

Ref.: Ms. No. RINENG-D-21-00242R1
Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate

Dear Dr. Ansar,

Results in Engineering has received your revised submission.

You may check the status of your manuscript by logging onto Editorial Manager at (https://www.editorialmanager.com/rineng/).

Kind regards,

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Ansar - <ansar72@unram.ac.id>

Your Submission

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Results in Engineering <em@editorialmanager.com> 10 November 2021 15.41
Balas Ke: Results in Engineering <support@elsevier.com>
Kepada: Ansar Ansar <ansar72@unram.ac.id>

CC: ezio.mancaruso@stems.cnr.it

Ref.: Ms. No. RINENG-D-21-00242
Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate
Results in Engineering

Dear Dr. Ansar,

Reviewers have now commented on your paper. You will see that they are advising that you revise your manuscript. If you are prepared to undertake the work required, I would be pleased to reconsider my decision.

For your guidance, reviewers' comments are appended below.

If you decide to revise the work, please submit a list of changes or a rebuttal against each point which is being raised when you submit the revised manuscript.

Please resubmit your revised manuscript by Dec 01, 2021.

To submit a revision, go to https://www.editorialmanager.com/rineng/ and log in as an Author. You will see a menu item call Submission Needing Revision. You will find your submission record there.

Yours sincerely

Antonio García, Ph.D
Editor in Chief
Results in Engineering

Comments from the Editors and Reviewers:

Your article would appear to be of interest to a wide engineering research community and in order to promote its visibility even more, may we recommend that you view the past published articles in Results in Engineering and if you find any relevant publications, CITE the article from this Journal.

Dear Dr Ansar Ansar,

Thank you for submitting your manuscript to Results in Engineering.

We have completed the review of your manuscript and a summary of comments is appended below this message.

Overall, the reviewers recommend a reconsideration of your paper following minor revision.

We invite you to resubmit your manuscript after addressing all reviewer comments.

When resubmitting your manuscript, please carefully consider all issues mentioned in the reviewer’s comments, outline every change made point by point, and provide suitable rebuttals for any comments not addressed.

Yours sincerely,

Ezio Mancaruso
Associate Editor

Results in Engineering

Reviewer 1: Review on "Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate" by Ansar et al.
Manuscript RINENG-D-21-00242

A- General Comments
The paper in hand concerns an examination of the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate. Drying was carried out at freezing temperature of -55 ºC and the drying time was 7 hours. The research parameters observed were water losses, water content, texture, color, weight losses, and total soluble solids. Particularly, it was shown by the authors that the exhaust gas heat in a vacuum freeze dryer can be used to optimize the water sublimation process.

The topic of the paper is interesting, within the scope of the journal, and worthy of investigation. The originality of the work is acceptable. However, the manuscript deserves major revisions and proofreading. I suggest that authors take into account the comments and questions below before it can be considered for publication in Results in Engineering.

B- Detailed Comments and questions

Title
The title is clear and consistent. However, it can be shortened.

Abstract
1- Results at the end of the abstract should be shortened by giving more explicit results with numbers.

Highlights
1- Highlights should be more explicit also with numbers.

Keywords
Keywords are ok.

1- Introduction
1- The literature review should be extended;
2- The originality of the work should be more highlighted especially with respect to other recently published papers on the matter and particularly those published in Results in Engineering if possible;

2- Materials and methods
1- References to the different equations presented should be provided;
2- This section lacks of illustrative figures and more elaborations on the connection among the different ideas (sub-sections).

3- Results and discussions
1- Physical analysis are to be added to this section.

4. Conclusions
Based on the results obtained, recommendations in terms of applications should be provided.

5- References
References relevant to Results in Engineering are to be added.

Reviewer 2:
It would be useful to present a scheme of the condenser exhaust heat drying system proposed.

Reviewer 3: Dear Author(s)

After an exhaustive revision, the manuscript is Minor revision. In general, the study is closely connected to the journal's objectives. The study is very interesting. The English is good. The introduction is complete, very detailed. The section of

materials and methods is very complete. The authors need to make changes and modify parts in the manuscript, mainly in the section "Results and Discussions".

In the following pages, I give a detailed revision of the manuscript.

Best regards

General comments
** The authors are misspelled **

ABSTRACT
The abstract is good. However, the authors need to add more numerical results.

1. INTRODUCTION
The introduction is very clear, with good English. The introduction is updated, with references of 2021.

Lines 30-35. The authors need to add examples, with references.

Lines 41-44. The authors should enhance the lines, i.e., the authors need to add more information.

2. MATERIALS AND METHODS
General comments
This section is clear. The English is good. The authors must add a Figure that represents all the methodology in the section Materials and Methods. This Figure will help to understand the methodology. Some observations:

Line 60. Another material were refrigerant R134A was obtained from a minimarket in Mataram City
The authors need to rewrite the line.

Line 92. 2.6. Texture analysis
The authors need to add the type(s) of test(s).

3. RESULTS AND DISCUSSIONS
"Results and Discussion" is characterized by a description of the results, the explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. My observations:

3.1. Water losses
This subsection is very complete. The authors should be more specific in the description (numbers) of the results, and in addition, the authors need to add the error bars in the Figure 1. The authors add the explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies.

3.2. Moisture content
This subsection is very complete. The authors should be more specific in the description (numbers) of the results, and in addition, the authors need to add the error bars in the Figure 1. The authors add the explication of the results, but the authors need to add references (Lines 159-162). The subsection has comparison with other studies, and explication (discussion) of the results obtained with respect to other studies.

There is no comparison with other studies, and explication (discussion) of the results obtained with respect to other studies.

Lines 165-166. Please, add more details.
Lines 167-169. Please, add more details.

3.3. Texture
The author needs to add more details on the results. There is explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies.
However, the authors need to add information on the texture test.

3.4. Color
It would be interesting if the authors added images of the samples before and after the treatment.

3.5. Weight losses (WL)
Table 2. The authors need to add the statistical differences.

3.6. Total Soluble Solids (TSS)

Table 3. The authors need to add the statistical differences.
Lines 294-299. What are the references?

4. Conclusions
The conclusions are good, and it has concordance with the results.

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POINT-BY-POINT RESPONSES TO REVIEWER'S COMMENTS

Reviewer #1a: The title is clear and consistent. However, it can be shortened.

Author response #1a: I think this title sentence is already short, only 11 words.

Reviewer #1b: Results at the end of the abstract should be shortened by giving more explicit results with numbers.

Author response #1b: It is has been revised based on suggestions (page 1 lines 23-25).

Reviewer #1c: Highlights should be more explicit also with numbers.

Author response #1c: It is has been revised based on suggestions.

Reviewer #1d: The literature review should be extended.

Author response #1d: It is has been revised based on suggestions.

Reviewer #1e: The originality of the work should be more highlighted especially with respect to other recently published papers on the matter and particularly those published in Results in Engineering if possible.

Author response #1e: It is has been revised based on suggestions (page 2 line 49 and page 9 line 179).

M. J. Al-Kheetan, M. M. Rahman, S. H. Ghaffar, M. Al-Tarawneh and Y. S. Jweihan, "Comprehensive investigation of the long-term performance of internally integrated concrete pavement with sodium acetate," *Results in Engineering*, vol. 6, p. 100110, 2020.

Z. M. Salisu, S. U. Ishiaku, D. Abdullahi, M. K. Yakubu and B. H. Diya'uddeen, "Development of kenaf shive bio–mop via surface deposit technique for water remediation from crude oil spill contamination," *Results in Engineering*, vol. 3, p. 100020, 2019.

Reviewer #1f: References to the different equations presented should be provided.

Author response #1f: It is has been revised based on suggestions (page 4 lines 87 and 94).

Reviewer #1g: This section lacks of illustrative figures and more elaborations on the connection among the different ideas (sub-sections).

Author response #1g: The main equipment used were a vacuum freeze dryer (VFD) and a modified vacuum freeze dryer with the use of exhaust gas heat (EGH) showed was in Figure 1 (page 4 line 70).

Reviewer #1h: Results and discussions. Physical analysis are to be added to this section.

Author response #1h: It is has been revised based on suggestions (page 9 lines 183- 219).

Reviewer #1i: Conclusions. Based on the results obtained, recommendations in terms of applications should be provided.

Author response #1i: It is has been revised based on suggestions (page 16 lines 308-310).

Reviewer #1j: References relevant to Results in Engineering are to be added.

Author response #1j: It is has been revised based on suggestions (page 2 line 49 and page 9 line 179).

Reviewer #2: It would be useful to present a scheme of the condenser exhaust heat drying system proposed.

Author response #2: The schematic of the condenser exhaust heat drying system has been added in Figure 1 (page 4 line 70).

Reviewer #3a: The abstract is good. However, the authors need to add more numerical results.

Author response #3a: It is has been revised based on suggestions (page 1 lines 23-25).

Reviewer #3b: The introduction is very clear, with good English. The introduction is updated, with references of 2021.

Author response #3b: Reference citations for 2021 are at numbers 12 and 16 (page 2 line 40 and 46).

Reviewer #3c: Texture analysis. The authors need to add the type(s) of test(s).

Author response #3c: It is has been revised based on suggestions (page 5 lines 94-96).

Reviewer #3d: Water losses. This subsection is very complete. The authors should be more specific in the description (numbers) of the results, and in addition, the authors need to add the error bars in the Figure 1. The authors add the explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies.

Author response #3d: It is has been revised based on suggestions (page 7 lines 146-147).

Reviewer #3e: Moisture content. This subsection is very complete. The authors should be more specific in the description (numbers) of the results, and in addition, the authors need to add the error bars in the Figure 1. The authors add the explication of the results, but the authors need to add references (Lines 159-162). The subsection has comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. There is no comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. Lines 165-166. Please, add more details. Lines 167-169. Please, add more details.

Author response #3e: It is has been revised based on suggestions (page 8 lines 166-168).

Reviewer #3f: Texture. The author needs to add more details on the results. There is explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. However, the authors need to add information on the texture test.

Author response #3f: It is has been revised based on suggestions (page 8 lines 186-188).

Reviewer #3g: Color. It would be interesting if the authors added images of the samples before and after the treatment.

Author response #3g: Images of fresh jackfruit pieces were added before and after vacuum freeze drying (Figure 6) (page 12 line 229).

Reviewer #3h: Weight losses (WL). Table 2. The authors need to add the statistical differences.

Author response #3h: It is has been revised based on suggestions (page 14 lines 266-269).

Reviewer #3i: Total Soluble Solids (TSS). Lines 294-299. What are the references?

Author response #3i: Reference has been added based on suggestions (page 16 line 303).

Reviewer #3j: Conclusions. The conclusions are good, and it has concordance with the results.

Author response #3j: Thank you very much for your attention.

Results in Engineering

Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate

--Manuscript Draft--

Manuscript Number:	RINENG-D-21-00242R1
Full Title:	Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate
Short Title:	Using of Exhaust Gas Heat from a Condenser
Article Type:	Research paper
Section/Category:	Energy
Keywords:	Color losses; Moisture content; Quality parameters; Total soluble solids; Water losses
Corresponding Author:	Ansar Ansar, Ph.D. Mataram University: Universitas Mataram Mataram, West Nusa Tenggara INDONESIA
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First Author:	Ansar A, Ph.D.
First Author Secondary Information:	
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	Sukmawaty
	Murad
	Maria Ulfa
	Atri Dewi Azis
Order of Authors Secondary Information:	
Abstract:	Vacuum freeze dryer is able to remove some of the moisture content of the material. However, the drying rate is very slow because the sublimation process must propagate through the layers of material. Therefore, the aim of this study is to examine the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate. Drying was carried out at freezing temperature of -55 ºC and the drying time was 7 hours. The research parameters observed were water losses, water content, texture, color, weight losses, and total soluble solids. The results showed that the exhaust gas heat in a vacuum freeze dryer can be used to optimize the water sublimation process. As a result, the drying process will be faster. The exhaust gas heat has a significantly effect on changes in water losses, moisture content, texture, weight losses, and total soluble solids, but does not significantly effect on the sample color. The drying system in the exhaust gas heat (EGH) method was more efficient because the final moisture content of the sample was 9.45% lower than the vacuum freeze dryer (VFD) method, which was 15.95%.
Suggested Reviewers:	Boris Golman Suranaree University of Technology golmanboris@gmail.com He has published article same with my manuscript
	Seishu Tojo Tokyo University of Agriculture and Technology: Tokyo Noko Daigaku tojo@cc.tuat.ac.jp

	He has published article same with my manuscript
	V. An-Erl King National Chung Hsing University aeking@dragon.nchu.edu.ta He has done a lot of research similar to mine
	Håkon Selvnes Norwegian University of Science and Technology Faculty of Science and Technology: Norges teknisk-naturvitenskapelige universitet Fakultet for naturvitenskap hakon.selvnes@ntnu.no He has published article same with my manuscript
Response to Reviewers:	POINT-BY-POINT RESPONSES TO REVIEWER'S COMMENTS Reviewer #1a: The title is clear and consistent. However, it can be shortened. Author response #1a: I think this title sentence is already short, only 11 words. Reviewer #1b: Results at the end of the abstract should be shortened by giving more explicit results with numbers. Author response #1b: It is has been revised based on suggestions (page 1 lines 23-25). Reviewer #1c: Highlights should be more explicit also with numbers. Author response #1c: It is has been revised based on suggestions. Reviewer #1d: The literature review should be extended. Author response #1d: It is has been revised based on suggestions. Reviewer #1e: The originality of the work should be more highlighted especially with respect to other recently published papers on the matter and particularly those published in Results in Engineering if possible. Author response #1e: It is has been revised based on suggestions (page 2 line 49 and page 9 line 179). M. J. Al-Kheetan, M. M. Rahman, S. H. Ghaffar, M. Al-Tarawneh and Y. S. Jweihan, "Comprehensive investigation of the long-term performance of internally integrated concrete pavement with sodium acetate," Results in Engineering, vol. 6, p. 100110, 2020. Z. M. Salisu, S. U. Ishiaku, D. Abdullahi, M. K. Yakubu and B. H. Diya'uddeen, "Development of kenaf shive bio–mop via surface deposit technique for water remediation from crude oil spill contamination," Results in Engineering, vol. 3, p. 100020, 2019. Reviewer #1f: References to the different equations presented should be provided. Author response #1f: It is has been revised based on suggestions (page 4 lines 87 and 94). Reviewer #1g: This section lacks of illustrative figures and more elaborations on the connection among the different ideas (sub-sections). Author response #1g: The main equipment used were a vacuum freeze dryer (VFD) and a modified vacuum freeze dryer with the use of exhaust gas heat (EGH) showed was in Figure 1 (page 4 line 70). Reviewer #1h: Results and discussions. Physical analysis are to be added to this section. Author response #1h: It is has been revised based on suggestions (page 9 lines 183-219). Reviewer #1i: Conclusions. Based on the results obtained, recommendations in terms of applications should be provided. Author response #1i: It is has been revised based on suggestions (page 16 lines 308-310). Reviewer #1j: References relevant to Results in Engineering are to be added. Author response #1j: It is has been revised based on suggestions (page 2 line 49 and page 9 line 179). Reviewer #2: It would be useful to present a scheme of the condenser exhaust heat drying system proposed. Author response #2: The schematic of the condenser exhaust heat drying system has been added in Figure 1 (page 4 line 70). Reviewer #3a: The abstract is good. However, the authors need to add more numerical results. Author response #3a: It is has been revised based on suggestions (page 1 lines 23-25). Reviewer #3b: The introduction is very clear, with good English. The introduction is

	updated, with references of 2021. Author response #3b: Reference citations for 2021 are at numbers 12 and 16 (page 2 line 40 and 46). Reviewer #3c: Texture analysis. The authors need to add the type(s) of test(s). Author response #3c: It is has been revised based on suggestions (page 5 lines 94-96). Reviewer #3d: Water losses. This subsection is very complete. The authors should be more specific in the description (numbers) of the results, and in addition, the authors need to add the error bars in the Figure 1. The authors add the explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. Author response #3d: It is has been revised based on suggestions (page 7 lines 146-147). Reviewer #3e: Moisture content. This subsection is very complete. The authors should be more specific in the description (numbers) of the results, and in addition, the authors need to add the error bars in the Figure 1. The authors add the explication of the results, but the authors need to add references (Lines 159-162). The subsection has comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. There is no comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. Lines 165-166. Please, add more details. Lines 167-169. Please, add more details. Author response #3e: It is has been revised based on suggestions (page 8 lines 166-168). Reviewer #3f: Texture. The author needs to add more details on the results. There is explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. However, the authors need to add information on the texture test. Author response #3f: It is has been revised based on suggestions (page 8 lines 186-188). Reviewer #3g: Color. It would be interesting if the authors added images of the samples before and after the treatment. Author response #3g: Images of fresh jackfruit pieces were added before and after vacuum freeze drying (Figure 6) (page 12 line 229). Reviewer #3h: Weight losses (WL). Table 2. The authors need to add the statistical differences. Author response #3h: It is has been revised based on suggestions (page 14 lines 266-269). Reviewer #3i: Total Soluble Solids (TSS). Lines 294-299. What are the references? Author response #3i: Reference has been added based on suggestions (page 16 line 303). Reviewer #3j: Conclusions. The conclusions are good, and it has concordance with the results. Author response #3j: Thank you very much for your attention.
Additional Information:	
Question	**Response**
Results in Engineering is an open access journal which charges an Article Publishing Charge (APC) to cover the cost associated with the publication process. All articles published Open Access will be immediately and permanently free on ScienceDirect for users to read, download, and use in accordance with the author's selected Creative Commons user license. **As an Author, I acknowledge I need to**	Yes

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Result in Engineering is an open access journal which charges an Article Publishing Charge (APC) to cover the cost associated with the publication process. All articles published Open Access will be immediately and permanently free on ScienceDirect for users to read, download, and use in accordance with the author's selected Creative Commons user license. **Please note that there is a fee if your manuscript is accepted for publication.**	Yes

13 August 2021

Dear Dr. Antonio Garcia Martinez
Editor in Chief: Results in Engineering

It is my great pleasure to submit our paper entitled "**Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate**" to be considered for publication in your journal.

Urgency of this paper:
Vacuum freeze dryer has been proven to be an effective drying method to produce freeze-dried products with the best quality compared to other drying methods. However, the drying rate is very slow because the sublimation process must propagate through the layers of material. Our results show that the exhaust gas heat from a condenser to increase the vacuum freeze dryer can be used to optimize the water sublimation process. As a result, the drying process will be faster.

Previously this manuscript was submitted to the journal **Thermal Science and Engineering Progress** (Manuscript ID: TSEP-D-21-00871), but was transferred for several reasons. The author has corrected it for submission to this journal **Results in Engineering**.

