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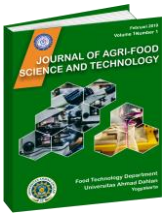

Characterization of Freeze-Dried Strawberries (*Fragaria x ananassa var. Mencir*): Quality on Physical Information

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ABSTRACT

*Drying fruits has many advantages for consumers, such as allowing them to be consumed in various processes and products during all seasons. Freeze-dried strawberries (FDS) are an alternative for adding value to fresh strawberries, extending shelf life, and maintaining fresh fruit characteristics. The study contributed to determine the quality physical characteristics of FDS produced using osmotic dehydration (OD) combined with freeze-drying. A combination of FDSs production with three factors and levels, freezing times (4 days, 14 days, and 21 days); OD solution concentrations (40 °Brix, 50 °Brix, and 60 °Brix); cleavage times (initial, pre-OD, and post-OD); immersion times of 120 minutes; and lyophilization times of 24 hours were used to prepare FDS. The quality of physical information of FDSs was the color of the skinned fruit (L*a*b* and change of color (ΔE)) and texture. The results of the study showed that the highest degree of L* and a* values were found in the combination of 14 days, 50 °Brix, post-OD; the lowest b* value was found in the combination of 21 days, 40 °Brix, initial split; the lowest ΔE value and the highest FDSs skin texture was found in the combination of 4 days, 60 °Brix, pre-OD. As an innovation, since no official Indonesian National Standard (SNI) is used as a reference for producing FDS, the research contributes to making good FDS products.*

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1. INTRODUCTION

Strawberries (*Fragaria x ananassa* var. Mencir) are the world's most important nutritional and economic horticultural crops (Li et al., 2022). Strawberry has many nutritious properties, including a high content of phytochemicals and vitamins, and is one of the dietary sources of polyphenols (de Souza et al., 2014; Kowalska et al., 2018; Barkaoui et al., 2021). However, strawberries are a perishable commodity with a shelf life of 2-3 days at room temperature. It is susceptible to postharvest deterioration due to its high respiration rate,

environmental stress, and pathogenic attack (Yue et al., 2020). Therefore, postharvest handling must be carefully considered to reduce postharvest losses and extend storage life (Barkaoui et al., 2021b).

The trend in the market for processed foods has been increasing from year to year. Due to their longer shelf life and guaranteed safety factor, fresh food groups have started to be replaced by processed foods. During 2021-2026, the global fruit and vegetable processing market is expected to grow at a CAGR of 8.3%. The global market for processed frozen dried fruits will grow at a CAGR of 6.6% from 2021 to 2026 (Anonimous, 2023).

Freeze-drying produces products with higher flavor quality than those dried by conventional methods. However, this process causes changes in the amorphous and hygroscopic structure of the strawberries (de Oliveira Alves et al., 2010). This structure is highly susceptible to changes in physical properties but extends the strawberry's shelf life. Low temperatures should be considered when freeze-drying strawberries due to their effect on changes in sensory characteristics (Muzaffar et al., 2018).

In the previous research by Putri et al. (2023), quality based on chemical information, such as total soluble solids, water content, vitamin C content, total phenolic content, and total acid of FDSs with a combination pretreatment of $NaHCO_3$ solution and dehydration (OD) were identified. Meanwhile, in research by Putri, Jumeri, et al. (2023) and Putri et al. (2024), physical and chemical quality characteristics and shelf-life prediction of FDSs untreated were identified. FDSs untreated were subjected to sensory tests with freeze-dried products in the Indonesian market, and it was also compared with products imported from Thailand with the brand Wel-B and local products from Indonesia. The findings indicate that consumers prefer the shape, color, and aroma attributes of the FDSs untreated. In contrast, they prefer the taste, texture, and overall sensory attributes of the strawberry imported from Thailand (Yuliani et al., 2023).

