

Research article

EFFECT OF DRYING TECHNIQUES ON THE PRESERVATION OF ANTIOXIDANT PROPERTIES IN *ANANAS COMOSUS*

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Abstract

Preservation of antioxidant properties in pineapple (*Ananas comosus*) is crucial to maintain its nutritional value and health benefits. Pineapple is rich in polyphenols, flavonoids and other bioactive compounds that combat oxidative stress and reduce the risk of chronic diseases. However, the drying process which is essential in preserving the fruit's shelf life has the potential to reduce antioxidants contents due to the sensitivity of these compounds to heat and oxidative stress. This study analysed the impact of three drying techniques namely microwave, oven, and infrared drying on the retention of antioxidant properties in pineapple. The antioxidant activity was assessed using 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity and Total Phenolic Content (TPC). To ensure consistency and to facilitate an accurate comparison across the techniques, all drying experiments were conducted in triplicate (n=3) and standardized at 80 °C with microwave drying operated at 300 W. Statistical analysis revealed significant differences ($p < 0.05$) among all three drying methods. Microwave drying was the most effective in preserving antioxidant properties, resulting in the fastest moisture removal and significantly higher antioxidant retention with a TPC 729.41 ± 12.35 mg GAE/100g and 56.03 ± 1.12 %DPPH inhibition. By comparison, infrared drying demonstrated moderate antioxidant retention (516.28 ± 9.84 mg GAE/100g TPC ; 44.03 ± 0.95 %DPPH), while oven drying was the least effective, resulting in the lowest retention (331.37 ± 8.15 mg GAE/100g TPC; 40.20 ± 0.88 %DPPH). The relatively poor antioxidant retention observed in oven dried samples is attributed to slower drying kinetics and extended heat exposure, which accelerates the thermal degradation of phenolic compounds.

1.Introduction

Pineapple (*Ananas comosus*), a tropical fruit which belongs to the *Bromeliaceae* family, is widely recognized for its rich nutritional and bioactive compounds. It is a

significant source of vitamins, particularly vitamin C and essential minerals such as manganese and potassium. These essential minerals contribute to immune function, bone health and metabolic processes (Mohd Ali et

al., 2020). Pineapple also contains antioxidants, including polyphenols and flavonoids which plays a crucial role in combating oxidative stress and lowering the risk of chronic diseases such as cardiovascular disorders and cancerous diseases (Sun et al., 2015). Additionally, pineapple is a source of bromelain, an enzyme known for its anti-inflammatory properties and digestive health benefits (Mohd Ali et al., 2020).

Drying is a common preservation method that reduces the moisture content of the food in which inhibits the microbial growth and enzymatic activity. By converting fresh pineapple into a more stable form through drying, it enhances the durability and usability of the pineapple in various food applications. However, the drying process can significantly impact the nutritional and antioxidant properties of pineapple. The thermal and oxidative stresses involved in drying can degrade heat-sensitive bioactive compounds where it can reduce the fruit's nutritional value and health benefits (Izli et al., 2018). For example, microwave drying has been shown to preserve antioxidants effectively due to its shorter drying time and it reduced thermal exposure (Chauhan et al., 2021). On the other hand, despite the simplicity of oven drying and its widespread application, it often leads to higher nutrient loss when operated at elevated temperature (Vidinamo et al., 2022). Meanwhile, infrared drying, which provides direct and efficient heating, is gaining attention for its potential to retain nutritional quality while improving drying rates (Adak et al., 2017).

This study focuses on three drying methods: microwave drying, oven drying, and infrared drying. Each method utilizes distinct mechanism and operating conditions, which influence the drying efficiency and the extent of the nutrient preservation. Microwave drying utilizes electromagnetic waves to heat and dry pineapple slices internally which offers faster

drying times but requires careful control to prevent thermal degradation (Zaki et al., 2017). Oven drying, a conventional method, relies on hot air circulation but often results in slower drying rates and potential nutrient loss (Vidinamo et al., 2022). Infrared drying, which uses infrared radiation to heat the fruit directly promises an efficient moisture removal but risks to an uneven heating and degradation of sensitive compounds (Adak et al., 2017).