As a corresponding author, we stated that:
1. That the work has not been published before
2. That it is not under consideration for publication elsewhere
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Sincerely,

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Credit Author Statement

The authors agreeing and contributions to the manuscript with the title: **Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate**.

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2	Sukmawaty	Department of Agricultural Engineering, University of Mataram, Indonesia	1) performed the experiments; 2) analyzed and interpreted the data.
3	Murad	Department of Agricultural Engineering, University of Mataram, Indonesia	1) performed the experiments; 2) analyzed and interpreted the data.
4	Maria Ulfa	Department of Chemistry, Faculty of Mathematics and Natural Sciences, University of Mataram, Indonesia	1) analyzed and interpreted the data; 2) contributed reagents, materials, analysis tools, or data.
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Declaration of Interest Statement

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Highlight

- Vacuum freeze-dryer utilizing condenser waste heat can optimize the water sublimation.
- Utilization of condenser waste heat can speed up the drying process.
- The EGH is more optimal than the CFD because the drying process is faster.
- The water loss in the EGH method is higher than the VFD method.
- The EGH method produces a higher WL value than the VFD method.

Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate

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Abstract

Vacuum freeze dryer is able to remove some of the moisture content of the material. However, the drying rate is very slow because the sublimation process must propagate through the layers of material. Therefore, the aim of this study is to examine the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate. Drying was carried out at freezing temperature of -55 ºC and the drying time was 7 hours. The research parameters observed were water losses, water content, texture, color, weight losses, and total soluble solids. The results showed that the exhaust gas heat in a vacuum freeze dryer can be used to optimize the water sublimation process. As a result, the drying process will be faster. The exhaust gas heat has a significantly effect on changes in water losses, moisture content, texture, weight losses, and total soluble solids, but does not significantly effect on the sample color. The drying system in the exhaust gas heat (EGH) method was more efficient because the final moisture content of the sample was 9.45% lower than the vacuum freeze dryer (VFD) method, which was 15.95%.

Keywords: Color losses; Moisture content; Quality parameters; Total soluble solids; Water losses

1. Introduction

Vacuum freeze drying has been proven to be an effective drying method to produce freeze-dried products with the best quality compared to other drying methods [1-3]. The advantages of freeze-drying products are the texture structure that does not shrink [4], thus allowing very fast rehydration, high flavor retention because drying takes place at low temperatures, and the reconstitution of living cells in freeze-dried products remains high [5-6]. It has been used to obtain high quality freeze-dried products [7-8].

Even though vacuum freeze drying is the best drying process [9], it has several drawbacks, including a slow drying rate because the heat used for the sublimation process must be propagated through the layer of material [10]. The porous structure of the material has a very low conductivity that the transfer of heat to the surface of the material is also very low [11-12].

Heating analysis to increase the efficiency of heat propagation to the material layer has been carried out by Reyes et al. [13], however, the use of exhaust gas heat a condenser has not been disclosed. Freeze drying using additional heating has been reported by Xu et al. [14] that the high drying temperature greatly affects the sublimation rate.

Freeze-drying kinetics are influenced by the freezing rate and heat and mass transfer rates during the sublimation process [15-16]. The freezing process is one of the stages of freeze drying which requires high energy [17-18]. Therefore, the search for a more appropriate method is one of the most needed efforts by the food processing industry today [19-20].

Research on the process of utilizing heat sources from the condenser has not been widely reported. Therefore, this research is very important to explain the efficiency of exhaust gas heat utilization that drying can take place quickly and produce hygienic frozen products. Therefore, the aim of this study was to examine the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate.

2. Materials and methods

2.1. Materials

The materials used in the study were fresh cut-jackfruit with a harvest age of 3 months. This fruit was obtained from farmers' gardens in Mataram, West Nusa Tenggara Province, Indonesia. The jackfruit was split, then the skin was separated and the seeds are removed. Another material were refrigerant R134A was obtained from a minimarket in Mataram City, West Nusa Tenggara, Indonesia.

2.2. Tools

The main equipment used were a vacuum freeze dryer (VFD) and a modified vacuum freeze dryer with the use of exhaust gas heat (EGH) (Figure 1). The other equipment were a digital refractometer type DR301-95, moisture tester, color meter TES135 series, and texture analyzer Brookfield model CT3.

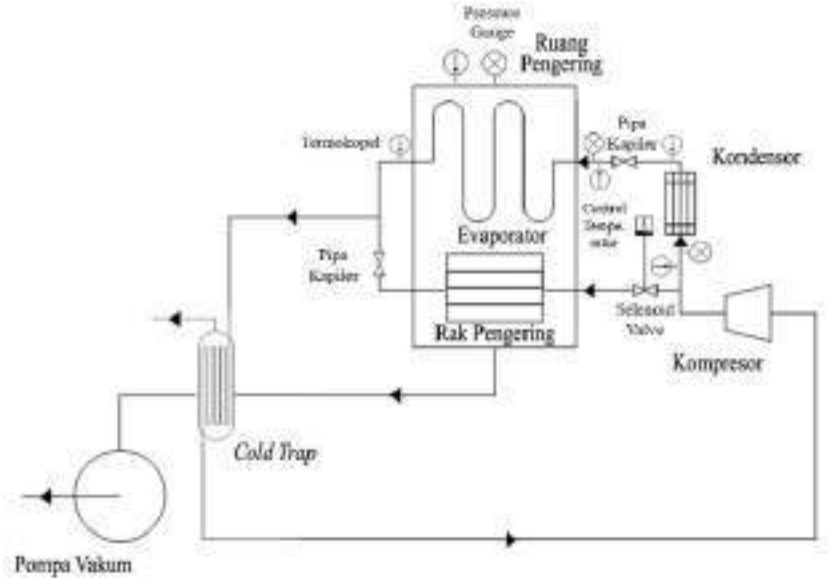

Figure 1. The vacuum freeze drying equipment sketch

2.3. Drying procedure

The drying process was carried out with a freeze temperature of -55 ºC and the drying time was 7 hours. Each treatment used a sample of 0.5 kg of fresh-cut jackfruit. The experiment was repeated 3 times.

2.4. Water Losses Analysis

Water losses (WL) describes the amount of water evaporated from the sample during the vacuum freeze drying process which can be calculated by equation (1) [21]:

$$WL = m_0 - m_t \frac{W_t}{W_0} \quad \text{(Eq. 1)}$$

Where, m_0 = sample moisture content at time 0 (%), m_t = sample moisture content at time t (%), W_0 = sample weight at time-0 (grams), W_t = sample weight at the time-t (gram).

2.5. Moisture content analysis

The moisture content of fresh-cut jackfruit was determined following the standard method of analysis [3]. Approximately 5 g of the sample was weighed into a can. The sample was heated to 50+1 °C until constant weight was reached, transferred to a desiccator, and was weighed soon after it had reached environment temperature. The moisture content was calculate by Equation (2) [5]:

$$M_c = \frac{a-b}{a} \times 100\% \quad \text{(Eq. 2)}$$

Where, M_c = moisture content (%), a = initial of moisture content (%), b = final of moisture content (%).

2.6. Texture analysis

The measurement of the sample texture of the result from the vacuum freeze dryer was carried out using a texture analyzer with a compression method. The loading was carried out with a compression speed of 4 mm/s. The result can be calculated using equation (3) [4]:

$$T = \frac{P}{A} \quad \text{(Eq. 3)}$$

Where, T = texture (N/mm^2), P = compressive force (N), and A = cross-sectional area (mm^2).

2.7. Color Analysis

The color of fresh-cut jackfruit was measurement using the Chroma meter type AT-13-04 Konica Minolta type CR-400. Color measurement using the Hunter L* a* b* color value system [22].

For lightness were defined as:

$$L* = L*_d - L*_f \quad \text{(Eq. 4)}$$

For redness were defined as:

$$a* = a*_d - a*_f \quad \text{(Eq. 5)}$$

For yellowness were defined as:

$$b* = b*_d - b*_f \quad \text{(Eq. 6)}$$

Where, L* = lightness (L* = 0 for black, L* = 100 for white), a* = green-red (a*<0 for green, a*>0 for red), b* = blue-yellow (b*<0 for blue, b*>0 for yellow), subscript 'f' refers to fresh samples and 'd' to the values of dried materials.

2.8. Weight losses analysis

The weight losses (WL) of the sample was measured before and after drying. Weight losses was calculated using the following equation (6) [23]:

$$WL = \frac{w_f - w_d}{w_f} 100\% \quad \text{(Eq. 7)}$$

Where, WL = weight losses (%), w_f = mass of sample before drying (grams), w_d = mass of sample after drying (gram).

2.9. Total soluble solids analysis

Total soluble solids (TSS) were measured using a digital refractometer type DR301-95. The TSS value is expressed in degrees of brix to indicate the dissolved sugar content in the sample. Measurements were made by crushing 2 grams of jackfruit and then placing it on the refractometer sensor. Each treatment was repeated three times.

2.10. Data analysis

Analysis of variance (ANOVA) was used to determine the comparison of the results of the two types of dryers to the characteristics of frozen jackfruit. If the ANOVA table the F-count value is greater than F-crit, it means that there is a difference at the 5% significance level [24].

3. Results and discussions

3.1. Water losses

The data of WL in the sample during vacuum freeze-drying was shown in Figure 2. In this figure, it can be seen that the water losses in the EGH method is higher than that of the VFD method. This is due to the exhaust gas heat from the condenser as a heating source in the EGH method which can significantly accelerate the evaporation rate of water, whereas in the VFD method the water evaporation process only occurs because of the difference in pressure inside and outside the drying chamber. In line with this, Westerterp et al. [25] also stated that the process of evaporation of the water on the material during vacuum freeze drying occurs because there are difference in pressure on the surface of the material with environmental pressure and the longer the drying process, the more water was evaporated.

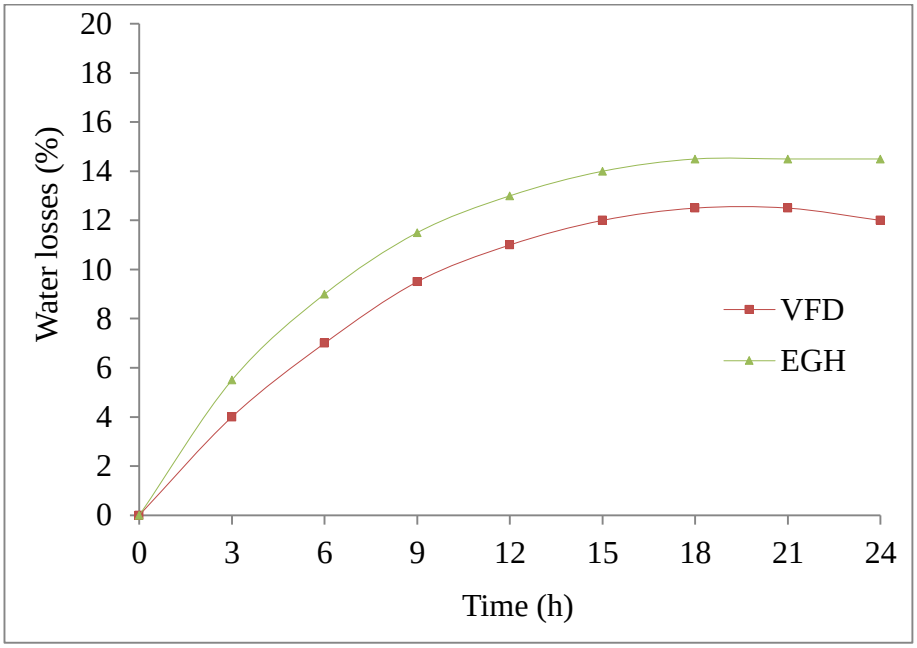

Figure 2. The water loss profile of fresh cut jackfruit during vacuum-freeze drying

Based on the results of the analysis of variance, it was known that the use of different drying methods provides different WL data. The EGH method produces a higher WL value

(14.50%) than the VFD method (12.06%). This shows that the use of additional heat energy from the exhaust gas heat of the condenser has a significant effect on the WL value.

Other factors that influence water losses during drying are temperature and drying time. This result in line with the opinion of Mello et al. [26] that many factors influence to the water losses in the drying process, including drying temperature, air humidity, and air flow velocity. The greater the temperature difference between the heating medium and the drying material, the faster the heat transfer into the material, the rate faster of water losses from the dried material. The air humidity was inversely related to drying time. The higher the humidity, the longer the drying process will be. Meanwhile, the air flow rate was directly proportional to the drying time. The higher the air flow rate, the faster the drying process.

3.2. Moisture content

Figure 2 presents the curves of the reduction in moisture content of the two different drying methods used in this study. To reach the moisture content of the frozen product, these two methods have different times. The final moisture content in the EGH method is much lower than the VFD method. This indicates that the use of exhaust gas heat from a condenser as a heating source can significantly accelerate the rate of decreasing moisture content. These data indicate that one of the important characteristics of vacuum freeze-dryers was the efficient use of energy to reduce moisture content compared to other drying methods.

In Figure 3 it can also be seen that the final water content of the sample in the VFD method is higher, namely 15.95% than the final water content in the EGH method which is only 9.45%. This happens because there are additional heat energy from the condenser that the water sublimation process in the EGH method takes place faster than the VFD method. The same study have been described by Zhang et al. [27] that by utilizing secondary drying

in a freeze dryer can optimize the sublimation process of water that the drying process takes place very quickly.

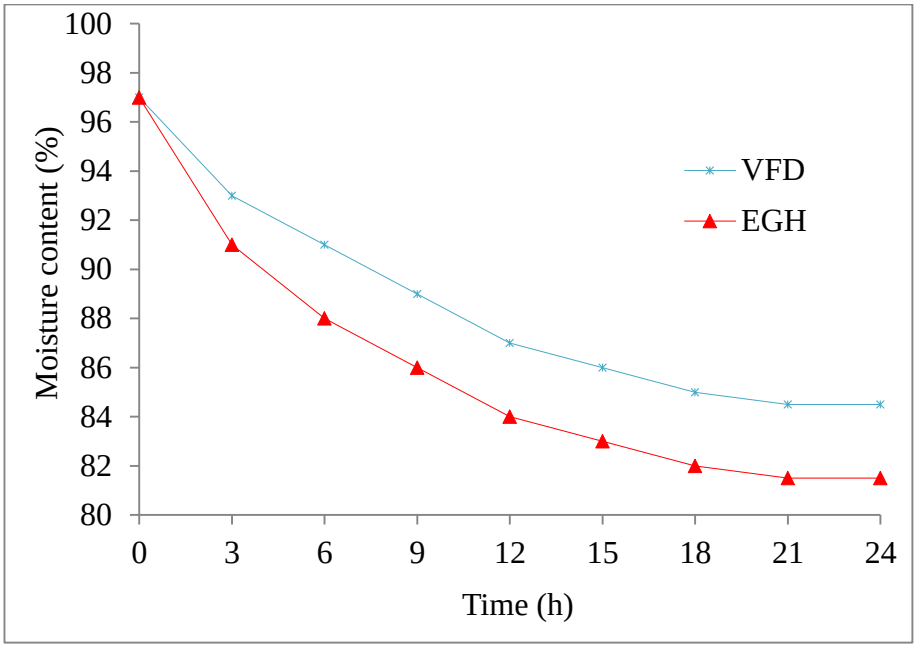

Figure 3. Curve of the rate of reduction in moisture content during vacuum freeze drying

The moisture content is a very important characteristic of freeze-dried food products because the moisture content can affect the appearance, texture, and taste of the product [28]. The moisture content also affects the freshness and shelf life of the product. The high water content can make bacteria, molds, and yeast easy to reproduce there will be changes in foodstuffs [29]. The vacuum freeze drying process can remove moisture content from the sample. The moisture content produced from the vacuum freeze dryer in this study has met the quality requirements of freeze-dried fruit products a maximum of 15% [30].

3.3. Texture

Vacuum-freeze drying is a drying method that causes sublimation of the water vapor in the material that the structure of the material expands. The results of the texture test using the compression method showed that the samples dried by the EGH method produced a

crispier texture than the VFD method (Figure 4). It shows that the water vapor sublimation process that occurs in the EGH method causes the sample texture to be crunchy and easy to break. The factors causing the crisp texture of the sample are due to the low pressure in the drying chamber and the relatively high internal vapor pressure during the vacuum freeze drying process.

In the EGH method, the sample structure changes due to the effect of additional heating energy from the exhaust gas heat of the condenser, after which the sample ice crystals turn into gas and then evaporate. Compared to the EGH method, the sublimation process in the VFD method was a heating process with low temperatures that the sample ice crystals evaporate more slowly. That's what causes sample shrinkage. The results of the same paper have been described by Liu et al. [31] that the shocking effect of the freezing process then heated to a higher temperature is the change of ice to vapor that the texture of the sample is crispier and more porous.

The changing process of the sample texture has occurred shortly after drying, then evaporation of the water occurs and air bubbles form. Previous studies have reported by Zielinska et al. [32] that the vacuum freeze drying process can cause water evaporation, then the product expands and forms air cavities. The high and low texture value of a material according to Bozkir et al. [33] depending on the characteristics of the material, such as thickness, homogenization, and composition.

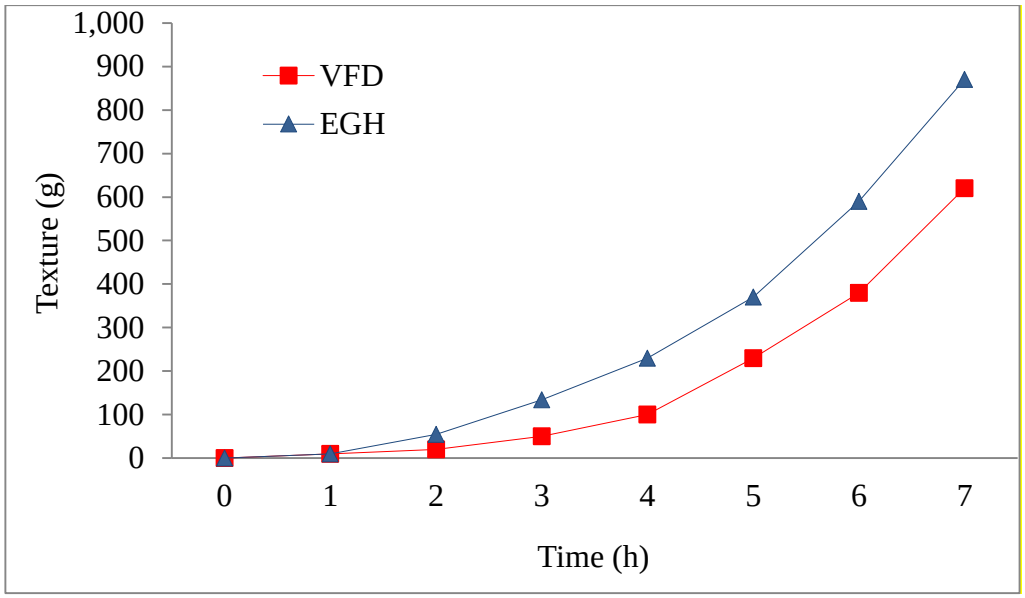

Figure 4. The texture profile of cut jackfruit during vacuum freeze dryer

The samples dried using the EGH method caused the water to come out of the fruit cell walls faster than the VFD method. This difference in the evaporation of high water content causes the texture structure of the sample to become more brittle and expand. This result in line with the study reported by Sobaszek et al. [34] that the vacuum freeze drying process resulted in water evaporation that the texture of the fruit would become hard.