The innovative process of developing FDS from tropical strawberry cultivation has yet to be widely explored and publicized, especially in Indonesia. Even though there are many studies about strawberry FDS products, more research is needed on different production and processing methods to optimize the preservation of nutritional and functional components. As an innovation, since there is no official Indonesian National Standard (SNI) as a reference for the production of FDS, the results of quality characteristics should be used by business operators to produce good FDS products. Therefore, this study aims to identify physical quality characteristics (texture and color) in FDSs combined using pretreatment of $NaHCO_3$ and freeze-drying technique with OD solution. The purpose of identifying these quality characteristics is to see the influence of the freezing time, the concentration of the OD solution, and the time of strawberry splitting on the physical quality characteristics of FDSs.

2. MATERIALS AND METHODS

2.1. Materials

The strawberry (*Fragaria x ananassa var. Mencir*), with more than 80% of the surface of the fruit showing a deep red color, is fully formed and grown (Rahman et al., 2016) is cultivated in the Inggit Strawberry orchard, Sawangan, Magelang, Central Java, Indonesia. This strawberry orchard is located at longitudes 110^o0 1’51’’ and 110^o26’58’’ as well as at latitudes of 7^o19’13’’ and 7^o42’16’’ at an altitude of 1200 meters above sea level. The picked strawberries are then stored in a cooling bag at the Faculty of Agricultural Technology UGM for production and analysis.

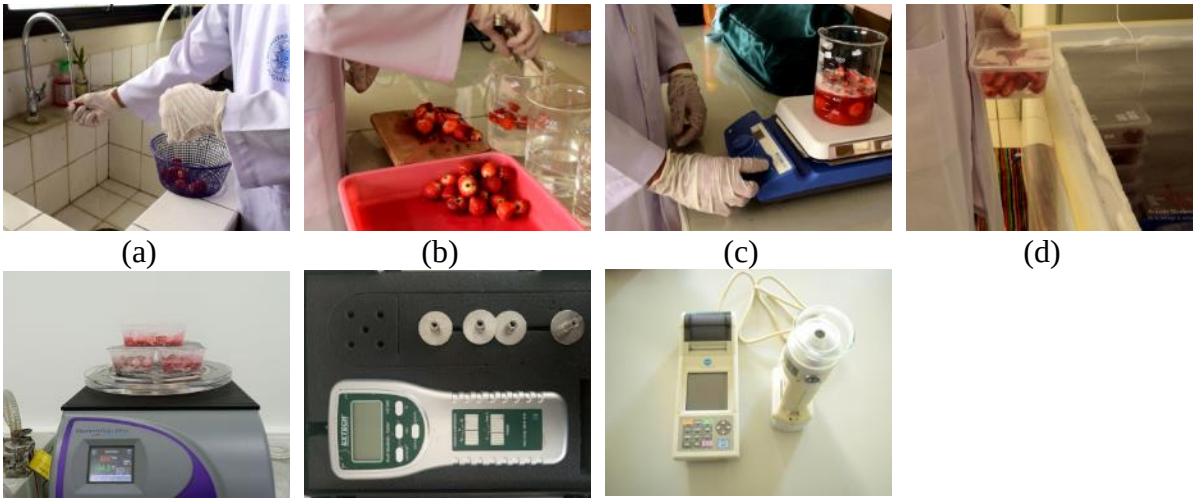
2.2. Research Methods

In this research, the first steps in the design system begin with the identification of the problem, the determination of the objectives and benefits of the research and literature review, the identification of the data needed and the selection of the research methodology, and the

determination of control factor, the number of levels and factor values. The experiment was carried out in a design experiment with three factorial levels. They were freezing time with three levels (4 days, 14 days, and 21 days), solution concentration of OD with three levels (40 °Brix, 50 °Brix, and 60 °Brix), and cleavage time with three levels (initial, pre-OD, and post-OD). The final step of the design system was to determine the quality parameters of FDSs. All measurements were tabulated and calculated using Microsoft Excel 2010 (Microsoft Corporation), and statistics using SPSS version 24.0 (SPSS Inc.).