Although microwave, infrared, and oven drying are widely used individually, comparative studies evaluating their performance under standardized thermal conditions while simultaneously assessing both drying kinetics and antioxidant retention in tropical fruits remain limited. Therefore, this study aimed to evaluate and compare the effects of microwave, infrared, and hot-air oven drying on the moisture removal kinetics and bioactive compound preservation (TPC and DPPH radical scavenging activity) of pineapple slices under identical processing parameters. Antioxidant activity was assessed using DPPH radical scavenging activity and Total Phenolic Content (TPC), while drying performance was evaluated based on moisture content, moisture ratio, and drying rate. The findings provide a comprehensive comparison of the drying techniques in terms of antioxidant preservation and drying efficiency, thereby contributing to the development of high-quality dried pineapple products with improved nutritional value.

2. Methodology

2.1. Material selection & preparation

Fresh and naturally ripened pineapples were sourced from a supermarket in Shah Alam, ensuring consistency in color and variety as Figure 1(a). Prior to the drying process, the pineapples were thoroughly cleaned, peeled, and manually sliced to uniform dimensions of 1 cm in thickness and 3 cm × 3 cm as Figure 1(b).

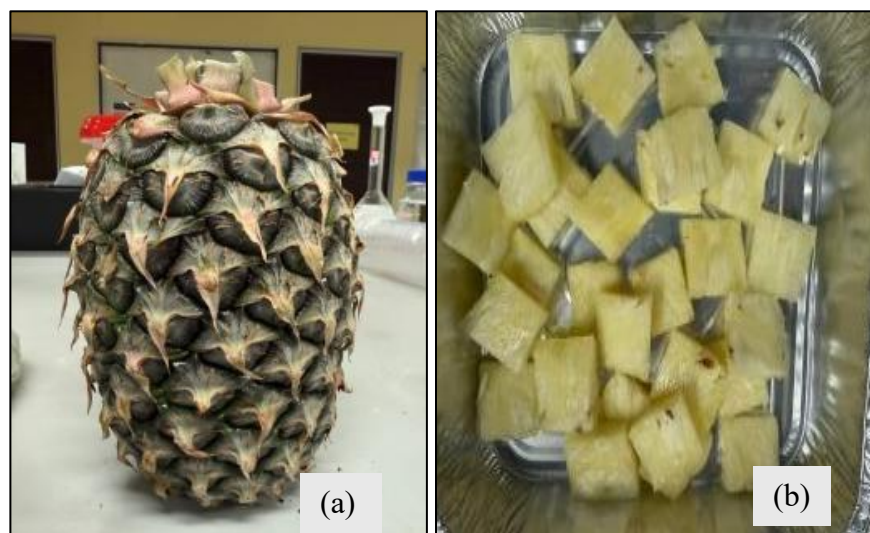


Figure 1. (a) Fresh pineapple fruit, (b) Diced pineapple flesh

2.2. Sample Extraction

The extraction method from Abd Hashib et al., (2019) was applied with modification. Dried pineapple samples were ground into a paste like consistency. Each sample was weighed at 5 grams and extracted using 80% ethanol in a 1:10 (w/v) ratio as illustrated in Figure 2. The mixtures were placed in a shaker incubator (Infors AG, Ritttergasse 27, 4103 Bottmingen Switzerland) and was left overnight at a room temperature and 150 rpm

to promote the extraction of antioxidants compounds. Following incubation, the extracts were filtered using a syringe-mounted membrane filter (0.45 μm pore size) to remove solids and obtained a clear solution. The filtered extracts were kept at room temperature prior to immediate use for determination of antioxidant activity using 2,2 diphenyl 1 picrylhydrazyl (DPPH) radical scavenging assay and Total Phenolic Content (TPC) analyses.