In general, the texture of the jackfruit from vacuum freeze drying depends on the cell wall tissue. The texture change occurs in the vacuum freeze drying process because the sample has lost some of its moisture content. This view is supported by Pei et al. [35] who writes that the texture structure of the fruit depends on the cell wall tissue that in the vacuum freeze dryer there is a hardening on the surface of the material accompanied by changes in the size of the product texture.

3.4. Color

Changes in the color of fresh cut jackfruit before and after vacuum freeze drying can be seen from the data in Figure 5. The graph of the color change of the fresh-cut jackfruit during vacuum freeze drying can be seen from the data in Table 1. Based on the Table 1 we can see that the type of dryer has no significant effect on lightness (L*), redness (a*), and yellowness (b*).

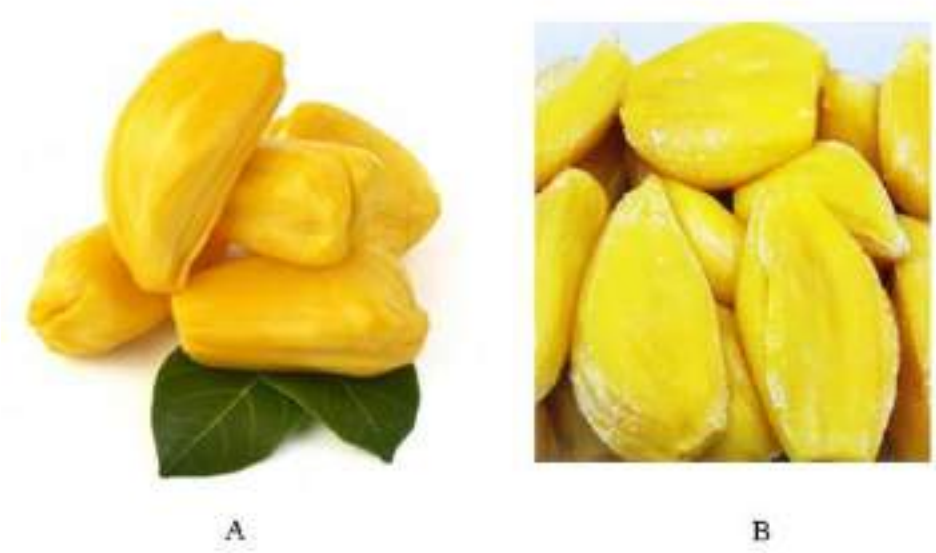

Figure 5. The color of fresh cut jackfruit before (A) and after (B) vacuum freeze-drying

Table 1. Value of lightness (L*), redness (a*), and yellowness (b*) of the fresh-cut jackfruit during vacuum freeze drying.

Drying methods	**Color**		
	L*	a*	b*
Control	58.62 ± 0.55 [a]	5.75 ± 0.78 [a]	67.23 ± 0.14 [a]
EGH	57.23 ± 0.21 [a]	5.92 ± 0.14 [a]	68.37 ± 0.42 [a]
VFD	57.12 ± 0.34 [a]	5.42 ± 0.56 [a]	69.63 ± 0.12 [a]

Note: numbers followed by different letter notations in the same column show significant differences at the 0.05 significance level ($P<0.05$).

Based the data in Table 1, it is apparent that the change in the lightness color of the freeze-dried jackfruit tended to decrease during the drying process. The sample color changes from shiny yellow become opaque yellow in both types of drying methods. The lightness value in the VFD method was lower (57.12) than the EGH method (57.23) although it was not significantly different. The lightness color shows a decreasing trend during drying in both methods. This is caused by a biological reaction, resulting in an enzymatic process that causes the color of the sample to decrease in brightness. This result is in line with Keutgen and Pawelzik [36] have reported that low temperatures in the vacuum freeze drying process have not been able to activate the polyphenolic enzymes in the sample and the enzymes can still be active at temperatures as low as -73 ºC, although with very low reaction rates.

The redness and yellowness color intensity did not change during the vacuum freeze drying process. The sample color before and after drying did not change significantly. Several investigators have also reported that the use of a vacuum freeze dryer did not result in color changes in the samples [37]. Sample color change usually occurs at high drying temperatures [38]. The same analogy has been explained by Falah et al. [39] that a significant change in sample color during high temperature drying can occur, but the change is not significant at cold temperature.

3.5. Weight losses (WL)

The results of the WL calculation of fresh-cut jackfruit during vacuum freeze drying are shown in Table 2. At the beginning of the drying process, the WL occurs very rapidly until 6th hour, then slowly until the end of drying. After reaching the saturated condition, the

sample WL no longer changes. Table 2 also shows that the WL is higher in the EGH method compared to the VFD method.

Table 2. Average of WL value of fresh cut jackfruit from vacuum freeze drying

Drying time (hour)	Weight losses (g)	
	EGH	VFD
1	0.00 [a]	0.00 [a]
2	7.29 [b]	6.53 [b]
3	10.12 [c]	9.41 [c]
4	15.13 [d]	13.75 [d]
5	23.14 [e]	18.65 [e]
6	35.67 [f]	29.42 [f]
7	37.32 [f]	31.82 [g]

Note: numbers followed by different letter notations in the same column show significant differences at the 0.05 significance level ($P < 0.05$).

From the table above we can see that the samples dried in the EGH method had a final WL of 37.32 g, while those dried in the VFD method had a final WL of 31.82 g. These data indicate that the use of exhaust gas heat form a condenser in the EGH method has a significant effect on reducing WL of fresh-cut jackfruit

The duration of the drying process also has a significant effect on the WL of fresh-cut jackfruit. The long drying process can trigger an increase in the percentage of WL in the sample. The same it cases has been reported by Singh and Khan [40] that WL is generally affected by the evaporation of moisture during drying due to the breakdown of organic compounds into inorganic compounds, namely compounds are oxidized to CO_2 and absorb O_2, then reduced to H_2O.

3.6. Total Soluble Solids (TSS)

The results of measuring the TSS value of fresh-cut jackfruit from vacuum freeze drying are shown in Table 3.

Table 3. Average TSS value of fresh-cut jackfruit from vacuum freeze drying

Drying time (hour)	Total soluble solids (°Brix)	
	EGH	VFD
1	8.04 [a]	8.04 [a]
2	10.19 [b]	09.83 [b]
3	11.23 [c]	10.31 [c]
4	12.33 [d]	11.67 [d]
5	14.46 [e]	13.55 [e]
6	15.67 [f]	14.92 [f]
7	17.32 [g]	16.22 [g]

Note: numbers followed by different letter notations in the same column show significant differences at the 0.05 significance level ($P<0.05$).

The data in Table 3 shows that during drying, there was an increase in the TSS value in the sample due to the respiration and transpiration processes that were still ongoing even though the fruit had been harvested. The increase in TSS value is also accelerated by vacuum freeze drying. The TSS value was higher in the EGH method than the VFD method. This is thought to be due to the influence of the exhaust gas heat from a condenser which triggers the carbohydrate content to become sugar levels. A similar thing has been reported by Rydzak et al. [41] that immature fruit stores a lot of carbohydrates in the form of starch and

during the process towards maturity the content will turn into sugar. According to Yusufe et al. [42], fruits at advanced maturity levels have the highest TSS content, due to hydrolysis of starch to sugar.

Total soluble solids are the combination of all inorganic and organic substances present in food. Based on the data in Table 3, it can be seen that at the beginning of drying the TSS value is still low. With the length of drying time, the TSS value tended to be higher in the two methods, but had different values. The difference in TSS value is thought to be due to the difference in temperature used between the EGH and VFD methods. The driving force of the exhaust gas heat from condenser in the EGH method causes some of the water to evaporate faster. In addition, the faster sublimation process can open larger pores of the sample surface. When the pores of the sample surface as the permeability membrane opens wider, the amount of water evaporating from the material will also increase [43].

4. Conclusions

The exhaust gas heat from a condenser can be used to accelerate the sublimation process during the vacuum-freeze drying process, the drying process can take place faster. The results of this study have proven that the use of exhaust gas heat from a condenser has a significant effect on the parameters of water losses, moisture content, texture, weight losses, and total dissolved solids, but it does not affect the sample color.

This new finding provides a better scientific understanding of the vacuum freeze-drying process. Therefore, the results of this study are recommended to be applied to vacuum freeze dryers for drying food products.

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Conflicts of Interest

The authors declared no conflict of interest.

References

[1] Z. Shaozhi, L. Jielin, C. Guangming and W. Qin, "Thermodynamic analysis of a freeze-dryer utilizing hygroscopic solution," *Drying Technology*, 2017.

[2] W. M. Obeidat, E. Sahni, W. Kessler and M. Pikal, "Development of a Mini-Freeze Dryer for Material-Sparing Laboratory Processing with Representative Product Temperature History," *AAPS PharmSciTech,* vol. 19, no. 12, pp. 599-609, 2017.

[3] Ansar, Nazaruddin and A. D. Azis, "Effect of vacuum freeze-drying condition and maltodextrin on the physical and sensory characteristics of passion fruit (Passiflora edulis sims) extract," in *IOP Conference Series: Earth and Environmental Science*, Makassar, 2019.

[4] H. T. Ngo, S. Tojo, T. Ban and T. Chosa, "Effects of Prior Freezing Conditions on the Quality of Blueberries in a Freeze-Drying Process," *Transactions of the ASABE,* vol. 60, no. 4, pp. 1369-1377, 2017.

[5] Ansar, Nazaruddin and A. D. Azis, "New frozen product development from strawberries (Fragaria Ananassa Duch.)," *Heliyon,* vol. 6, no. 9, p. e05118, 2020.

[6] V. B. Nguyen, D. H. Nguyen and H. V. Nguyen, "Combination effects of calcium chloride and nano-chitosan on the postharvest quality of strawberry (Fragaria x ananassa Duch.)," *Postharvest Biology and Technology,* vol. 162, no. 111103, 2020.

[7] B. Schulze, E. M. Hubbermann and K. Schwarz, "Stability of quercetin derivatives in vacuum impregnated apple slices after drying (microwave vacuum drying, air drying, freeze drying) and storage," *LWT-Food Science and Technology,* vol. 57, no. 1, pp. 426-433, 2014.

[8] K. Sun, R. Li, W. Jiang, Y. Sun and H. Li, "Comparison of three-dimensional printing and vacuum freeze-dried techniques for fabricating composite scaffolds," *Biochemical and Biophysical Research Communications,* vol. 477, no. 4, pp. 1085-1091, 2016.

[9] Y. M. Chew and V. E. King, "Microwave Drying of Pitaya (Hylocereus) Peel and the Effects Compared with Hot-Air and Freeze-drying," *Transactions of the ASABE,* vol. 62, no. 4, pp. 919-928, 2019.

[10] A. Khampakool, S. Soisungwan and S. H. Park, "Potential application of infrared assisted freeze drying (IRAFD) for banana snacks: Drying kinetics, energy consumption, and texture," *LWT-Food Science and Technology,* 2018.

[11] L. J. Wang and W. Sun, "Numerical analysis of the three–dimensional mass and heat transfer with inner moisture evaporation in porous cooked meat joints during vacuum cooling," *Transactions of the ASAE,* vol. 46, no. 1, pp. 107-115, 2003.

[12] A. Lakatos, A. Csik and I. Csarnovics, "Experimental verification of thermal properties of the aerogel blanket," *Case Studies in Thermal Engineering,* vol. 21, p. 100966, 2021.

[13] V. Reyes, R. Bubnovich, M. Bustos, R. Vásquez, R. Vega and E. Scheuermann, "Comparative study of different process conditions of freeze drying of 'Murtilla' berry," *Drying Technology: An International Journal, 28:12, 1416-1425,* vol. 28, no. 12, pp. 1416-1425, 2010.

[14] Y. Xu, M. Zhang, A. S. Mujumdar, X. Duan and S. Jin-cai, "A two-stage vacuum freeze and convective air drying method for strawberries," *Drying Technology: An International Journal,* vol. 24, no. 8, pp. 1019-1023, 2006.

[15] X. F. Wu, M. Zhang, Y. Ye and D. Yu, "Influence of ultrasonic pretreatments on drying kinetics and quality attributes of sweet potato slices in infrared freeze drying (IRFD)," *LWT,* vol. 131, p. 109801, 2020.

[16] H. Selvnes, Y. Allouche, R. I. Manescu and A. Hafner, "Review on cold thermal energy storage applied to refrigeration systems using phase change materials," *Thermal Science and Engineering Progress,* vol. 22, p. 100807, 2021.

[17] G. Assegehegn, E. B. Fuente, J. M. Franco and C. Gallegos, "The Importance of Understanding the Freezing Step and Its Impact on Freeze-Drying Process Performance," *Journal of Pharmaceutical Sciences,* vol. 108, no. 4, pp. 1378-1395, 2019.

[18] M. Shehadi, "Optimizing solar cooling systems," *Case Studies in Thermal Engineering,* vol. 21, p. 100663, 2020.

[19] A. U. Shingisov and R. S. Alibekov, "Analysis of the moisture evaporation process during vacuum freeze-drying of koumiss and shubat," *Heat and Mass Transfer,* vol. 53, no. 5, p. 1571–1578, 2017.

[20] M. J. Al-Kheetan, M. M. Rahman, S. H. Ghaffar, M. Al-Tarawneh and Y. S. Jweihan, "Comprehensive investigation of the long-term performance of internally integrated concrete pavement with sodium acetate," *Results in Engineering,* vol. 6, p. 100110, 2020.

[21] J. S. Souza, M. D. Medeiros, M. A. Magalhaes and F. N. Fernandes, "Optimization of osmotic dehydration of tomatoes in a ternary system followed by air-drying," *Journal of Food Engineering,* vol. 83, no. 1, pp. 501-509, 2007.

[22] J. Chapman, A. Elbourne, V. K. Truong, L. Newman, S. Gangadoo, P. Rajapaksha Pathirannahalage and D. Cozzolino, "Sensomics - from conventional to functional NIR spectroscopy-shining light over the aroma and taste of foods," *Trends in Food Science & Technology,* 2019.

[23] S. M. Goni and V. O. Salvadori, "Prediction of cooking times and weight losses during meat roasting," *Journal of Food Engineering,* vol. 100, no. 1, pp. 1-11, 2010.

[24] Ansar, Nazaruddin and A. D. Azis, "Caking mechanisms of passion fruit powder during storage," *International Journal of Innovation, Creatifity, and Change,* vol. 13, no. 2, pp. 618-628, 2020.

[25] K. Westerterp, G. Plasqui and A. Goris, "Water loss as a function of energy intake, physical activity and season," *British Journal of Nutrition,* vol. 93, no. 2, pp. 199-203, 2005.

[26] R. E. Mello, A. Fontana, A. Mulet, J. Luiz, G. Correa and J. A. Cárcel, "Ultrasound-assisted drying of orange peel in atmospheric freeze-dryer and convective dryer operated at moderate temperature," *Drying Technology,* vol. 38, no. 1, pp. 259-267, 2020.

[27] C. Zhang, X. Bu, J. He, C. Liu, G. Lin and J. Miao, "Simulation of evaporation and sublimation process in porous plate water sublimator based on a reduced CFD model," *International Journal of Heat and Mass Transfer,* vol. 154, p. 119787, 2020.

[28] X. Xu, Q. Li, Y. Lai, W. Pang and R. Zhang, "Effect of moisture content on mechanical and damage behavior of frozen loess under triaxial condition along with different confining pressures," *Cold Regions Science and Technology,* vol. 157, pp. 110-118, 2019.

[29] V. I. Aksenov, S. G. Gevorkyan and V. V. Doroshin, "Dependence of Strength and Physical Properties of Frozen Sands on Moisture Content," *Soil Mechanics and Foundation Engineering,* vol. 54, p. 420–424, 2018.

[30] Z. M. Salisu, S. U. Ishiaku, D. Abdullahi, M. K. Yakubu and B. H. Diya'uddeen, "Development of kenaf shive bio–mop via surface deposit technique for water

remediation from crude oil spill contamination," *Results in Engineering,* vol. 3, p. 100020, 2019.

[31] B. Liu, Y. Zhao, Y. Jia and J. Liu, "Heating Drives DNA to Hydrophobic Regions While Freezing Drives DNA to Hydrophilic Regions of Graphene Oxide for Highly Robust Biosensors," *Journal of the American Chemical Society,* vol. 142, no. 34, pp. 14702-14709, 2020.

[32] M. Zielinska, M. Markowski and D. Zielinska, "The effect of freezing on the hot air and microwave vacuum drying kinetics and texture of whole cranberries," *Drying Technology,* vol. 37, no. 13, pp. 1714-1730, 2019.

[33] H. Bozkir, Y. Tekgül and E. S. Erten, "Effects of tray drying, vacuum infrared drying, and vacuum microwave drying techniques on quality characteristics and aroma profile of orange peels," *Journal of Food Process Engineering,* vol. 44, no. 1, p. e13611, 2021.

[34] P. Sobaszek, R. Różyło, L. Dziki, U. Gawlik-Dziki, B. Biernacka and M. Panasiewicz, "Evaluation of Color, Texture, Sensory and Antioxidant Properties of Gels Composed of Freeze-Dried Maqui Berries and Agave Sugar," *Processes,* vol. 8, no. 10, p. 1294, 2020.

[35] F. Pei, W. Yang, Y. Shi, Y. Sun, A. M. Mariga, L. Y. Zhao, Y. Fang, N. Ma, X. An and Q. Hu, "Comparison of Freeze-Drying with Three Different Combinations of Drying Methods and Their Influence on Colour, Texture, Microstructure and Nutrient Retention of Button Mushroom (Agaricus bisporus) Slices," *Technology,* vol. 7, p. 702–710, 2014.

[36] A. J. Keutgen and E. Pawelzik, "Qualit yand nutrition value of strawberry fruit under longterm salt stress," *Journal Food Chemistry,* vol. 107, no. 2, pp. 1413-1420, 2007.

[37] X. Q. Yue, Z. Y. Shang, J. Y. Yang, L. Huang and Y. Q. Wang, "A smart data-driven rapid method to recognize the strawberry maturity," *Information Processing in Agriculture,* 2019.