Wash and remove leaves from strawberry, then divide in two depending on division time and soak in 4% $NaHCO_3$ solution for 4 hours. Subsequently, the strawberries were dehydrated and immersed in sucrose solution at different concentrations (40 °Brix, 50 °Brix, and 60 °Brix) for 2 hours, without temperature treatment using a hot plate magnetic stirring (C-MAG HS7, IKA, Selangor, Malaysia). OD is a process of water removal from a material with the principle of cellular material immersion in a hypertonic solution where the reduction in water content is due to a higher osmotic pressure compared to a hypertonic solution (Ahmed et al., 2016; Rahaman et al., 2019). Sucrose solution reduces browning due to oxygen depletion, stabilizes dyes, and retains volatile compounds during drying (Yadav & Singh, 2014; Ahmed et al., 2016).

They were then placed in a plastic container that was sealed and stored inside a freezer at a temperature of -18°±2 °C (Ciurzyńska et al., 2014) for 4 days, 14 days, and 21 days. The drying process lasts 24 hours for optimal results with a freeze-dryer (BenchTop Pro with Omnitronics, BTP.3XL.OOX series 323257 IPSWICH, England). The initial freeze dryer temperature is -3 °C and continues to drop to -70 °C, while the initial pressure is 914 Torr and continues to drop to 94 mTorr. Samples of FDSs are further analyzed and measured for physical quality following the existing parameters. The FDS manufacturing process and physical testing tools are shown in Figure 1.



(a) (b) (c) (d)

(e) (f) (g)

Figure 1. The steps involved in producing FDSs are (a) wash processing, (b) immersed in $NaHCO_3$ solution, (c) the OD processing, (d) freezing, (e) the FD process, and the equipment used for physical testing, (f) Fruit Hardness Tester; (g) Chromameter.

This study measured physical quality (color and texture). Physical quality analysis of FDSs color using chromameter (Minolta, CR-400, Japan) in L* (lightness), a* (redness), and b* (yellowness) notation. ΔE (color change) was calculated using equation (1).

$$\Delta E = \sqrt{\left(a_f^* - a_0^*\right)^2 + \left(b_f^* - b_0^*\right)^2 + \left(L_f^* - L_0^*\right)^2} \quad (1)$$

The subscripts 0 and f refer to the fresh and freeze-dried states (de Bruijn et al., 2015). Measurement of strawberry skin texture using a Fruit Hardness Tester (EXTECH Instruments, FHT 200, Taiwan).

The quality of strawberries was identified based on fruit weight, measured for seven periods (April-July 2022). The number of strawberries harvested in each period ranged from 79 to 118 fruits, with details of 8 to 24 pieces for size B codes, size C codes using 38 to 68 pieces, and 24 to 40 pieces for below minimum standard for size C codes.

3. RESULT AND DISCUSSION

Freeze-drying is one food processing method that extends fruit shelf life (Muzaffar et al., 2018; Zhang et al., 2020). However, the improper freeze-drying method can cause the quality of the product to deteriorate, including its color and texture (Zhang et al., 2017; Prosapio & Norton, 2017; Xu et al., 2021). Efforts have been made to reduce the impact of freeze-drying through OD (Sulistyawati et al., 2018; Bozkir et al., 2019). Processing in mass transfer of the strawberry fruit slices that occurred in between the dissolved solids into the liquid medium takes place during the process of OD with the sucrose solution (Yadav & Singh, 2014; Ahmed et al., 2016). Using the OD process as a pretreatment before freezing is practical to cause mass reduction to accelerate the freeze-drying process (Sulistyawati et al., 2018; Xu et al., 2021). OD can also improve the color stability of frozen stored materials (Ciurzyńska et al., 2014).

The physical quality of fresh strawberries and the FDSs for the color and texture of the fruit at different levels of pretreatment are shown in Table 1. The degrees of lightness, redness, yellowness, and color change of FDSs differ from those of fresh strawberries. The lightness value of FDS tends to be higher than fresh strawberries (the highest value is a combination of 14 days, 50 °Brix, post-OD); this is due to the occurrence of red color fading at the time of pretreatment immersion in the $NaHCO_3$ solution. This is also supported by research conducted by Prosapio & Norton (2018), Biernacka et al. (2022), and Putri, Jumeri, et al. (2023); the freeze-drying process had the most significant effect on increasing the L* coefficient value.