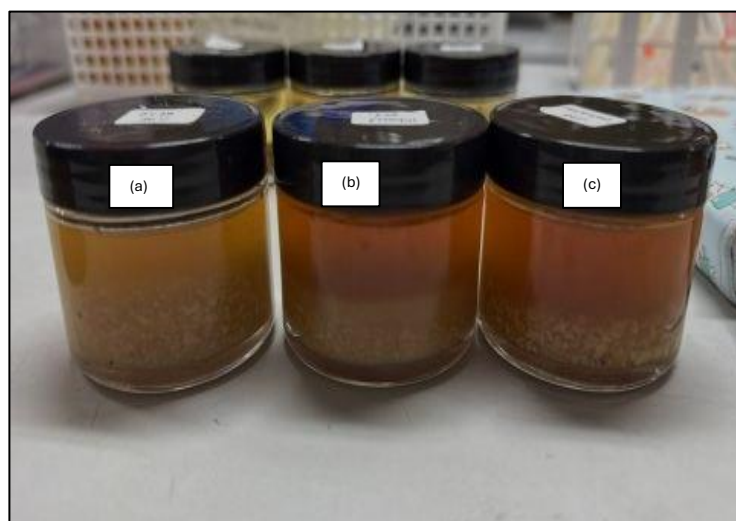


Figure 2. Sample extraction from oven drying (a), infrared (b) and microwave drying(c)

2.3. Microwave Drying

For the microwave drying process, the prepared pineapple slices were subjected to microwave drying at a power level of 300 W. The drying process was monitored by weighing the samples at 5 minutes intervals

until equilibrium moisture content was achieved.

A microwave power level of 300 W was selected to achieve efficient moisture removal while minimizing thermal degradation of heat-sensitive antioxidant compounds.

2.4.Oven Drying

For the oven drying process, the prepared sliced were arranged in a single layer on stainless steel trays and placed in a preheated hot-air oven at 80°C for the drying process. Samples were weighed at 30-minutes intervals to monitor moisture loss, and the drying process continued until three consecutive weights of reading remained constant, indicating the completion of drying. Following the drying, the weight data were utilised to compute the drying rates and moisture ratios.

2.5.Infrared Drying

For the infrared drying process, the pineapple slices were evenly arranged on trays within the infrared dryer without overlapping to ensure uniform drying. The dryer was operated at 80°C, a temperature selected to promote efficient moisture removal while minimizing thermal degradation of heat-sensitive antioxidant compounds. The samples were weighed at 15-minute intervals throughout the drying process to monitor moisture loss and evaluate the drying behaviour of the pineapple slices.

2.6.Antioxidant Activity Analysis

The antioxidant activity of the samples was determined using a modified 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay adapted from Harith et al. (2023). A DPPH solution was prepared by dissolving 10 mg of DPPH powder in 100 mL of 80% methanol and storing the solution in the dark at room temperature. For the analysis, 1.0 mL of fruit extract was mixed with 2.0 mL of DPPH solution. The reaction mixture was incubated in the dark for 60 min, after which the absorbance was measured at 517 nm using a UV-Vis spectrophotometer. An 80% methanol solution was used as the blank, while the control solution consisted of 4.0 mL of 80% methanol and 1.0 mL of DPPH solution. According to Šturm et al. (2019), the spectrophotometer has an accuracy of ± 0.01 AU. The DPPH radical scavenging activity was expressed as percentage inhibition (%) and calculated using Equation (1) (Chaudhuri et al., 2012):

$$\text{Inhibition (\%)} = \left(\frac{A_0 - A_1}{A_0} \right) \times 100 \quad (1)$$

Where:

A_0 = the absorbance control DPPH

A_1 = the absorbance of the sample

2.7.Total Phenolic Content (TPC) Analysis

The Total Phenolic Content (TPC) of the samples was determined using the *Folin-Ciocalteu* method as described by Harith et al. (2023) with slight modifications. A gallic acid stock solution (1000 mg/L) was prepared by dissolving 30 mg of gallic acid in 10 mL of 80% ethanol, and the volume was subsequently made up to 100 mL using the same solvent. A series of gallic acid standard solutions of different concentrations were then prepared by appropriate dilution of the stock solution using 80% ethanol.