[38] Y. Zhang and S. Barringe, "Effect of hydrocolloids, sugar, and citric acid on strawberry volatiles in a gummy candy," *J Food Process Preserv,* p. 00:e13327., 2017.

[39] M. A. Falah, P. Yuliastuti, R. Hanifah, P. Saroyo and Jumeri, "Quality of fresh strawberry (fragaria sp cv. holibert) from Ketep Magelang Central Java and its storage in tropical environment," *Jurnal Agro Industri,* vol. 8, no. 1, pp. 1-10, 2018.

[40] Z. Singh and A. S. Khan, "Physiology of plum fruit ripening," *Stewart Postharvest Rev.,* vol. 2, no. 1, pp. 3-12, 2010.

[41] L. Rydzak, Z. Kobus, R. Nadulski, K. Wilczyński, A. Pecyna, F. Santoro, A. Sagan, A. Starek-Wójcick and M. Krzywicka, "Analysis of Selected Physicochemical Properties of Commercial Apple Juices," *Processes,* vol. 8, p. 1457, 2020.

[42] M. Yusufe, A. Mohammed and N. Satheesh, "Effect of duration and drying temperature on characteristics of dried tomato (Lycopersicon esculentum L.) cochoro variety," *Journal of Food Technology,* vol. 21, no. 1, pp. 41-50, 2017.

[43] Q. V. Nguyen and H. V. Chuyen, "Processing of Herbal Tea from Roselle (Hibiscus sabdariffa L.): Effects of Drying Temperature and Brewing Conditions on Total Soluble Solid, Phenolic Content, Antioxidant Capacity and Sensory Quality," *Beverages,* vol. 6, no. 1, pp. 1-11, 2020.

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POINT-BY-POINT RESPONSES TO REVIEWER'S COMMENTS

Reviewer #1a: The title is clear and consistent. However, it can be shortened.

Author response #1a: I think this title sentence is already short, only 11 words.

Reviewer #1b: Results at the end of the abstract should be shortened by giving more explicit results with numbers.

Author response #1b: It is has been revised based on suggestions (page 1 lines 23-25).

Reviewer #1c: Highlights should be more explicit also with numbers.

Author response #1c: It is has been revised based on suggestions.

Reviewer #1d: The literature review should be extended.

Author response #1d: It is has been revised based on suggestions.

Reviewer #1e: The originality of the work should be more highlighted especially with respect to other recently published papers on the matter and particularly those published in Results in Engineering if possible.

Author response #1e: It is has been revised based on suggestions (page 2 line 49 and page 9 line 179).

M. J. Al-Kheetan, M. M. Rahman, S. H. Ghaffar, M. Al-Tarawneh and Y. S. Jweihan, "Comprehensive investigation of the long-term performance of internally integrated concrete pavement with sodium acetate," *Results in Engineering,* vol. 6, p. 100110, 2020.

Z. M. Salisu, S. U. Ishiaku, D. Abdullahi, M. K. Yakubu and B. H. Diya'uddeen, "Development of kenaf shive bio–mop via surface deposit technique for water remediation from crude oil spill contamination," *Results in Engineering,* vol. 3, p. 100020, 2019.

Reviewer #1f: References to the different equations presented should be provided.

Author response #1f: It is has been revised based on suggestions (page 4 lines 87 and 94).

Reviewer #1g: This section lacks of illustrative figures and more elaborations on the connection among the different ideas (sub-sections).

Author response #1g: The main equipment used were a vacuum freeze dryer (VFD) and a modified vacuum freeze dryer with the use of exhaust gas heat (EGH) showed was in Figure 1 (page 4 line 70).

Reviewer #1h: Results and discussions. Physical analysis are to be added to this section.

Author response #1h: It is has been revised based on suggestions (page 9 lines 183- 219).

Reviewer #1i: Conclusions. Based on the results obtained, recommendations in terms of applications should be provided.

Author response #1i: It is has been revised based on suggestions (page 16 lines 308-310).

Reviewer #1j: References relevant to Results in Engineering are to be added.

Author response #1j: It is has been revised based on suggestions (page 2 line 49 and page 9 line 179).

Reviewer #2: It would be useful to present a scheme of the condenser exhaust heat drying system proposed.

Author response #2: The schematic of the condenser exhaust heat drying system has been added in Figure 1 (page 4 line 70).

Reviewer #3a: The abstract is good. However, the authors need to add more numerical results.

Author response #3a: It is has been revised based on suggestions (page 1 lines 23-25).

Reviewer #3b: The introduction is very clear, with good English. The introduction is updated, with references of 2021.

Author response #3b: Reference citations for 2021 are at numbers 12 and 16 (page 2 line 40 and 46).

Reviewer #3c: Texture analysis. The authors need to add the type(s) of test(s).

Author response #3c: It is has been revised based on suggestions (page 5 lines 94-96).

Reviewer #3d: Water losses. This subsection is very complete. The authors should be more specific in the description (numbers) of the results, and in addition, the authors need to add the error bars in the Figure 1. The authors add the explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies.

Author response #3d: It is has been revised based on suggestions (page 7 lines 146-147).

Reviewer #3e: Moisture content. This subsection is very complete. The authors should be more specific in the description (numbers) of the results, and in addition, the authors need to add the error bars in the Figure 1. The authors add the explication of the results, but the authors need to add references (Lines 159-162). The subsection has comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. There is no comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. Lines 165-166. Please, add more details. Lines 167-169. Please, add more details.

Author response #3e: It is has been revised based on suggestions (page 8 lines 166-168).

Reviewer #3f: Texture. The author needs to add more details on the results. There is explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. However, the authors need to add information on the texture test.

Author response #3f: It is has been revised based on suggestions (page 8 lines 186-188).

Reviewer #3g: Color. It would be interesting if the authors added images of the samples before and after the treatment.

Author response #3g: Images of fresh jackfruit pieces were added before and after vacuum freeze drying (Figure 6) (page 12 line 229).

Reviewer #3h: Weight losses (WL). Table 2. The authors need to add the statistical differences.

Author response #3h: It is has been revised based on suggestions (page 14 lines 266-269).

Reviewer #3i: Total Soluble Solids (TSS). Lines 294-299. What are the references?

Author response #3i: Reference has been added based on suggestions (page 16 line 303).

Reviewer #3j: Conclusions. The conclusions are good, and it has concordance with the results.

Author response #3j: Thank you very much for your attention.

Ansar - <ansar72@unram.ac.id>

Your Submission

1 pesan

Results in Engineering <em@editorialmanager.com> 10 November 2021 15.41
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Kepada: Ansar Ansar <ansar72@unram.ac.id>

CC: ezio.mancaruso@stems.cnr.it

Ref.: Ms. No. RINENG-D-21-00242
Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate
Results in Engineering

Dear Dr. Ansar,

Reviewers have now commented on your paper. You will see that they are advising that you revise your manuscript. If you are prepared to undertake the work required, I would be pleased to reconsider my decision.

For your guidance, reviewers' comments are appended below.

If you decide to revise the work, please submit a list of changes or a rebuttal against each point which is being raised when you submit the revised manuscript.

Please resubmit your revised manuscript by Dec 01, 2021.

To submit a revision, go to https://www.editorialmanager.com/rineng/ and log in as an Author. You will see a menu item call Submission Needing Revision. You will find your submission record there.

Yours sincerely

Antonio García, Ph.D
Editor in Chief
Results in Engineering

Comments from the Editors and Reviewers:

Your article would appear to be of interest to a wide engineering research community and in order to promote its visibility even more, may we recommend that you view the past published articles in Results in Engineering and if you find any relevant publications, CITE the article from this Journal.

Dear Dr Ansar Ansar,

Thank you for submitting your manuscript to Results in Engineering.

We have completed the review of your manuscript and a summary of comments is appended below this message.

Overall, the reviewers recommend a reconsideration of your paper following minor revision.

We invite you to resubmit your manuscript after addressing all reviewer comments.

When resubmitting your manuscript, please carefully consider all issues mentioned in the reviewer’s comments, outline every change made point by point, and provide suitable rebuttals for any comments not addressed.

Yours sincerely,

Ezio Mancaruso
Associate Editor

Results in Engineering

Reviewer 1: Review on "Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate" by Ansar et al.
Manuscript RINENG-D-21-00242

A- General Comments
The paper in hand concerns an examination of the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate. Drying was carried out at freezing temperature of -55 ºC and the drying time was 7 hours. The research parameters observed were water losses, water content, texture, color, weight losses, and total soluble solids. Particularly, it was shown by the authors that the exhaust gas heat in a vacuum freeze dryer can be used to optimize the water sublimation process.

The topic of the paper is interesting, within the scope of the journal, and worthy of investigation. The originality of the work is acceptable. However, the manuscript deserves major revisions and proofreading. I suggest that authors take into account the comments and questions below before it can be considered for publication in Results in Engineering.

B- Detailed Comments and questions

Title
The title is clear and consistent. However, it can be shortened.

Abstract
1- Results at the end of the abstract should be shortened by giving more explicit results with numbers.

Highlights
1- Highlights should be more explicit also with numbers.

Keywords
Keywords are ok.

1- Introduction
1- The literature review should be extended;
2- The originality of the work should be more highlighted especially with respect to other recently published papers on the matter and particularly those published in Results in Engineering if possible;

2- Materials and methods
1- References to the different equations presented should be provided;
2- This section lacks of illustrative figures and more elaborations on the connection among the different ideas (sub-sections).

3- Results and discussions
1- Physical analysis are to be added to this section.

4. Conclusions
Based on the results obtained, recommendations in terms of applications should be provided.

5- References
References relevant to Results in Engineering are to be added.

Reviewer 2:
It would be useful to present a scheme of the condenser exhaust heat drying system proposed.

Reviewer 3: Dear Author(s)

After an exhaustive revision, the manuscript is Minor revision. In general, the study is closely connected to the journal's objectives. The study is very interesting. The English is good. The introduction is complete, very detailed. The section of

materials and methods is very complete. The authors need to make changes and modify parts in the manuscript, mainly in the section "Results and Discussions".

In the following pages, I give a detailed revision of the manuscript.

Best regards

General comments
** The authors are misspelled **

ABSTRACT
The abstract is good. However, the authors need to add more numerical results.

1. INTRODUCTION
The introduction is very clear, with good English. The introduction is updated, with references of 2021.

Lines 30-35. The authors need to add examples, with references.

Lines 41-44. The authors should enhance the lines, i.e., the authors need to add more information.

2. MATERIALS AND METHODS
General comments
This section is clear. The English is good. The authors must add a Figure that represents all the methodology in the section Materials and Methods. This Figure will help to understand the methodology. Some observations:

Line 60. Another material were refrigerant R134A was obtained from a minimarket in Mataram City
The authors need to rewrite the line.

Line 92. 2.6. Texture analysis
The authors need to add the type(s) of test(s).

3. RESULTS AND DISCUSSIONS
"Results and Discussion" is characterized by a description of the results, the explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies. My observations:

3.1. Water losses
This subsection is very complete. The authors should be more specific in the description (numbers) of the results, and in addition, the authors need to add the error bars in the Figure 1. The authors add the explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies.

3.2. Moisture content
This subsection is very complete. The authors should be more specific in the description (numbers) of the results, and in addition, the authors need to add the error bars in the Figure 1. The authors add the explication of the results, but the authors need to add references (Lines 159-162). The subsection has comparison with other studies, and explication (discussion) of the results obtained with respect to other studies.

There is no comparison with other studies, and explication (discussion) of the results obtained with respect to other studies.

Lines 165-166. Please, add more details.
Lines 167-169. Please, add more details.

3.3. Texture
The author needs to add more details on the results. There is explication of the results, comparison with other studies, and explication (discussion) of the results obtained with respect to other studies.
However, the authors need to add information on the texture test.

3.4. Color
It would be interesting if the authors added images of the samples before and after the treatment.

3.5. Weight losses (WL)
Table 2. The authors need to add the statistical differences.

3.6. Total Soluble Solids (TSS)

Table 3. The authors need to add the statistical differences.
Lines 294-299. What are the references?

4. Conclusions
The conclusions are good, and it has concordance with the results.

#AU_RINENG#

To ensure this email reaches the intended recipient, please do not delete the above code

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Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Freeze-Drying Rate

Ansar [a, *)], Sukmawaty [a], Murad [a], Maria Ulfa [b], Atri Dewi Azis [c]

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[b] Department of Chemistry, Faculty of Mathematics and Natural Sciences, University of Mataram, Indonesia

[c] Department of English Education, Faculty of Teacher Training and Education, University of Mataram, Indonesia

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Abstract

Vacuum freeze dryer is able to remove some of the moisture content of the material. However, the drying rate is very slow because the sublimation process must propagate through the layers of material. Therefore, the aim of this study is to examine the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate. Drying was carried out at freezing temperature of -55 ºC and the drying time was 7 hours. The research parameters observed were water losses, water content, texture, color, weight losses, and total soluble solids. The results showed that the exhaust gas heat in a vacuum freeze dryer can be used to optimize the water sublimation process. As a result, the drying process will be faster. The exhaust gas heat has a significantly effect on changes in water losses, moisture content, texture, weight losses, and total soluble solids, but does not significantly effect on the sample color. The drying system in the exhaust gas heat (EGH) method was more efficient because the final moisture content of the sample was 9.45% lower than the vacuum freeze dryer (VFD) method, which was 15.95%.

Keywords: Color losses; Moisture content; Quality parameters; Total soluble solids; Water losses

1. Introduction

Vacuum freeze drying has been proven to be an effective drying method to produce freeze-dried products with the best quality compared to other drying methods [1-3]. The advantages of freeze-drying products are the texture structure that does not shrink [4], thus allowing very fast rehydration, high flavor retention because drying takes place at low temperatures, and the reconstitution of living cells in freeze-dried products remains high [5-6]. It has been used to obtain high quality freeze-dried products [7-8].

Even though vacuum freeze drying is the best drying process [9], it has several drawbacks, including a slow drying rate because the heat used for the sublimation process must be propagated through the layer of material [10]. The porous structure of the material has a very low conductivity that the transfer of heat to the surface of the material is also very low [11-12].

Heating analysis to increase the efficiency of heat propagation to the material layer has been carried out by Reyes et al. [13], however, the use of exhaust gas heat a condenser has not been disclosed. Freeze drying using additional heating has been reported by Xu et al. [14] that the high drying temperature greatly affects the sublimation rate.

Freeze-drying kinetics are influenced by the freezing rate and heat and mass transfer rates during the sublimation process [15-16]. The freezing process is one of the stages of freeze drying which requires high energy [17-18]. Therefore, the search for a more appropriate method is one of the most needed efforts by the food processing industry today [19-20].

Research on the process of utilizing heat sources from the condenser has not been widely reported. Therefore, this research is very important to explain the efficiency of exhaust gas heat utilization that drying can take place quickly and produce hygienic frozen products. Therefore, the aim of this study was to examine the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate.

2. Materials and methods

2.1. Materials

The materials used in the study were fresh cut-jackfruit with a harvest age of 3 months. This fruit was obtained from farmers' gardens in Mataram, West Nusa Tenggara Province, Indonesia. The jackfruit was split, then the skin was separated and the seeds are removed. Another material were refrigerant R134A was obtained from a minimarket in Mataram City, West Nusa Tenggara, Indonesia.

2.2. Tools

The main equipment used were a vacuum freeze dryer (VFD) and a modified vacuum freeze dryer with the use of exhaust gas heat (EGH) (Figure 1). The other equipment were a digital refractometer type DR301-95, moisture tester, color meter TES135 series, and texture analyzer Brookfield model CT3.

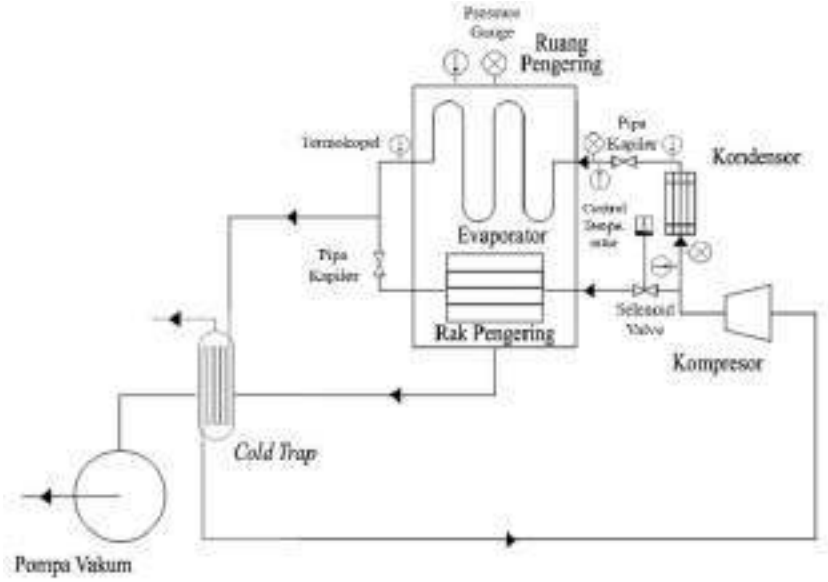

Figure 1. The vacuum freeze drying equipment sketch

2.3. Drying procedure

The drying process was carried out with a freeze temperature of -55 ºC and the drying time was 7 hours. Each treatment used a sample of 0.5 kg of fresh-cut jackfruit. The experiment was repeated 3 times.

2.4. Water Losses Analysis

Water losses (WL) describes the amount of water evaporated from the sample during the vacuum freeze drying process which can be calculated by equation (1) [21]:

$$WL = m_0 - m_t \frac{W_t}{W_0} \quad \text{(Eq. 1)}$$

Where, m_0 = sample moisture content at time 0 (%), m_t = sample moisture content at time t (%), W_0 = sample weight at time-0 (grams), W_t = sample weight at the time-t (gram).

2.5. Moisture content analysis

The moisture content of fresh-cut jackfruit was determined following the standard method of analysis [3]. Approximately 5 g of the sample was weighed into a can. The sample was heated to 50+1 °C until constant weight was reached, transferred to a desiccator, and was weighed soon after it had reached environment temperature. The moisture content was calculate by Equation (2) [5]:

$$M_c = \frac{a-b}{a} \times 100\% \quad \text{(Eq. 2)}$$

Where, M_c = moisture content (%), a = initial of moisture content (%), b = final of moisture content (%).

2.6. Texture analysis

The measurement of the sample texture of the result from the vacuum freeze dryer was carried out using a texture analyzer with a compression method. The loading was carried out with a compression speed of 4 mm/s. The result can be calculated using equation (3) [4]:

$$T = \frac{P}{A} \quad \text{(Eq. 3)}$$

Where, T = texture (N/mm^2), P = compressive force (N), and A = cross-sectional area (mm^2).

2.7. Color Analysis

The color of fresh-cut jackfruit was measurement using the Chroma meter type AT-13-04 Konica Minolta type CR-400. Color measurement using the Hunter L* a* b* color value system [22].