The red color of strawberries comes from anthocyanins (Maraei & Elsawy, 2017; Teribia et al., 2021). Anthocyanins have hydrophilic properties, which make them easily soluble in water (Priska et al., 2018). Pretreatment of strawberries by immersion in $NaHCO_3$ solution tends to increase the value of lightness in comparison with fresh strawberries. The anthocyanin color pigment in strawberries also dissolves during the soaking process. The redness and yellowness values tend to be lower than those of fresh strawberries (the highest value of redness is found in the combination of 14 days, 50 °Brix, post-OD, and the lowest value of yellowness is found in the combination of 21 days, 40 °Brix, initial). The destruction of cell fluids and anthocyanin pigments during the pretreatment process with OD is released outside the cell, resulting in a more intense red color in the OD solution (Xu et al., 2021). However, these results are inconsistent with the studies conducted by Jiang et al. (2021), Xu et al. (2021), and Putri, Jumeri, et al. (2023), where strawberries treated with osmotic dehydration and processed through freeze-drying have a redness degree (a*) value that is greater than fresh strawberries. Meanwhile, the yellowness degree value decreased after processing through freeze-drying (Prosapio & Norton, 2018; Putri, Jumeri, et al., 2023).

The value of color change in FDSs tends to change appearance, which is due to the use of pretreatment in the form of immersion in $NaHCO_3$ and OD solution (the lowest color change value is found in the combination of 4 days, 60 °Brix, pre-OD). The timing of strawberry splitting influenced the occurrence of significant color change in this combination. As previously described, strawberries lose many anthocyanins during initial splitting due to soaking in several solutions. From the calculations and analysis using the independent sample T-test, comparing fresh strawberries with each of the existing combinations for freeze-dried of

its color parameters, there is only one parameter that has a significant difference (<0.05), namely in the color change between fresh strawberries and a combination of 21 days, 40 °Brix, initial. The other parameters do not have a significant difference (>0.05).

FDS color change is a complex color change due to several simultaneous reactions. Changes influence this color change in the physiology and chemistry of the strawberry fruit (Ansar et al., 2020). The red color can easily be changed to a dull brownish color. Browning is related to non-enzymatic reactions with the degradation of anthocyanins and polymerization reactions with other phenols, such as the degradation of ascorbic acid, the Maillard reaction, and the acid-catalyzed degradation of sugars (Buvé et al., 2018; Valentina et al., 2018; Teribia et al., 2021). Several factors, such as the concentration of ascorbic acid, sugars and amino acids, oxygen availability, pH, and processing and storage conditions, affect anthocyanin degradation and non-enzymatic browning reaction (Buvé et al., 2018; Önal et al., 2019). The color change value can be used as an indicator to check whether the human eye can perceive the color change. The color difference is visible to consumers when the color change value exceeds 3.0 (Wang et al., 2022).

Table 1. Physical quality parameter values of color (left) and texture (right) of fresh and FDSs.

Combination	L*	a*	b*	ΔE	Texture
Fresh Strawberry	39.79 ± 1.85	24.29 ± 2.11	17.39 ± 1.34	-	2.76 ± 0.71
21 days, 40 °Brix, Initial	38.34 ± 2.85	20.67 ± 1.52	7.47 ± 0.93	10.02 ± 3.82	12.01 ± 0.04
14 days, 50 °Brix, Post-OD	49.24 ± 0.18	23.73 ± 1.41	12.37 ± 0.36	7.96 ± 2.99	16.18 ± 0.84
4 days, 60 °Brix, Pre-OD	45.94 ± 6.20	25.57 ± 4.42	11.26 ± 1.02	7.01 ± 3.04	28.76 ± 4.56

Description: The data is the average of the three replicates using the standard deviation.