For lightness were defined as:

$$L* = L*_d - L*_f \quad \text{(Eq. 4)}$$

For redness were defined as:

$$a* = a*_d - a*_f \quad \text{(Eq. 5)}$$

For yellowness were defined as:

$$b* = b*_d - b*_f \quad \text{(Eq. 6)}$$

Where, L* = lightness (L* = 0 for black, L* = 100 for white), a* = green-red (a*<0 for green, a*>0 for red), b* = blue-yellow (b*<0 for blue, b*>0 for yellow), subscript 'f' refers to fresh samples and 'd' to the values of dried materials.

2.8. Weight losses analysis

The weight losses (WL) of the sample was measured before and after drying. Weight losses was calculated using the following equation (6) [23]:

$$WL = \frac{w_f - w_d}{w_f} 100\% \quad \text{(Eq. 7)}$$

Where, WL = weight losses (%), w_f = mass of sample before drying (grams), w_d = mass of sample after drying (gram).

2.9. Total soluble solids analysis

Total soluble solids (TSS) were measured using a digital refractometer type DR301-95. The TSS value is expressed in degrees of brix to indicate the dissolved sugar content in the sample. Measurements were made by crushing 2 grams of jackfruit and then placing it on the refractometer sensor. Each treatment was repeated three times.

2.10. Data analysis

Analysis of variance (ANOVA) was used to determine the comparison of the results of the two types of dryers to the characteristics of frozen jackfruit. If the ANOVA table the F-count value is greater than F-crit, it means that there is a difference at the 5% significance level [24].

3. Results and discussions

3.1. Water losses

The data of WL in the sample during vacuum freeze-drying was shown in Figure 2. In this figure, it can be seen that the water losses in the EGH method is higher than that of the VFD method. This is due to the exhaust gas heat from the condenser as a heating source in the EGH method which can significantly accelerate the evaporation rate of water, whereas in the VFD method the water evaporation process only occurs because of the difference in pressure inside and outside the drying chamber. In line with this, Westerterp et al. [25] also stated that the process of evaporation of the water on the material during vacuum freeze drying occurs because there are difference in pressure on the surface of the material with environmental pressure and the longer the drying process, the more water was evaporated.

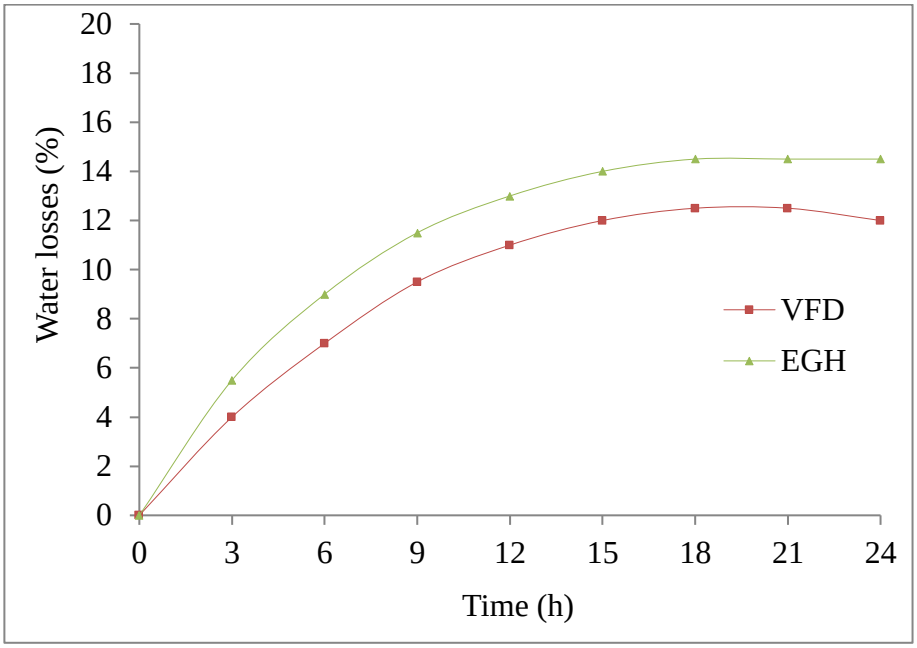

Figure 2. The water loss profile of fresh cut jackfruit during vacuum-freeze drying

Based on the results of the analysis of variance, it was known that the use of different drying methods provides different WL data. The EGH method produces a higher WL value

(14.50%) than the VFD method (12.06%). This shows that the use of additional heat energy from the exhaust gas heat of the condenser has a significant effect on the WL value.

Other factors that influence water losses during drying are temperature and drying time. This result in line with the opinion of Mello et al. [26] that many factors influence to the water losses in the drying process, including drying temperature, air humidity, and air flow velocity. The greater the temperature difference between the heating medium and the drying material, the faster the heat transfer into the material, the rate faster of water losses from the dried material. The air humidity was inversely related to drying time. The higher the humidity, the longer the drying process will be. Meanwhile, the air flow rate was directly proportional to the drying time. The higher the air flow rate, the faster the drying process.

3.2. Moisture content

Figure 2 presents the curves of the reduction in moisture content of the two different drying methods used in this study. To reach the moisture content of the frozen product, these two methods have different times. The final moisture content in the EGH method is much lower than the VFD method. This indicates that the use of exhaust gas heat from a condenser as a heating source can significantly accelerate the rate of decreasing moisture content. These data indicate that one of the important characteristics of vacuum freeze-dryers was the efficient use of energy to reduce moisture content compared to other drying methods.

In Figure 3 it can also be seen that the final water content of the sample in the VFD method is higher, namely 15.95% than the final water content in the EGH method which is only 9.45%. This happens because there are additional heat energy from the condenser that the water sublimation process in the EGH method takes place faster than the VFD method. The same study have been described by Zhang et al. [27] that by utilizing secondary drying

in a freeze dryer can optimize the sublimation process of water that the drying process takes place very quickly.

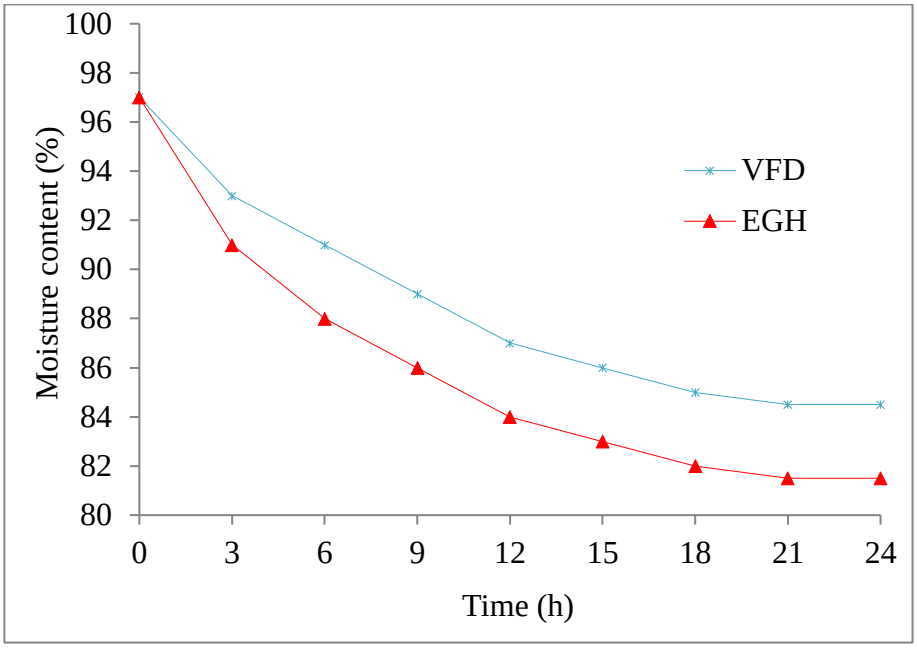

Figure 3. Curve of the rate of reduction in moisture content during vacuum freeze drying

The moisture content is a very important characteristic of freeze-dried food products because the moisture content can affect the appearance, texture, and taste of the product [28]. The moisture content also affects the freshness and shelf life of the product. The high water content can make bacteria, molds, and yeast easy to reproduce there will be changes in foodstuffs [29]. The vacuum freeze drying process can remove moisture content from the sample. The moisture content produced from the vacuum freeze dryer in this study has met the quality requirements of freeze-dried fruit products a maximum of 15% [30].

3.3. Texture

Vacuum-freeze drying is a drying method that causes sublimation of the water vapor in the material that the structure of the material expands. The results of the texture test using the compression method showed that the samples dried by the EGH method produced a

crispier texture than the VFD method (Figure 4). It shows that the water vapor sublimation process that occurs in the EGH method causes the sample texture to be crunchy and easy to break. The factors causing the crisp texture of the sample are due to the low pressure in the drying chamber and the relatively high internal vapor pressure during the vacuum freeze drying process.

In the EGH method, the sample structure changes due to the effect of additional heating energy from the exhaust gas heat of the condenser, after which the sample ice crystals turn into gas and then evaporate. Compared to the EGH method, the sublimation process in the VFD method was a heating process with low temperatures that the sample ice crystals evaporate more slowly. That's what causes sample shrinkage. The results of the same paper have been described by Liu et al. [31] that the shocking effect of the freezing process then heated to a higher temperature is the change of ice to vapor that the texture of the sample is crispier and more porous.

The changing process of the sample texture has occurred shortly after drying, then evaporation of the water occurs and air bubbles form. Previous studies have reported by Zielinska et al. [32] that the vacuum freeze drying process can cause water evaporation, then the product expands and forms air cavities. The high and low texture value of a material according to Bozkir et al. [33] depending on the characteristics of the material, such as thickness, homogenization, and composition.

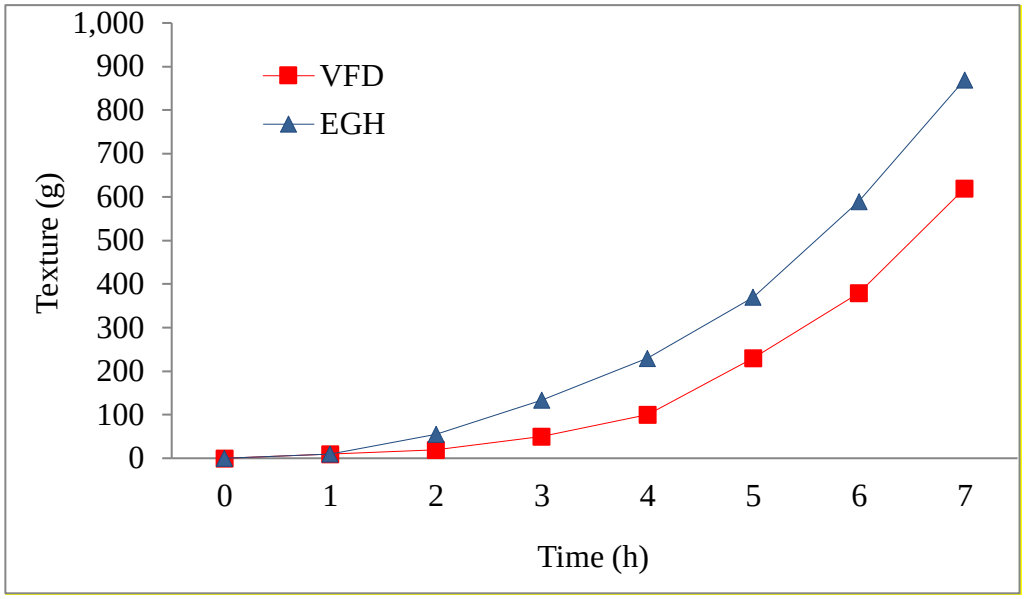

Figure 4. The texture profile of cut jackfruit during vacuum freeze dryer

The samples dried using the EGH method caused the water to come out of the fruit cell walls faster than the VFD method. This difference in the evaporation of high water content causes the texture structure of the sample to become more brittle and expand. This result in line with the study reported by Sobaszek et al. [34] that the vacuum freeze drying process resulted in water evaporation that the texture of the fruit would become hard.

In general, the texture of the jackfruit from vacuum freeze drying depends on the cell wall tissue. The texture change occurs in the vacuum freeze drying process because the sample has lost some of its moisture content. This view is supported by Pei et al. [35] who writes that the texture structure of the fruit depends on the cell wall tissue that in the vacuum freeze dryer there is a hardening on the surface of the material accompanied by changes in the size of the product texture.

3.4. Color

Changes in the color of fresh cut jackfruit before and after vacuum freeze drying can be seen from the data in Figure 5. The graph of the color change of the fresh-cut jackfruit during vacuum freeze drying can be seen from the data in Table 1. Based on the Table 1 we can see that the type of dryer has no significant effect on lightness (L*), redness (a*), and yellowness (b*).

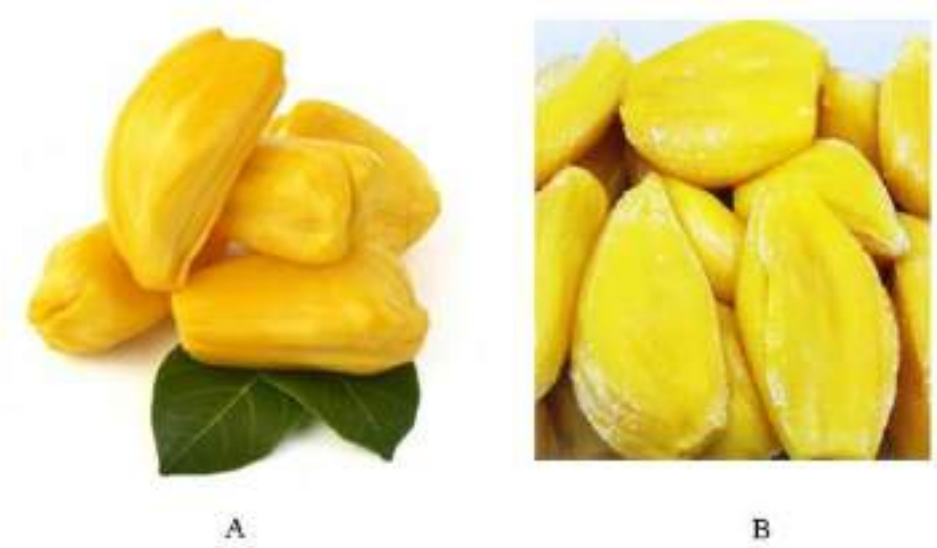

Figure 5. The color of fresh cut jackfruit before (A) and after (B) vacuum freeze-drying

Table 1. Value of lightness (L*), redness (a*), and yellowness (b*) of the fresh-cut jackfruit during vacuum freeze drying.

Drying methods	**Color**		
	L*	a*	b*
Control	58.62 ± 0.55 [a]	5.75 ± 0.78 [a]	67.23 ± 0.14 [a]
EGH	57.23 ± 0.21 [a]	5.92 ± 0.14 [a]	68.37 ± 0.42 [a]
VFD	57.12 ± 0.34 [a]	5.42 ± 0.56 [a]	69.63 ± 0.12 [a]

Note: numbers followed by different letter notations in the same column show significant differences at the 0.05 significance level ($P<0.05$).

Based the data in Table 1, it is apparent that the change in the lightness color of the freeze-dried jackfruit tended to decrease during the drying process. The sample color changes from shiny yellow become opaque yellow in both types of drying methods. The lightness value in the VFD method was lower (57.12) than the EGH method (57.23) although it was not significantly different. The lightness color shows a decreasing trend during drying in both methods. This is caused by a biological reaction, resulting in an enzymatic process that causes the color of the sample to decrease in brightness. This result is in line with Keutgen and Pawelzik [36] have reported that low temperatures in the vacuum freeze drying process have not been able to activate the polyphenolic enzymes in the sample and the enzymes can still be active at temperatures as low as -73 ºC, although with very low reaction rates.

The redness and yellowness color intensity did not change during the vacuum freeze drying process. The sample color before and after drying did not change significantly. Several investigators have also reported that the use of a vacuum freeze dryer did not result in color changes in the samples [37]. Sample color change usually occurs at high drying temperatures [38]. The same analogy has been explained by Falah et al. [39] that a significant change in sample color during high temperature drying can occur, but the change is not significant at cold temperature.

3.5. Weight losses (WL)

The results of the WL calculation of fresh-cut jackfruit during vacuum freeze drying are shown in Table 2. At the beginning of the drying process, the WL occurs very rapidly until 6^{th} hour, then slowly until the end of drying. After reaching the saturated condition, the

sample WL no longer changes. Table 2 also shows that the WL is higher in the EGH method compared to the VFD method.

Table 2. Average of WL value of fresh cut jackfruit from vacuum freeze drying

Drying time (hour)	Weight losses (g)	
	EGH	VFD
1	0.00 [a]	0.00 [a]
2	7.29 [b]	6.53 [b]
3	10.12 [c]	9.41 [c]
4	15.13 [d]	13.75 [d]
5	23.14 [e]	18.65 [e]
6	35.67 [f]	29.42 [f]
7	37.32 [f]	31.82 [g]

Note: numbers followed by different letter notations in the same column show significant differences at the 0.05 significance level ($P < 0.05$).

From the table above we can see that the samples dried in the EGH method had a final WL of 37.32 g, while those dried in the VFD method had a final WL of 31.82 g. These data indicate that the use of exhaust gas heat form a condenser in the EGH method has a significant effect on reducing WL of fresh-cut jackfruit

The duration of the drying process also has a significant effect on the WL of fresh-cut jackfruit. The long drying process can trigger an increase in the percentage of WL in the sample. The same it cases has been reported by Singh and Khan [40] that WL is generally affected by the evaporation of moisture during drying due to the breakdown of organic compounds into inorganic compounds, namely compounds are oxidized to CO_2 and absorb O_2, then reduced to H_2O.

276

277 *3.6. Total Soluble Solids (TSS)*

278 The results of measuring the TSS value of fresh-cut jackfruit from vacuum freeze
279 drying are shown in Table 3.

280

281 Table 3. Average TSS value of fresh-cut jackfruit from vacuum freeze drying

Drying time (hour)	Total soluble solids (ºBrix)	
	EGH	VFD
1	8.04 [a]	8.04 [a]
2	10.19 [b]	09.83 [b]
3	11.23 [c]	10.31 [c]
4	12.33 [d]	11.67 [d]
5	14.46 [e]	13.55 [e]
6	15.67 [f]	14.92 [f]
7	17.32 [g]	16.22 [g]

282 Note: numbers followed by different letter notations in the same column show significant
283 differences at the 0.05 significance level ($P<0.05$).

284

285 The data in Table 3 shows that during drying, there was an increase in the TSS value
286 in the sample due to the respiration and transpiration processes that were still ongoing even
287 though the fruit had been harvested. The increase in TSS value is also accelerated by vacuum
288 freeze drying. The TSS value was higher in the EGH method than the VFD method. This is
289 thought to be due to the influence of the exhaust gas heat from a condenser which triggers
290 the carbohydrate content to become sugar levels. A similar thing has been reported by
291 Rydzak et al. [41] that immature fruit stores a lot of carbohydrates in the form of starch and

during the process towards maturity the content will turn into sugar. According to Yusufe et al. [42], fruits at advanced maturity levels have the highest TSS content, due to hydrolysis of starch to sugar.

Total soluble solids are the combination of all inorganic and organic substances present in food. Based on the data in Table 3, it can be seen that at the beginning of drying the TSS value is still low. With the length of drying time, the TSS value tended to be higher in the two methods, but had different values. The difference in TSS value is thought to be due to the difference in temperature used between the EGH and VFD methods. The driving force of the exhaust gas heat from condenser in the EGH method causes some of the water to evaporate faster. In addition, the faster sublimation process can open larger pores of the sample surface. When the pores of the sample surface as the permeability membrane opens wider, the amount of water evaporating from the material will also increase [43].

4. Conclusions

The exhaust gas heat from a condenser can be used to accelerate the sublimation process during the vacuum-freeze drying process, the drying process can take place faster. The results of this study have proven that the use of exhaust gas heat from a condenser has a significant effect on the parameters of water losses, moisture content, texture, weight losses, and total dissolved solids, but it does not affect the sample color.

This new finding provides a better scientific understanding of the vacuum freeze-drying process. Therefore, the results of this study are recommended to be applied to vacuum freeze dryers for drying food products.

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318 **Conflicts of Interest**

319 The authors declared no conflict of interest.

320

321 **References**

[1] Z. Shaozhi, L. Jielin, C. Guangming and W. Qin, "Thermodynamic analysis of a freeze-dryer utilizing hygroscopic solution," *Drying Technology*, 2017.

[2] W. M. Obeidat, E. Sahni, W. Kessler and M. Pikal, "Development of a Mini-Freeze Dryer for Material-Sparing Laboratory Processing with Representative Product Temperature History," *AAPS PharmSciTech*, vol. 19, no. 12, pp. 599-609, 2017.

[3] Ansar, Nazaruddin and A. D. Azis, "Effect of vacuum freeze-drying condition and maltodextrin on the physical and sensory characteristics of passion fruit (Passiflora edulis sims) extract," in *IOP Conference Series: Earth and Environmental Science*, Makassar, 2019.

[4] H. T. Ngo, S. Tojo, T. Ban and T. Chosa, "Effects of Prior Freezing Conditions on the Quality of Blueberries in a Freeze-Drying Process," *Transactions of the ASABE*, vol. 60, no. 4, pp. 1369-1377, 2017.

[5] Ansar, Nazaruddin and A. D. Azis, "New frozen product development from strawberries (Fragaria Ananassa Duch.)," *Heliyon*, vol. 6, no. 9, p. e05118, 2020.

[6] V. B. Nguyen, D. H. Nguyen and H. V. Nguyen, "Combination effects of calcium chloride and nano-chitosan on the postharvest quality of strawberry (Fragaria x ananassa Duch.)," *Postharvest Biology and Technology*, vol. 162, no. 111103, 2020.

[7] B. Schulze, E. M. Hubbermann and K. Schwarz, "Stability of quercetin derivatives in vacuum impregnated apple slices after drying (microwave vacuum drying, air drying, freeze drying) and storage," *LWT-Food Science and Technology*, vol. 57, no. 1, pp. 426-433, 2014.

[8] K. Sun, R. Li, W. Jiang, Y. Sun and H. Li, "Comparison of three-dimensional printing and vacuum freeze-dried techniques for fabricating composite scaffolds," *Biochemical and Biophysical Research Communications*, vol. 477, no. 4, pp. 1085-1091, 2016.

[9] Y. M. Chew and V. E. King, "Microwave Drying of Pitaya (Hylocereus) Peel and the Effects Compared with Hot-Air and Freeze-drying," *Transactions of the ASABE,* vol. 62, no. 4, pp. 919-928, 2019.

[10] A. Khampakool, S. Soisungwan and S. H. Park, "Potential application of infrared assisted freeze drying (IRAFD) for banana snacks: Drying kinetics, energy consumption, and texture," *LWT-Food Science and Technology,* 2018.

[11] L. J. Wang and W. Sun, "Numerical analysis of the three–dimensional mass and heat transfer with inner moisture evaporation in porous cooked meat joints during vacuum cooling," *Transactions of the ASAE,* vol. 46, no. 1, pp. 107-115, 2003.

[12] A. Lakatos, A. Csik and I. Csarnovics, "Experimental verification of thermal properties of the aerogel blanket," *Case Studies in Thermal Engineering,* vol. 21, p. 100966, 2021.

[13] V. Reyes, R. Bubnovich, M. Bustos, R. Vásquez, R. Vega and E. Scheuermann, "Comparative study of different process conditions of freeze drying of 'Murtilla' berry," *Drying Technology: An International Journal, 28:12, 1416-1425,* vol. 28, no. 12, pp. 1416-1425, 2010.

[14] Y. Xu, M. Zhang, A. S. Mujumdar, X. Duan and S. Jin-cai, "A two-stage vacuum freeze and convective air drying method for strawberries," *Drying Technology: An International Journal,* vol. 24, no. 8, pp. 1019-1023, 2006.

[15] X. F. Wu, M. Zhang, Y. Ye and D. Yu, "Influence of ultrasonic pretreatments on drying kinetics and quality attributes of sweet potato slices in infrared freeze drying (IRFD)," *LWT,* vol. 131, p. 109801, 2020.

[16] H. Selvnes, Y. Allouche, R. I. Manescu and A. Hafner, "Review on cold thermal energy storage applied to refrigeration systems using phase change materials," *Thermal Science and Engineering Progress,* vol. 22, p. 100807, 2021.

[17] G. Assegehegn, E. B. Fuente, J. M. Franco and C. Gallegos, "The Importance of Understanding the Freezing Step and Its Impact on Freeze-Drying Process Performance," *Journal of Pharmaceutical Sciences,* vol. 108, no. 4, pp. 1378-1395, 2019.

[18] M. Shehadi, "Optimizing solar cooling systems," *Case Studies in Thermal Engineering,* vol. 21, p. 100663, 2020.

[19] A. U. Shingisov and R. S. Alibekov, "Analysis of the moisture evaporation process during vacuum freeze-drying of koumiss and shubat," *Heat and Mass Transfer,* vol. 53, no. 5, p. 1571–1578, 2017.

[20] M. J. Al-Kheetan, M. M. Rahman, S. H. Ghaffar, M. Al-Tarawneh and Y. S. Jweihan, "Comprehensive investigation of the long-term performance of internally integrated concrete pavement with sodium acetate," *Results in Engineering,* vol. 6, p. 100110, 2020.

[21] J. S. Souza, M. D. Medeiros, M. A. Magalhaes and F. N. Fernandes, "Optimization of osmotic dehydration of tomatoes in a ternary system followed by air-drying," *Journal of Food Engineering,* vol. 83, no. 1, pp. 501-509, 2007.

[22] J. Chapman, A. Elbourne, V. K. Truong, L. Newman, S. Gangadoo, P. Rajapaksha Pathirannahalage and D. Cozzolino, "Sensomics - from conventional to functional NIR spectroscopy-shining light over the aroma and taste of foods," *Trends in Food Science & Technology,* 2019.

[23] S. M. Goni and V. O. Salvadori, "Prediction of cooking times and weight losses during meat roasting," *Journal of Food Engineering,* vol. 100, no. 1, pp. 1-11, 2010.

[24] Ansar, Nazaruddin and A. D. Azis, "Caking mechanisms of passion fruit powder during storage," *International Journal of Innovation, Creatifity, and Change,* vol. 13, no. 2, pp. 618-628, 2020.

[25] K. Westerterp, G. Plasqui and A. Goris, "Water loss as a function of energy intake, physical activity and season," *British Journal of Nutrition,* vol. 93, no. 2, pp. 199-203, 2005.

[26] R. E. Mello, A. Fontana, A. Mulet, J. Luiz, G. Correa and J. A. Cárcel, "Ultrasound-assisted drying of orange peel in atmospheric freeze-dryer and convective dryer operated at moderate temperature," *Drying Technology,* vol. 38, no. 1, pp. 259-267, 2020.

[27] C. Zhang, X. Bu, J. He, C. Liu, G. Lin and J. Miao, "Simulation of evaporation and sublimation process in porous plate water sublimator based on a reduced CFD model," *International Journal of Heat and Mass Transfer,* vol. 154, p. 119787, 2020.

[28] X. Xu, Q. Li, Y. Lai, W. Pang and R. Zhang, "Effect of moisture content on mechanical and damage behavior of frozen loess under triaxial condition along with different confining pressures," *Cold Regions Science and Technology,* vol. 157, pp. 110-118, 2019.

[29] V. I. Aksenov, S. G. Gevorkyan and V. V. Doroshin, "Dependence of Strength and Physical Properties of Frozen Sands on Moisture Content," *Soil Mechanics and Foundation Engineering,* vol. 54, p. 420–424, 2018.

[30] Z. M. Salisu, S. U. Ishiaku, D. Abdullahi, M. K. Yakubu and B. H. Diya'uddeen, "Development of kenaf shive bio–mop via surface deposit technique for water

remediation from crude oil spill contamination," *Results in Engineering,* vol. 3, p. 100020, 2019.

[31] B. Liu, Y. Zhao, Y. Jia and J. Liu, "Heating Drives DNA to Hydrophobic Regions While Freezing Drives DNA to Hydrophilic Regions of Graphene Oxide for Highly Robust Biosensors," *Journal of the American Chemical Society,* vol. 142, no. 34, pp. 14702-14709, 2020.

[32] M. Zielinska, M. Markowski and D. Zielinska, "The effect of freezing on the hot air and microwave vacuum drying kinetics and texture of whole cranberries," *Drying Technology,* vol. 37, no. 13, pp. 1714-1730, 2019.

[33] H. Bozkir, Y. Tekgül and E. S. Erten, "Effects of tray drying, vacuum infrared drying, and vacuum microwave drying techniques on quality characteristics and aroma profile of orange peels," *Journal of Food Process Engineering,* vol. 44, no. 1, p. e13611, 2021.

[34] P. Sobaszek, R. Różyło, L. Dziki, U. Gawlik-Dziki, B. Biernacka and M. Panasiewicz, "Evaluation of Color, Texture, Sensory and Antioxidant Properties of Gels Composed of Freeze-Dried Maqui Berries and Agave Sugar," *Processes,* vol. 8, no. 10, p. 1294, 2020.

[35] F. Pei, W. Yang, Y. Shi, Y. Sun, A. M. Mariga, L. Y. Zhao, Y. Fang, N. Ma, X. An and Q. Hu, "Comparison of Freeze-Drying with Three Different Combinations of Drying Methods and Their Influence on Colour, Texture, Microstructure and Nutrient Retention of Button Mushroom (Agaricus bisporus) Slices," *Technology,* vol. 7, p. 702–710, 2014.

[36] A. J. Keutgen and E. Pawelzik, "Qualit yand nutrition value of strawberry fruit under longterm salt stress," *Journal Food Chemistry,* vol. 107, no. 2, pp. 1413-1420, 2007.

[37] X. Q. Yue, Z. Y. Shang, J. Y. Yang, L. Huang and Y. Q. Wang, "A smart data-driven rapid method to recognize the strawberry maturity," *Information Processing in Agriculture,* 2019.

[38] Y. Zhang and S. Barringe, "Effect of hydrocolloids, sugar, and citric acid on strawberry volatiles in a gummy candy," *J Food Process Preserv,* p. 00:e13327., 2017.

[39] M. A. Falah, P. Yuliastuti, R. Hanifah, P. Saroyo and Jumeri, "Quality of fresh strawberry (fragaria sp cv. holibert) from Ketep Magelang Central Java and its storage in tropical environment," *Jurnal Agro Industri,* vol. 8, no. 1, pp. 1-10, 2018.

[40] Z. Singh and A. S. Khan, "Physiology of plum fruit ripening," *Stewart Postharvest Rev.,* vol. 2, no. 1, pp. 3-12, 2010.

[41] L. Rydzak, Z. Kobus, R. Nadulski, K. Wilczyński, A. Pecyna, F. Santoro, A. Sagan, A. Starek-Wójcick and M. Krzywicka, "Analysis of Selected Physicochemical Properties of Commercial Apple Juices," *Processes,* vol. 8, p. 1457, 2020.

[42] M. Yusufe, A. Mohammed and N. Satheesh, "Effect of duration and drying temperature on characteristics of dried tomato (Lycopersicon esculentum L.) cochoro variety," *Journal of Food Technology,* vol. 21, no. 1, pp. 41-50, 2017.

[43] Q. V. Nguyen and H. V. Chuyen, "Processing of Herbal Tea from Roselle (Hibiscus sabdariffa L.): Effects of Drying Temperature and Brewing Conditions on Total Soluble Solid, Phenolic Content, Antioxidant Capacity and Sensory Quality," *Beverages,* vol. 6, no. 1, pp. 1-11, 2020.

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From: Administrator
Date: 15/12/2021 05.30 PM
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Ansar - <ansar72@unram.ac.id> 17 Desember 2021 06.49
Kepada: Researcher Support <support@elsevier.com>

Dear Jana S. Nolos
Research Support
ELSEVIER

We are hereby sent a Waiver Request (Fact-find) form. Hopefully, it can be considered.

Best regards,
Dr. Ansar
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Researcher Support <support@elsevier.com> 18 Desember 2021 23.46
Balas Ke: Researcher Support <support@elsevier.com>
Kepada: ansar72@unram.ac.id

Dear Dr. Ansar,

Article reference: RINENG_100317

Thank you for completing the Fact Find Sheet.

I have noted that you input "Yes" in all authors Grantee's field.

In this case, could you please confirm if all authors received grants from their Institution.

Looking forward to your response.

Kind regards,

Jana S. Nolos
Researcher Support
ELSEVIER

From: Ansar Ansar
Date: Thursday, December 16, 2021 10:49 PM GMT

Dear Jana S. Nolos
Research Support
ELSEVIER

We are hereby sent a Waiver Request (Fact-find) form. Hopefully, it can be considered.

Best regards,
Dr. Ansar

Pada tanggal Rab, 15 Des 2021 pukul 01.17 Researcher Support <support@elsevier.com> menulis:

From: Administrator
Date: Thursday, December 16, 2021 05:30 PM GMT

Dear Ansar

Our reference: 211211-008712

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From: Jana Sentillas Nolos
Date: Tuesday, December 14, 2021 05:17 PM GMT
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[Kutipan teks disembunyikan]

Ansar - <ansar72@unram.ac.id> 19 Desember 2021 21.46
Kepada: Researcher Support <support@elsevier.com>

Dear **Jana S. Nolos**
Researcher Support
ELSEVIER

Thank you for your email.
I have completed the fact-find form. Hope it can be considered.

Best regards,
Dr. Ansar

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Researcher Support <support@elsevier.com> 21 Desember 2021 20.13
Balas Ke: Researcher Support <support@elsevier.com>
Kepada: ansar72@unram.ac.id

Dear Dr. Ansar,

Article reference: RINENG_100317

Thank you for your reply.

I have checked the Fact Find Sheet and I have noted that you input "Yes" in all authors Grantee fields.

Could you please confirm if all authors received Grants from their Institution.

Thank you for your time and I am looking forward to your response.

Kind regards,

Jana S. Nolos
Researcher Support
ELSEVIER

From: Ansar Ansar
Date: Sunday, December 19, 2021 01:47 PM GMT

Dear **Jana S. Nolos**
Researcher Support
ELSEVIER

Thank you for your email.
I have completed the fact-find form. Hope it can be considered.

Best regards,
Dr. Ansar

Pada tanggal Rab, 15 Des 2021 pukul 01.17 Researcher Support <support@elsevier.com> menulis:

From: Jana Sentillas Nolos
Date: Saturday, December 18, 2021 03:46 PM GMT

Dear Dr. Ansar,

Article reference: RINENG_100317

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From: Jana Sentillas Nolos
Date: Tuesday, December 14, 2021 05:17 PM GMT

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[Kutipan teks disembunyikan]

Ansar - <ansar72@unram.ac.id> 21 Desember 2021 21.38
Kepada: Researcher Support <support@elsevier.com>

Dear **Jana S. Nolos**
Researcher Support
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Thank you very much for your attention.
I have changed the input "NO" in all author's Grantee fields.

Best regards,

Dr. Ansar
[Kutipan teks disembunyikan]

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Researcher Support <support@elsevier.com> 23 Desember 2021 23.38
Balas Ke: Researcher Support <support@elsevier.com>
Kepada: ansar72@unram.ac.id

Dear Dr. Ansar,

Article reference: RINENG_100317

Thank you for completing the Fact Find Sheet.

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Best regards,
Dr. Ansar

Pada tanggal Sel, 21 Des 2021 pukul 20.13 Researcher Support <support@elsevier.com> menulis:

From: Jana Sentillas Nolos
Date: Tuesday, December 21, 2021 12:13 PM GMT
[Kutipan teks disembunyikan]
[Kutipan teks disembunyikan]

Researcher Support <support@elsevier.com> 24 Desember 2021 23.45
Balas Ke: Researcher Support <support@elsevier.com>
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Dear Ansar

Our reference: 211211-008712

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Jana S. Nolos
Researcher Support
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From: Ansar Ansar
Date: 19/12/2021 01.47 PM

Dear **Jana S. Nolos**
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Best regards,
Dr. Ansar

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From: Jana Sentillas Nolos
Date: 18/12/2021 03.46 PM

Dear Dr. Ansar,

Article reference: RINENG_100317

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Kind regards,

Jana S. Nolos
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Date: 16/12/2021 10.49 PM

Dear Jana S. Nolos
Research Support
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Ansar - <ansar72@unram.ac.id> 25 Desember 2021 07.22
Kepada: Researcher Support <support@elsevier.com>

Dear **Jana S. Nolos**
Researcher Support
ELSEVIER

Article reference: RINENG_100317

Attached is a letter from the Head of the Agricultural Engineering Study Program explaining that our research was not get funding from our institution.

Best regards,
Dr. Ansar

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Letter of Study Program.jpg
146K

Researcher Support <support@elsevier.com> 31 Desember 2021 20.38
Balas Ke: Researcher Support <support@elsevier.com>
Kepada: ansar72@unram.ac.id

Dear Dr. Ansar,

Article reference: RINENG_100317
Article title: Using of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate

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Researcher Support
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From: Ansar Ansar
Date: Friday, December 24, 2021 11:22 PM GMT

Dear **Jana S. Nolos**
Researcher Support
ELSEVIER

Article reference: RINENG_100317

Attached is a letter from the Head of the Agricultural Engineering Study Program explaining that our research was not get funding from our institution.