The texture of the fruit after the FDSs has a value that tends to increase (the highest texture value is found in a combination of 4 days, 60 °Brix, pre-OD). The OD technique allows for removing some of the water from the product to improve the structure of the product (Yadav & Singh, 2014; Jiang et al., 2021). During drying, food tissues are subjected to pressure that can cause cracking and deformation, which can soften the tissue (Prosapio & Norton, 2018). Freeze-dried products are more brittle and crumbly than air-dried (Lammerskitten et al., 2020). From the calculations and analysis using the independent sample T-test, comparing fresh strawberries with each of the existing combinations for freeze-dried of its texture parameters, there is not a significant difference (>0.05).

The visual difference between fresh and FDSs for each combination is shown in Figure 2. Descriptively, in general, FDSs from the research have the shape of strawberries divided into two equal parts vertically, a not-strong strawberry aroma, a red-brown color, a robust sour taste without sweetness, and a texture that is not crunchy and crispy. From the results of visual difference, physical quality characteristics in this research, chemical quality characteristics (Putri, Fallah, et al., 2023), and FDSs untreated (Putri, Jumeri, et al., 2023), the results still are not yet optimal, allowing further research on the FDS production process with other pretreatment combinations and the optimal freeze-drying process.

The freeze-drying method produces small changes in color, flavor, chemical composition, texture, and better product quality compared to other dehydration processes (Prosapio & Norton, 2017). However, it has the disadvantages of high energy costs and long processing times, which limit its application to high-value products and require pretreatment methods to reduce production costs (Figiel & Michalska, 2017; Prosapio & Norton, 2017). The

freeze-drying method sometimes produces poor-quality products caused by the quality of raw materials (nature and maturity level) and processing conditions (operating pressure, heating temperature, freezing rate, freeze-drying process control) (Muzaffar et al., 2018). Strawberries, as the main ingredient in this study, contain a high amount of freezable water content, so freezing impacts cell damage and product quality deterioration (Zhao et al., 2022). Therefore, to prevent quality changes and texture damage due to ice crystal formation, especially in fruits that contain high water content, it is necessary to pretreatment the production process.

Based on consumer preferences from research by Yuliani et al. (2023), the sensory panel members preferred the shape of FDSs, which still resembled fresh strawberries, the color of FDSs, which retained the red color of fresh strawberries, more of the sweet and fruity aromas of fresh strawberries, the taste of sweetness, and the texture, which was complex, crunchy, and crispy. Furthermore, optimizing processes to receive good appearance and visual quality characterization must be conducted for the following research to compete with similar foreign products and be acceptable to the consumer.

(a) (b) (c) (d)

Figure 2. Visual difference between (a) fresh strawberries; (b) FDS combination of 21 days, 40 °Brix, initial; (c) 14 days, 50 °Brix, post-OD; (d) 4 days, 60 °Brix, pre-OD.

4. CONCLUSIONS

The study's results showed that the highest value of lightness (L*) and redness (a*) was found in the combination of 14 days, 50 °Brix, post-OD, the lowest value of yellowness (b*) was found in the combination of 21 days, 40 °Brix, initial, the lowest value of color change (ΔE), and the highest value of FDSs skin texture were found in the combination of 4 days, 60 °Brix, pre-OD. The best characteristics of FDSs are their shape, which still resembles fresh strawberries; their color, which retains the red color of fresh strawberries; their sweet and fruity aromas; their taste of sweetness; and their texture, which is complex and crunchy.

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REFERENCES

Ahmed, I., Qazi, I. M., & Jamal, S. (2016). Developments in osmotic dehydration technique for the preservation of fruits and vegetables. *Innovative Food Science and Emerging Technologies*, *34*, 29–43. https://doi.org/10.1016/j.ifset.2016.01.003.

Anonimous. (2023). *Fruit & Vegetable Processing Market Size & Share Analysis - Growth Trends & Forecasts (2024 - 2029)*. https://www.mordorintelligence.com/industry-reports/fruit-and-vegetable-processing-market.