Best regards,
Dr. Ansar

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Date: Friday, December 24, 2021 03:45 PM GMT

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From: Jana Sentillas Nolos
Date: Thursday, December 23, 2021 03:38 PM GMT

Dear Dr. Ansar,

Article reference: RINENG_100317

Thank you for completing the Fact Find Sheet.

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Many thanks and I look forward to hear from you.

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Jana S. Nolos
Researcher Support
ELSEVIER

From: Ansar Ansar
Date: Tuesday, December 21, 2021 01:45 PM GMT

Dear **Jana S. Nolos**
Researcher Support
ELSEVIER

Thank you very much for your attention.
I have changed the input "NO" in all author's Grantee fields.

Best regards,

Dr. Ansar

Pada tanggal Sel, 21 Des 2021 pukul 20.13 Researcher Support <support@elsevier.com> menulis:

From: Jana Sentillas Nolos
Date: Tuesday, December 21, 2021 12:13 PM GMT

Dear Dr. Ansar,

Article reference: RINENG_100317

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3. Telephone number - not essential but may be used if we need to ask additional information

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Researcher Support <support@elsevier.com> 2 Januari 2022 22.08
Balas Ke: Researcher Support <support@elsevier.com>
Kepada: ansar72@unram.ac.id

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Article title: Using of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate

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I wish to inform you that I received confirmation from the publisher that the open access fee for your article RINENG_100317, "Using of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate" has been waived.

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I hope this helps, but please let me know if I can be of further assistance.

Kind regards,

Jana S. Nolos
Researcher Support
ELSEVIER

From: Jana Sentillas Nolos
Date: Friday, December 31, 2021 12:38 PM GMT

[Kutipan teks disembunyikan]
[Kutipan teks disembunyikan]

Ansar - <ansar72@unram.ac.id>

Re: Using of Exhaust Gas Heat from a Condenser to Increase the Vacuum Free [211211-008712]

Researcher Support <support@elsevier.com> 2 Januari 2022 22.08
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Kepada: ansar72@unram.ac.id

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Article reference: RINENG_100317
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Researcher Support
ELSEVIER

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Date: Friday, December 31, 2021 12:38 PM GMT
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Ansar - <ansar72@unram.ac.id>

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Kepada: ansar72@unram.ac.id

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1 pesan

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ELSEVIER

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https://doi.org/10.1016/j.rineng.2021.100317

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Results in Engineering 13 (2022) 100317

Contents lists available at ScienceDirect

Results in Engineering

journal homepage: www.sciencedirect.com/journal/results-in-engineering

Using of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate

Ansar [a,*], Sukmawaty [a], Murad [a], Maria Ulfa [b], Atri Dewi Azis [c]

[a] Department of Agricultural Engineering, Faculty of Food Technology and Agroindustry, University of Mataram, Indonesia
[b] Department of Chemistry, Faculty of Mathematics and Natural Sciences, University of Mataram, Indonesia
[c] Department of English Education, Faculty of Teacher Training and Education, University of Mataram, Indonesia

ARTICLE INFO

Keywords:
Color losses
Moisture content
Quality parameters
Total soluble solids
Water losses

ABSTRACT

Vacuum freeze dryer is able to remove some of the moisture content of the material. However, the drying rate is very slow because the sublimation process must propagate through the layers of material. Therefore, the aim of this study is to examine the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate. Drying was carried out at freezing temperature of −55 °C and the drying time was 7 h. The research parameters observed were water losses, water content, texture, color, weight losses, and total soluble solids. The results showed that the exhaust gas heat in a vacuum freeze dryer can be used to optimize the water sublimation process. As a result, the drying process will be faster. The exhaust gas heat has a significantly effect on changes in water losses, moisture content, texture, weight losses, and total soluble solids, but does not significantly effect on the sample color. The drying system in the exhaust gas heat (EGH) method was more efficient because the final moisture content of the sample was 9.45% lower than the vacuum freeze dryer (VFD) method, which was 15.95%.

1. Introduction

Vacuum freeze drying has been proven to be an effective drying method to produce freeze-dried products with the best quality compared to other drying methods [1–3]. The advantages of freeze-drying products are the texture structure that does not shrink [4], thus allowing very fast rehydration, high flavor retention because drying takes place at low temperatures, and the reconstitution of living cells in freeze-dried products remains high [5,6]. It has been used to obtain high quality freeze-dried products [7,8].

Even though vacuum freeze drying is the best drying process [9], it has several drawbacks, including a slow drying rate because the heat used for the sublimation process must be propagated through the layer of material [10]. The porous structure of the material has a very low conductivity that the transfer of heat to the surface of the material is also very low [11,12].

Heating analysis to increase the efficiency of heat propagation to the material layer has been carried out by Reyes et al. [13], however, the use of exhaust gas heat a condenser has not been disclosed. Freeze drying using additional heating has been reported by Xu et al. [14] that the high drying temperature greatly affects the sublimation rate.

Freeze-drying kinetics are influenced by the freezing rate and heat and mass transfer rates during the sublimation process [15,16]. The freezing process is one of the stages of freeze drying which requires high energy [17,18]. Therefore, the search for a more appropriate method is one of the most needed efforts by the food processing industry today [19,20].

Research on the process of utilizing heat sources from the condenser has not been widely reported. Therefore, this research is very important to explain the efficiency of exhaust gas heat utilization that drying can take place quickly and produce hygienic frozen products. Therefore, the aim of this study was to examine the use of exhaust gas heat from a condenser to increase the vacuum freeze-drying rate.

2. Materials and methods

2.1. Materials

The materials used in the study were fresh cut-jackfruit with a harvest age of 3 months. This fruit was obtained from farmers' gardens in Mataram, West Nusa Tenggara Province, Indonesia. The jackfruit was split, then the skin was separated and the seeds are removed. Another

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material were refrigerant R134A was obtained from a minimarket in Mataram City, West Nusa Tenggara, Indonesia.

2.2. Tools

The main equipment used were a vacuum freeze dryer (VFD) and a modified vacuum freeze dryer with the use of exhaust gas heat (EGH) (Fig. 1). The other equipment were a digital refractometer type DR301-95, moisture tester, color meter TES135 series, and texture analyzer Brookfield model CT3.

2.3. Drying procedure

The drying process was carried out with a freeze temperature of −55 °C and the drying time was 7 h. Each treatment used a sample of 0.5 kg of fresh-cut jackfruit. The experiment was repeated 3 times.

2.4. Water losses analysis

Water losses (WL) describes the amount of water evaporated from the sample during the vacuum freeze drying process which can be calculated by equation (1) [21]:

$$WL = m_0 - m_t\frac{W_t}{W_0} \tag{1}$$

where, m_0 = sample moisture content at time 0 (%), m_t = sample moisture content at time t (%), W_0 = sample weight at time-0 (grams), W_t = sample weight at the time-t (gram).

2.5. Moisture content analysis

The moisture content of fresh-cut jackfruit was determined following the standard method of analysis [3]. Approximately 5 g of the sample was weighed into a can. The sample was heated to 50 + 1 °C until constant weight was reached, transferred to a desiccator, and was weighed soon after it had reached environment temperature. The moisture content was calculate by Equation (2) [5]:

$$M_c = \frac{a-b}{a} \times 100\% \tag{2}$$

where, M_c = moisture content (%), a = initial of moisture content (%), b = final of moisture content (%).

2.6. Texture analysis

The measurement of the sample texture of the result from the vacuum freeze dryer was carried out using a texture analyzer with a compression method. The loading was carried out with a compression speed of 4 mm/s. The result can be calculated using equation (3) [4]:

$$T = \frac{P}{A} \tag{3}$$

where, T = texture (N/mm^2), P = compressive force (N), and A = cross-sectional area (mm^2).

2.7. Color analysis

The color of fresh-cut jackfruit was measurement using the Chroma meter type AT-13-04 Konica Minolta type CR-400. Color measurement using the Hunter L* a* b* color value system [22].

For lightness were defined as:

$$L* = L*_d - L*_f \tag{4}$$

For redness were defined as:

$$a* = a*_d - a*_f \tag{5}$$

For yellowness were defined as:

$$b* = b*_d - b*_f \tag{6}$$

where, L* = lightness (L* = 0 for black, L* = 100 for white), a* = green-red (a*<0 for green, a*>0 for red), b* = blue-yellow (b*<0 for blue, b*>0 for yellow), subscript 'f' refers to fresh samples and 'd' to the values of dried materials.

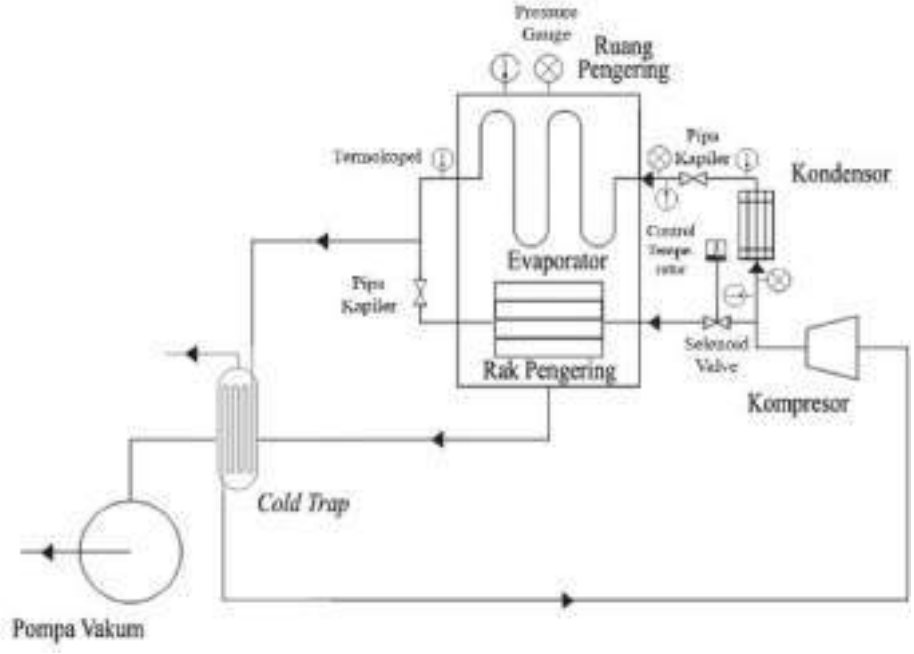

Fig. 1. The vacuum freeze drying equipment sketch.

2.8. Weight losses analysis

The weight losses (WL) of the sample was measured before and after drying. Weight losses was calculated using the following equation (6) [23]:

$$WL = \frac{w_f - w_d}{w_f} 100\% \quad (7)$$

where, WL = weight losses (%), w_f = mass of sample before drying (grams), w_d = mass of sample after drying (gram).

2.9. Total soluble solids analysis

Total soluble solids (TSS) were measured using a digital refractometer type DR301-95. The TSS value is expressed in degrees of brix to indicate the dissolved sugar content in the sample. Measurements were made by crushing 2 g of jackfruit and then placing it on the refractometer sensor. Each treatment was repeated three times.

2.10. Data analysis

Analysis of variance (ANOVA) was used to determine the comparison of the results of the two types of dryers to the characteristics of frozen jackfruit. If the ANOVA table the F-count value is greater than F-crit, it means that there is a difference at the 5% significance level [24].

3. Results and discussions

3.1. Water losses

The data of WL in the sample during vacuum freeze-drying was shown in Fig. 2. In this figure, it can be seen that the water losses in the EGH method is higher than that of the VFD method. This is due to the exhaust gas heat from the condenser as a heating source in the EGH method which can significantly accelerate the evaporation rate of water, whereas in the VFD method the water evaporation process only occurs because of the difference in pressure inside and outside the drying chamber. In line with this, Westerterp et al. [25] also stated that the process of evaporation of the water on the material during vacuum freeze drying occurs because there are difference in pressure on the surface of the material with environmental pressure and the longer the drying process, the more water was evaporated.

Based on the results of the analysis of variance, it was known that the use of different drying methods provides different WL data. The EGH method produces a higher WL value (14.50%) than the VFD method (12.06%). This shows that the use of additional heat energy from the exhaust gas heat of the condenser has a significant effect on the WL value.

Other factors that influence water losses during drying are temperature and drying time. This result in line with the opinion of Mello et al. [26] that many factors influence to the water losses in the drying process, including drying temperature, air humidity, and air flow velocity. The greater the temperature difference between the heating medium and the drying material, the faster the heat transfer into the material, the rate faster of water losses from the dried material. The air humidity was inversely related to drying time. The higher the humidity, the longer the drying process will be. Meanwhile, the air flow rate was directly proportional to the drying time. The higher the air flow rate, the faster the drying process.

3.2. Moisture content

Fig. 2 presents the curves of the reduction in moisture content of the two different drying methods used in this study. To reach the moisture content of the frozen product, these two methods have different times. The final moisture content in the EGH method is much lower than the VFD method. This indicates that the use of exhaust gas heat from a condenser as a heating source can significantly accelerate the rate of decreasing moisture content. These data indicate that one of the important characteristics of vacuum freeze-dryers was the efficient use of energy to reduce moisture content compared to other drying methods.

In Fig. 3 it can also be seen that the final water content of the sample in the VFD method is higher, namely 15.95% than the final water content in the EGH method which is only 9.45%. This happens because there are additional heat energy from the condenser that the water sublimation process in the EGH method takes place faster than the VFD method. The same study have been described by Zhang et al. [27] that by utilizing secondary drying in a freeze dryer can optimize the sublimation process of water that the drying process takes place very quickly.

The moisture content is a very important characteristic of freeze-dried food products because the moisture content can affect the appearance, texture, and taste of the product [28]. The moisture content also affects the freshness and shelf life of the product. The high water content can make bacteria, molds, and yeast easy to reproduce there will be changes in foodstuffs [29]. The vacuum freeze drying process can remove moisture content from the sample. The moisture content produced from the vacuum freeze dryer in this study has met the quality requirements of freeze-dried fruit products a maximum of 15% [30].

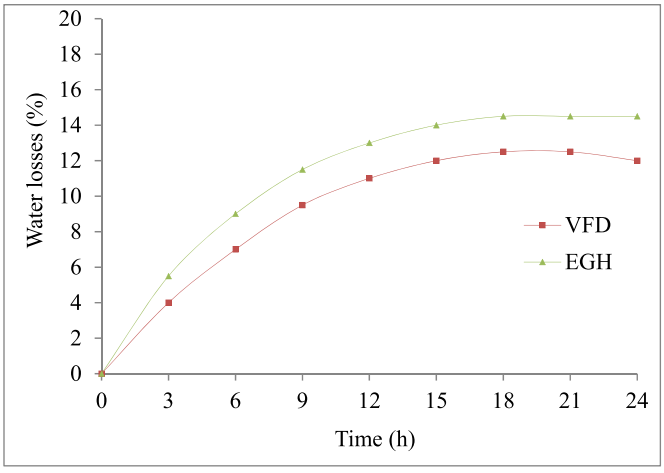

Fig. 2. The water loss profile of fresh cut jackfruit during vacuum-freeze drying.

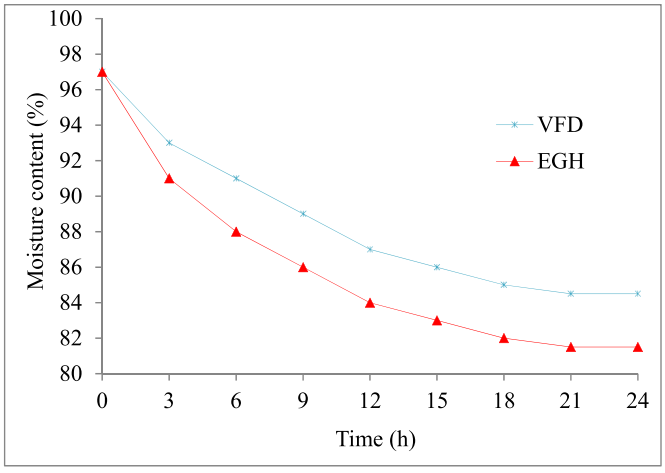

Fig. 3. Curve of the rate of reduction in moisture content during vacuum freeze drying.

3.3. Texture

Vacuum-freeze drying is a drying method that causes sublimation of the water vapor in the material that the structure of the material expands. The results of the texture test using the compression method showed that the samples dried by the EGH method produced a crispier texture than the VFD method (Fig. 4). It shows that the water vapor sublimation process that occurs in the EGH method causes the sample texture to be crunchy and easy to break. The factors causing the crisp texture of the sample are due to the low pressure in the drying chamber and the relatively high internal vapor pressure during the vacuum freeze drying process.

In the EGH method, the sample structure changes due to the effect of additional heating energy from the exhaust gas heat of the condenser, after which the sample ice crystals turn into gas and then evaporate. Compared to the EGH method, the sublimation process in the VFD method was a heating process with low temperatures that the sample ice crystals evaporate more slowly. That's what causes sample shrinkage. The results of the same paper have been described by Liu et al. [31] that the shocking effect of the freezing process then heated to a higher temperature is the change of ice to vapor that the texture of the sample is crispier and more porous.

The changing process of the sample texture has occurred shortly after drying, then evaporation of the water occurs and air bubbles form. Previous studies have reported by Zielinska et al. [32] that the vacuum freeze drying process can cause water evaporation, then the product expands and forms air cavities. The high and low texture value of a material according to Bozkir et al. [33] depending on the characteristics of the material, such as thickness, homogenization, and composition.

The samples dried using the EGH method caused the water to come out of the fruit cell walls faster than the VFD method. This difference in the evaporation of high water content causes the texture structure of the sample to become more brittle and expand. This result in line with the study reported by Sobaszek et al. [34] that the vacuum freeze drying process resulted in water evaporation that the texture of the fruit would become hard.

In general, the texture of the jackfruit from vacuum freeze drying depends on the cell wall tissue. The texture change occurs in the vacuum freeze drying process because the sample has lost some of its moisture content. This view is supported by Pei et al. [35] who writes that the texture structure of the fruit depends on the cell wall tissue that in the vacuum freeze dryer there is a hardening on the surface of the material accompanied by changes in the size of the product texture.

3.4. Color

Changes in the color of fresh cut jackfruit before and after vacuum freeze drying can be seen from the data in Fig. 5. The graph of the color change of the fresh-cut jackfruit during vacuum freeze drying can be seen from the data in Table 1. Based on the Table 1 we can see that the type of dryer has no significant effect on lightness (L*), redness (a*), and yellowness (b*).