Ansar, N., & Azis, A. D. (2020). New frozen product development from strawberries (*Fragaria ananassa* Duch.). *Heliyon*, *6*(9). https://doi.org/10.1016/j.heliyon.2020.e05118.

Barkaoui, S., Mankai, M., Miloud, N. B., Kraïem, M., Madureira, J., Verde, S. C., &

Boudhrioua, N. (2021a). E-beam irradiation of strawberries: investigation of microbiological, physicochemical, sensory acceptance properties and bioactive content. *Innovative Food Science and Emerging Technologies*, *73*. https://doi.org/10.1016/j.ifset.2021.102769.

Barkaoui, S., Mankai, M., Miloud, N. B., Kraïem, M., Madureira, J., Verde, S. C., & Boudhrioua, N. (2021b). Effect of gamma radiation coupled to refrigeration on antioxidant capacity, sensory properties and shelf life of strawberries. *LWT - Food Science and Technology*, *150*. https://doi.org/10.1016/j.lwt.2021.112088.

Biernacka, B., Dziki, D., Rudy, S., Krzykowski, A., Polak, R., & Dziki, L. (2022). Influence of pretreatments and freeze-drying conditions of strawberries on drying kinetics and physicochemical properties. *Processes*, *10*(8), 1588. https://doi.org/10.3390/pr10081588.

Bozkir, H., Rayman Ergün, A., Serdar, E., Metin, G., & Baysal, T. (2019). Influence of ultrasound and osmotic dehydration pretreatments on drying and quality properties of persimmon fruit. *Ultrasonics Sonochemistry*, *54*, 135–141. https://doi.org/10.1016/j.ultsonch.2019.02.006.

Buvé, C., Kebede, B. T., De Batselier, C., Carrillo, C., Pham, H. T. T., Hendrickx, M., Grauwet, T., & Van Loey, A. (2018). Kinetics of colour changes in pasteurised strawberry juice during storage. *Journal of Food Engineering*, *216*, 42–51. https://doi.org/10.1016/j.jfoodeng.2017.08.002.

Ciurzyńska, A., Lenart, A., & Greda, K. J. (2014). Effect of pretreatment conditions on content and activity of water and colour of freeze-dried pumpkin. *LWT - Food Science and Technology*, *59*(2P1), 1075–1081. https://doi.org/10.1016/j.lwt.2014.06.035.

de Bruijn, J., Rivas, F., Rodriguez, Y., Loyola, C., Flores, A., Melin, P., & Borquez, R. (2015). Effect of vacuum microwave drying on the quality and storage stability of strawberries. *Journal of Food Processing and Preservation*, *40*(5), 1104–1115. https://doi.org/10.1111/jfpp.12691.

de Oliveira Alves, C. C., de Resende, J. V., Prado, M. E. T., & Cruvinel, R. S. R. (2010). The effects of added sugars and alcohols on the induction of crystallization and the stability of the freeze-dried peki (*Caryocar brasiliense* Camb.) fruit pulps. *LWT - Food Science and Technology*, *43*(6), 934–941. https://doi.org/10.1016/j.lwt.2010.01.029.

De Souza, V. R., Pereira, P. A. P., Da Silva, T. L. T., De Oliveira Lima, L. C., Pio, R., & Queiroz, F. (2014). Determination of the bioactive compounds, antioxidant activity and chemical composition of Brazilian blackberry, red raspberry, strawberry, blueberry and sweet cherry fruits. *Food Chemistry*, *156*, 362–368. https://doi.org/10.1016/j.foodchem.2014.01.125.

Figiel, A., & Michalska, A. (2017). Overall quality of fruits and vegetables products affected by the drying processes with the assistance of vacuum-microwaves. *International Journal of Molecular Sciences*, *18*(1). https://doi.org/10.3390/ijms18010071.

Jiang, J., Zhang, M., Devahastin, S., & Yu, D. (2021). Effect of ultrasound-assisted osmotic dehydration pretreatments on drying and quality characteristics of pulsed fluidized bed microwave freeze-dried strawberries. *LWT - Food Science and Technology*, *145*, 111300. https://doi.org/10.1016/j.lwt.2021.111300.

Kowalska, J., Kowalska, H., Marzec, A., Brzeziński, T., Samborska, K., & Lenart, A. (2018). Dried strawberries as a high nutritional value fruit snack. *Food Science and Biotechnology*, *27*(3), 799–807. https://doi.org/10.1007/s10068-018-0304-6.

Lammerskitten, A., Wiktor, A., Mykhailyk, V., Samborska, K., Gondek, E., Witrowa-Rajchert, D., Toepfl, S., & Parniakov, O. (2020). Pulsed electric field pretreatment improves microstructure and crunchiness of freeze-dried plant materials: Case of strawberry. *LWT - Food Science and Technology*, *134*. https://doi.org/10.1016/j.lwt.2020.110266.

Li, T. Y., Wang, S. X., Tang, X. G., Dong, X. X., & Li, H. (2022). The FvemiR167b-FveARF6

module increases the number of roots and leaves in woodland strawberry. *Scientia Horticulturae*, *293*. https://doi.org/10.1016/j.scienta.2021.110692.

Maraei, R. W., & Elsawy, K. M. (2017). Chemical quality and nutrient composition of strawberry fruits treated by γ-irradiation. *Journal of Radiation Research and Applied Sciences*, *10*(1), 80–87. https://doi.org/10.1016/j.jrras.2016.12.004.

Muzaffar, H., Rouf, A., Muzaffar, Z., & Noor, F. (2018). Dehydration of strawberry-a review. *International Journal of Current Microbiology and Applied Sciences*, *7*(01), 1216–1224. https://doi.org/10.20546/ijcmas.2018.701.148.

Önal, B., Adiletta, G., Crescitelli, A., Di Matteo, M., & Russo, P. (2019). Optimization of hot air drying temperature combined with pretreatment to improve physico-chemical and nutritional quality of 'Annurca' apple. *Food and Bioproducts Processing*, *115*, 87–99. https://doi.org/10.1016/j.fbp.2019.03.002.

Priska, M., Peni, N., Carvallo, L., & Ngapa, Y. D. (2018). Antosianin dan pemanfaatannya. *Cakra Kimia (Indonesian E-Journal of Applied Chemistry)*, *6*(2), 79–97. https://doi.org/10.24843/CK.2018.v06.i02.

Prosapio, V., & Norton, I. (2017). Influence of osmotic dehydration pretreatment on oven drying and freeze drying performance. *LWT - Food Science and Technology*, *80*, 401–408. https://doi.org/10.1016/j.lwt.2017.03.012.

Prosapio, V., & Norton, I. (2018). Simultaneous application of ultrasounds and firming agents to improve the quality properties of osmotic + freeze-dried foods. *LWT - Food Science and Technology*, *96*, 402–410. https://doi.org/10.1016/j.lwt.2018.05.068.

Putri, R. M., Fallah, A. M., Yuliani, W., Wagiman, & Falah, M. A. F. (2023). Chemical quality of osmotically pretreated freeze-dried strawberries. *Atlantis Press International BV*. https://doi.org/10.2991/978-94-6463-122-7_27.

Putri, R. M., Jumeri, & Falah, M. A. F. (2023). Effects of osmotic dehydration pretreatment on process and quality of freeze-dried strawberries (*Fragaria x ananassa* var. Mencir). *IOP Conference Series: Earth and Environmental Science*, *1200*(1), 012030. https://doi.org/10.1088/1755-1315/1200/1/012030.

Putri, R. M., Jumeri, & Falah, M. A. F. (2024). Shelf-life prediction of freeze-dried strawberries using accelerated shelf-life testing method in a tropical environment. *International Journal of Agricultural Technolgy*, *20*(1), 329–342.