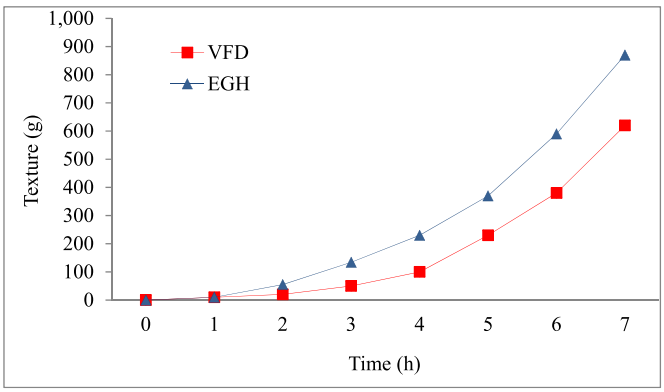

Fig. 4. The texture profile of cut jackfruit during vacuum freeze dryer.

Based the data in Table 1, it is apparent that the change in the lightness color of the freeze-dried jackfruit tended to decrease during the drying process. The sample color changes from shiny yellow become opaque yellow in both types of drying methods. The lightness value in the VFD method was lower (57.12) than the EGH method (57.23) although it was not significantly different. The lightness color shows a decreasing trend during drying in both methods. This is caused by a biological reaction, resulting in an enzymatic process that causes the color of the sample to decrease in brightness. This result is in line with Keutgen and Pawelzik [36] have reported that low temperatures in the vacuum freeze drying process have not been able to activate the polyphenolic enzymes in the sample and the enzymes can still be active at temperatures as low as −73 °C, although with very low reaction rates.

The redness and yellowness color intensity did not change during the vacuum freeze drying process. The sample color before and after drying did not change significantly. Several investigators have also reported that the use of a vacuum freeze dryer did not result in color changes in the samples [37]. Sample color change usually occurs at high drying temperatures [38]. The same analogy has been explained by Falah et al. [39] that a significant change in sample color during high temperature drying can occur, but the change is not significant at cold temperature.

3.5. Weight losses (WL)

The results of the WL calculation of fresh-cut jackfruit during vacuum freeze drying are shown in Table 2. At the beginning of the drying process, the WL occurs very rapidly until 6th hour, then slowly until the end of drying. After reaching the saturated condition, the sample WL no longer changes. Table 2 also shows that the WL is higher in the EGH method compared to the VFD method.

From the table above we can see that the samples dried in the EGH method had a final WL of 37.32 g, while those dried in the VFD method had a final WL of 31.82 g. These data indicate that the use of exhaust gas heat form a condenser in the EGH method has a significant effect on reducing WL of fresh-cut jackfruit.

The duration of the drying process also has a significant effect on the WL of fresh-cut jackfruit. The long drying process can trigger an increase in the percentage of WL in the sample. The same it cases has been reported by Singh and Khan [40] that WL is generally affected by the evaporation of moisture during drying due to the breakdown of organic compounds into inorganic compounds, namely compounds are oxidized to CO_2 and absorb O_2, then reduced to H_2O.

3.6. Total soluble solids (TSS)

The results of measuring the TSS value of fresh-cut jackfruit from vacuum freeze drying are shown in Table 3.

The data in Table 3 shows that during drying, there was an increase in the TSS value in the sample due to the respiration and transpiration processes that were still ongoing even though the fruit had been harvested. The increase in TSS value is also accelerated by vacuum freeze drying. The TSS value was higher in the EGH method than the VFD method. This is thought to be due to the influence of the exhaust gas heat from a condenser which triggers the carbohydrate content to become sugar levels. A similar thing has been reported by Rydzak et al. [41] that immature fruit stores a lot of carbohydrates in the form of starch and during the process towards maturity the content will turn into sugar. According to Yusufe et al. [42], fruits at advanced maturity levels have the highest TSS content, due to hydrolysis of starch to sugar.

Total soluble solids are the combination of all inorganic and organic substances present in food. Based on the data in Table 3, it can be seen that at the beginning of drying the TSS value is still low. With the length of drying time, the TSS value tended to be higher in the two methods,

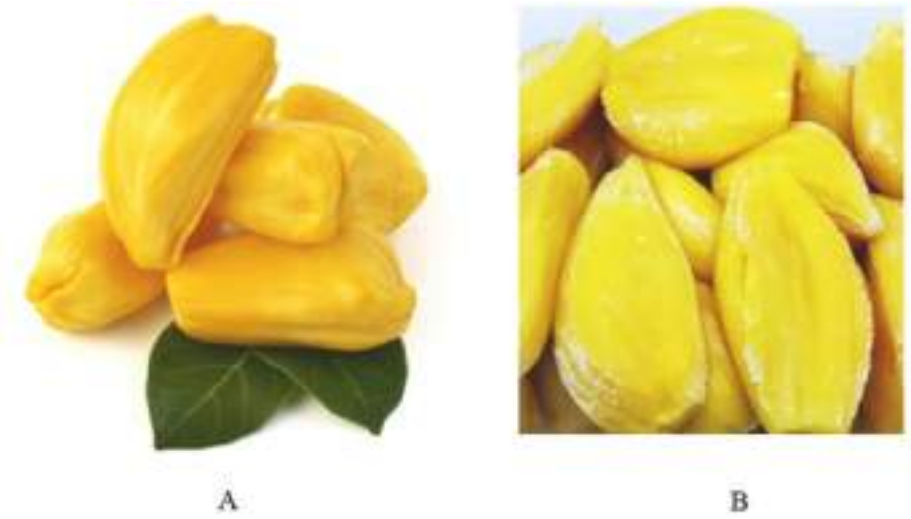

Fig. 5. The color of fresh cut jackfruit before (A) and after (B) vacuum freeze-drying. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Value of lightness (L*), redness (a*), and yellowness (b*) of the fresh-cut jackfruit during vacuum freeze drying.

Drying methods	Color		
	L*	a*	b*
Control	58.62 ± 0.55^{a}	5.75 ± 0.78^{a}	67.23 ± 0.14^{a}
EGH	57.23 ± 0.21^{a}	5.92 ± 0.14^{a}	68.37 ± 0.42^{a}
VFD	57.12 ± 0.34^{a}	5.42 ± 0.56^{a}	69.63 ± 0.12^{a}

Note: numbers followed by different letter notations in the same column show significant differences at the 0.05 significance level ($P < 0.05$).

Table 2
Average of WL value of fresh cut jackfruit from vacuum freeze drying.

Drying time (hour)	Weight losses (g)	
	EGH	VFD
1	0.00^{a}	0.00^{a}
2	7.29^{b}	6.53^{b}
3	10.12^{c}	9.41^{c}
4	15.13^{d}	13.75^{d}
5	23.14^{e}	18.65^{e}
6	35.67^{f}	29.42^{f}
7	37.32^{f}	31.82^{g}

Note: numbers followed by different letter notations in the same column show significant differences at the 0.05 significance level ($P < 0.05$).

Table 3
Average TSS value of fresh-cut jackfruit from vacuum freeze drying.

Drying time (hour)	Total soluble solids (°Brix)	
	EGH	VFD
1	8.04^{a}	8.04^{a}
2	10.19^{b}	09.83^{b}
3	11.23^{c}	10.31^{c}
4	12.33^{d}	11.67^{d}
5	14.46^{e}	13.55^{e}
6	15.67^{f}	14.92^{f}
7	17.32^{g}	16.22^{g}

Note: numbers followed by different letter notations in the same column show significant differences at the 0.05 significance level ($P < 0.05$).

but had different values. The difference in TSS value is thought to be due to the difference in temperature used between the EGH and VFD methods. The driving force of the exhaust gas heat from condenser in the EGH method causes some of the water to evaporate faster. In addition, the faster sublimation process can open larger pores of the sample surface. When the pores of the sample surface as the permeability membrane opens wider, the amount of water evaporating from the material will also increase [43].

4. Conclusions

The exhaust gas heat from a condenser can be used to accelerate the sublimation process during the vacuum-freeze drying process, the drying process can take place faster. The results of this study have proven that the use of exhaust gas heat from a condenser has a significant effect on the parameters of water losses, moisture content, texture, weight losses, and total dissolved solids, but it does not affect the sample color.

This new finding provides a better scientific understanding of the vacuum freeze-drying process. Therefore, the results of this study are recommended to be applied to vacuum freeze dryers for drying food products.

Credit author statement

Ansar: conceived and designed the experiments; analyzed and interpreted the data; wrote the paper. Sukmawaty: performed the experiments; analyzed and interpreted the data. Murad: performed the experiments; analyzed and interpreted the data. Maria Ulfa: analyzed and interpreted the data; contributed reagents, materials, analysis tools, or data. Atri Dewi Azis: analyzed and interpreted the data; contributed reagents, materials, analysis tools, or data. Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Z. Shaozhi, L. Jielin, C. Guangming, W. Qin, Thermodynamic Analysis of a Freeze-Dryer Utilizing Hygroscopic Solution, Drying Technology, 2017.

[2] W.M. Obeidat, E. Sahni, W. Kessler, M. Pikal, Development of a mini-freeze dryer for material-sparing laboratory processing with representative product temperature history, AAPS PharmSciTech 19 (12) (2017) 599–609.

[3] Ansar, Nazaruddin, A.D. Azis, Effect of vacuum freeze-drying condition and maltodextrin on the physical and sensory characteristics of passion fruit (Passiflora edulis sims) extract, in: M. Iqbal (Ed.), IOP Conference Series: Earth and Environmental Science, Makassar, IOP Conference Series, 2019.

[4] H.T. Ngo, S. Tojo, T. Ban, T. Chosa, Effects of prior freezing conditions on the quality of blueberries in a freeze-drying process, Trans. ASABE 60 (4) (2017) 1369–1377.

[5] Ansar, Nazaruddin, A.D. Azis, New frozen product development from strawberries (Fragaria Ananassa Duch.), Heliyon 6 (9) (2020) e05118.

[6] V.B. Nguyen, D.H. Nguyen, H.V. Nguyen, Combination effects of calcium chloride and nano-chitosan on the postharvest quality of strawberry (Fragaria x ananassa Duch.), Postharvest Biol. Technol. 162 (111103) (2020).

[7] B. Schulze, E.M. Hubbermann, K. Schwarz, Stability of quercetin derivatives in vacuum impregnated apple slices after drying (microwave vacuum drying, air drying, freeze drying) and storage, LWT-Food Sci. Technol. 57 (1) (2014) 426–433.

[8] K. Sun, R. Li, W. Jiang, Y. Sun, H. Li, Comparison of three-dimensional printing and vacuum freeze-dried techniques for fabricating composite scaffolds, Biochem. Biophys. Res. Commun. 477 (4) (2016) 1085–1091.

[9] Y.M. Chew, V.E. King, Microwave drying of pitaya (hylocereus) peel and the effects compared with hot-air and freeze-drying, Trans. ASABE 62 (4) (2019) 919–928.

[10] A. Khampakool, S. Soisungwan, S.H. Park, Potential Application of Infrared Assisted Freeze Drying (IRAFD) for Banana Snacks: Drying Kinetics, Energy Consumption, and Texture, LWT-Food Science and Technology, 2018.

[11] L.J. Wang, W. Sun, Numerical analysis of the three–dimensional mass and heat transfer with inner moisture evaporation in porous cooked meat joints during vacuum cooling, Trans. ASAE 46 (1) (2003) 107–115.

[12] A. Lakatos, A. Csik, I. Csarnovics, Experimental verification of thermal properties of the aerogel blanket, Case Stud. Therm. Eng. 21 (2021) 100966.

[13] V. Reyes, R. Bubnovich, M. Bustos, R. Vásquez, R. Vega, E. Scheuermann, Comparative study of different process conditions of freeze drying of 'Murtilla' berry, Dry. Technol.: Int. J. 28 (12) (2010) 1416–1425, 28:12, 1416-1425.

[14] Y. Xu, M. Zhang, A.S. Mujumdar, X. Duan, S. Jin-cai, A two-stage vacuum freeze and convective air drying method for strawberries, Dry. Technol.: Int. J. 24 (8) (2006) 1019–1023.

[15] X.F. Wu, M. Zhang, Y. Ye, D. Yu, Influence of ultrasonic pretreatments on drying kinetics and quality attributes of sweet potato slices in infrared freeze drying (IRFD), LWT 131 (2020) 109801.

[16] H. Selvnes, Y. Allouche, R.I. Manescu, A. Hafner, Review on cold thermal energy storage applied to refrigeration systems using phase change materials, Therm. Sci. Eng. Progress 22 (2021) 100807.

[17] G. Assegehegn, E.B. Fuente, J.M. Franco, C. Gallegos, The importance of understanding the freezing step and its impact on freeze-drying process performance, J. Pharmaceut. Sci. 108 (4) (2019) 1378–1395.

[18] M. Shehadi, Optimizing solar cooling systems, Case Stud. Therm. Eng. 21 (2020) 100663.

[19] A.U. Shingisov, R.S. Alibekov, Analysis of the moisture evaporation process during vacuum freeze-drying of koumiss and shubat, Heat Mass Tran. 53 (5) (2017) 1571–1578.

[20] M.J. Al-Kheetan, M.M. Rahman, S.H. Ghaffar, M. Al-Tarawneh, Y.S. Jweihan, Comprehensive investigation of the long-term performance of internally integrated concrete pavement with sodium acetate, Results Eng. 6 (2020) 100110.

[21] J.S. Souza, M.D. Medeiros, M.A. Magalhaes, F.N. Fernandes, Optimization of osmotic dehydration of tomatoes in a ternary system followed by air-drying, J. Food Eng. 83 (1) (2007) 501–509.

[22] J. Chapman, A. Elbourne, V.K. Truong, L. Newman, S. Gangadoo, P. Rajapaksha Pathirannahalage, D. Cozzolino, Sensomics - from conventional to functional NIR spectroscopy-shining light over the aroma and taste of foods, Trends in Food Sci. Technol. 91 (2019) 274–281, https://doi.org/10.1016/j.tifs.2019.07.013.

[23] S.M. Goni, V.O. Salvadori, Prediction of cooking times and weight losses during meat roasting, J. Food Eng. 100 (1) (2010) 1–11.

[24] Ansar Ansar, Nazaruddin Nazaruddin, Atri Azis Dewi, Caking mechanisms of passion fruit powder during storage, Int. J. Innov. Creat. Change 13 (2) (2020) 618–628.

[25] K. Westerterp, G. Plasqui, A. Goris, Water loss as a function of energy intake, physical activity and season, Br. J. Nutr. 93 (2) (2005) 199–203.

[26] R.E. Mello, A. Fontana, A. Mulet, J. Luiz, G. Correa, J.A. Cárcel, Ultrasound-assisted drying of orange peel in atmospheric freeze-dryer and convective dryer operated at moderate temperature, Dry. Technol. 38 (1) (2020) 259–267.

[27] C. Zhang, X. Bu, J. He, C. Liu, G. Lin, J. Miao, Simulation of evaporation and sublimation process in porous plate water sublimator based on a reduced CFD model, Int. J. Heat Mass Tran. 154 (2020) 119787.

[28] X. Xu, Q. Li, Y. Lai, W. Pang, R. Zhang, Effect of moisture content on mechanical and damage behavior of frozen loess under triaxial condition along with different confining pressures, Cold Reg. Sci. Technol. 157 (2019) 110–118.

[29] V.I. Aksenov, S.G. Gevorkyan, V.V. Doroshin, Dependence of strength and physical properties of frozen sands on moisture content, Soil Mech. Found. Eng. 54 (2018) 420–424.

[30] Z.M. Salisu, S.U. Ishiaku, D. Abdullahi, M.K. Yakubu, B.H. Diya'uddeen, Development of kenaf shive bio–mop via surface deposit technique for water remediation from crude oil spill contamination, Results Eng. 3 (2019) 100020.

[31] B. Liu, Y. Zhao, Y. Jia, J. Liu, Heating drives DNA to hydrophobic regions while freezing drives DNA to hydrophilic regions of graphene oxide for highly robust biosensors, J. Am. Chem. Soc. 142 (34) (2020) 14702–14709.

[32] M. Zielinska, M. Markowski, D. Zielinska, The effect of freezing on the hot air and microwave vacuum drying kinetics and texture of whole cranberries, Dry. Technol. 37 (13) (2019) 1714–1730.

[33] H. Bozkir, Y. Tekgül, E.S. Erten, Effects of tray drying, vacuum infrared drying, and vacuum microwave drying techniques on quality characteristics and aroma profile of orange peels, J. Food Process. Eng. 44 (1) (2021) e13611.

[34] P. Sobaszek, R. Różyło, L. Dziki, U. Gawlik-Dziki, B. Biernacka, M. Panasiewicz, Evaluation of color, texture, sensory and antioxidant properties of gels composed of freeze-dried maqui berries and agave sugar, Processes 8 (10) (2020) 1294.

[35] F. Pei, W. Yang, Y. Shi, Y. Sun, A.M. Mariga, L.Y. Zhao, Y. Fang, N. Ma, X. An, Q. Hu, Comparison of freeze-drying with three different combinations of drying methods and their influence on colour, texture, microstructure and nutrient retention of button mushroom (agaricus bisporus) slices, Technology 7 (2014) 702–710.

[36] A.J. Keutgen, E. Pawelzik, Qualit yand nutrition value of strawberry fruit under longterm salt stress, J. Food Chem. 107 (2) (2007) 1413–1420.

[37] X.Q. Yue, Z.Y. Shang, J.Y. Yang, L. Huang, Y.Q. Wang, A smart data-driven rapid method to recognize the strawberry maturity, Inform. Process. Agric. (2019).

[38] Y. Zhang, S. Barringe, Effect of hydrocolloids, sugar, and citric acid on strawberry volatiles in a gummy candy, J. Food Process. Preserv. (2017), e13327.

[39] M.A. Falah, P. Yuliastuti, R. Hanifah, P. Saroyo, Jumeri, Quality of fresh strawberry (fragaria sp cv. holibert) from Ketep Magelang Central Java and its storage in tropical environment, J. Agro Indus. 8 (1) (2018) 1–10.

[40] Z. Singh, A.S. Khan, Physiology of plum fruit ripening, Stewart Postharvest Rev. 2 (1) (2010) 3–12.

[41] L. Rydzak, Z. Kobus, R. Nadulski, K. Wilczyński, A. Pecyna, F. Santoro, A. Sagan, A. Starek-Wójcick, M. Krzywicka, Analysis of selected physicochemical properties of commercial apple juices, Processes 8 (2020) 1457.

[42] M. Yusufe, A. Mohammed, N. Satheesh, Effect of duration and drying temperature on characteristics of dried tomato (Lycopersicon esculentum L.) cochoro variety, J. Food Technol. 21 (1) (2017) 41–50.

[43] Q.V. Nguyen, H.V. Chuyen, Processing of herbal tea from roselle (Hibiscus sabdariffa L.): effects of drying temperature and brewing conditions on total soluble solid, phenolic content, antioxidant capacity and sensory quality, Beverages 6 (1) (2020) 1–11.