Rahaman, A., Zeng, X. A., Kumari, A., Rafiq, M., Siddeeg, A., Manzoor, M. F., Baloch, Z., & Ahmed, Z. (2019). Influence of ultrasound-assisted osmotic dehydration on texture, bioactive compounds and metabolites analysis of plum. *Ultrasonics Sonochemistry*, *58*. https://doi.org/10.1016/j.ultsonch.2019.104643.

Rahman, M. M., Moniruzzaman, M., Ahmad, M. R., Sarker, B. C., & Khurshid Alam, M. (2016). Maturity stages affect the postharvest quality and shelf-life of fruits of strawberry genotypes growing in subtropical regions. *Journal of the Saudi Society of Agricultural Sciences*, *15*(1), 28–37. https://doi.org/10.1016/j.jssas.2014.05.002.

Sulistyawati, I., Dekker, M., Fogliano, V., & Verkerk, R. (2018). Osmotic dehydration of mango: Effect of vacuum impregnation, high pressure, pectin methylesterase and ripeness on quality. *LWT*, *98*, 179–186. https://doi.org/10.1016/j.lwt.2018.08.032.

Teribia, N., Buvé, C., Bonerz, D., Aschoff, J., Goos, P., Hendrickx, M., & Van Loey, A. (2021). The effect of thermal processing and storage on the color stability of strawberry puree originating from different cultivars. *LWT - Food Science and Technology*, *145*. https://doi.org/10.1016/j.lwt.2021.111270.

Wang, B. B., Sun, P. Y., Chen, B. L., Sajjad, U., & Yan, W. M. (2022). Influence of the process parameters on the energy conservation and quality of the kiwi fruit subjected to vacuum freeze-drying. *Case Studies in Thermal Engineering*, *33*. https://doi.org/10.1016/j.csite.2022.101935.

Xu, B., Chen, J., Sylvain Tiliwa, E., Yan, W., Roknul Azam, S. M., Yuan, J., Wei, B., Zhou, C., & Ma, H. (2021). Effect of multi-mode dual-frequency ultrasound pretreatment on the vacuum freeze-drying process and quality attributes of the strawberry slices. *Ultrasonics Sonochemistry*, *78*. https://doi.org/10.1016/j.ultsonch.2021.105714.

Yadav, A. K., & Singh, S. V. (2014). Osmotic dehydration of fruits and vegetables: a review. *Journal of Food Science and Technology*, *51*(9), 1654–1673. https://doi.org/10.1007/s13197-012-0659-2.

Yue, X. Q., Shang, Z. Y., Yang, J. Y., Huang, L., & Wang, Y. Q. (2020). A smart data-driven rapid method to recognize the strawberry maturity. *Information Processing in Agriculture*, *7*(4), 575–584. https://doi.org/10.1016/j.inpa.2019.10.005.

Yuliani, W., Putri, R. M., Ismoyowati, D., & Falah, M. A. F. (2023). Sensory properties characterization of freeze-dried strawberries. *Proceedings of the 3rd International Conference on Smart and Innovative Agriculture (ICoSIA 2022)*, 351–359. https://doi.org/https://doi.org/10.2991/978-94-6463-122-7 _33.

Zhang, L., Qiao, Y., Wang, C., Liao, L., Shi, D., An, K., Hu, J., Wang, J., & Shi, L. (2020). Influence of high hydrostatic pressure pretreatment on properties of vacuum-freeze dried strawberry slices. *Food Chemistry*, *331*, 127203. https://doi.org/10.1016/j.foodchem.2020.127203.

Zhang, M., Chen, H., Mujumdar, A. S., Tang, J., Miao, S., & Wang, Y. (2017). Recent developments in high-quality drying of vegetables, fruits, and aquatic products. *Critical Reviews in Food Science and Nutrition*, *57*(6), 1239–1255. https://doi.org/10.1080/10408398.2014.979280.

Zhao, Y., Ning, J., & Sun, Z. (2022). Study on liquid nitrogen and carbon dioxide combined jet quick-frozen strawberry. *International Journal of Refrigeration*, *136*, 1–7. https://doi.org/10.1016/j.ijrefrig.2022.01.008.