For both standard and sample analyses, 0.3 mL of the solution was transferred into a test tube, followed by the addition of 1.5 mL of diluted Folin-Ciocalteu reagent. The mixture was allowed to stand at room temperature for 10 min before adding 1.2 mL of 7.5% (w/v) sodium carbonate solution. The reaction mixture was then incubated in the dark for 30 min. Absorbance was measured at 765 nm using a UV-Vis spectrophotometer, with 80% ethanol serving as the blank.

A calibration curve was established using the gallic acid standard solutions. The absorbance values obtained from the standards were plotted against their corresponding concentrations to generate the calibration equation, as shown in Equation (2).

$$y = 0.1027 x + 0.0595, R^2 = 0.9812 \quad (2)$$

Where:

y represents the absorbance and x represents the concentration of gallic acid standard solution.

The total phenolic content of the sample extracts was determined by interpolating their absorbance values into the calibration equation. The TPC was calculated using Equation (3) and expressed as milligrams of gallic acid equivalents (GAE) per 100 g of dried pineapple

$$\text{TPC} = C \times V/M \quad (3)$$

Where:

TPC = total phenolic content (mg GAE/g)

C = concentration of gallic acid established from the calibration curve (mg/mL)

V = volume of extract solution (mL)

M = weight of extract (g)

2.8. Moisture Content Analysis

The moisture content (MC) was recorded at fixed intervals times following respective drying methods. The moisture content is calculated by using Equation (4):

$$\text{Moisture Content (\%)} = \frac{(\text{Weight}_1 \text{ (g)} - \text{Weight}_2 \text{ (g)})}{(\text{Weight}_2 \text{ (g)})} \times 100 \quad (4)$$

Where:

Weight₁ = Initial weight of powder (g)

Weight₂ = Final weight of powder (g)

2.9. Drying Kinetics

The drying kinetics can be obtained based on method described by Izli et al., (2018) with some modifications. The collected data for moisture content is used to calculate the drying rate and drying time for each technique. The drying rate will be calculated using equation (5):

$$\text{Drying Rate (gram H}_2\text{O/gram dry matter.time)} = \frac{(X_1 - X_2)}{(t_1 - t_2)} \quad (5)$$

Where :

X₁ = gram dry matter moisture content of sample at time t₁ ,

X₂ = moisture content of sample at time , t₂

t₁ , t₂ = time in minute

Moisture ratio (MR), defined as the ratio of current moisture content to the initial moisture content, represented moisture removal over time and essentially important for analysing drying kinetics. The moisture ratio data were calculated using Equation (6):

$$\text{MR} = \frac{(M_t - M_e)}{(M_o - M_e)} \quad (6)$$

Where:

MR = Moisture Ratio

M_t = moisture content at a given time

M_o = initial moisture content

M_e = equilibrium moisture content

In this study, the equilibrium moisture content (M_e) was not directly used in the calculation of moisture ratio (MR). This approach is consistent with common practice in many drying studies, especially under high temperatures conditions where the equilibrium moisture content is very low and the drying curve did not reach a stable plateau. Therefore, the drying process is stopped before reaching equilibrium to avoid thermal degradation. Following (Samad et al., 2024) , M_e was assumed negligible (M_e ≈ 0) and MR equation (6) was simplified into equation (7) followed with drying curves plot (for drying rate and moisture ratio against time).

$$\text{MR} = M_t/M_o \quad (7)$$

Where :

MR = Moisture Ratio

M_t = moisture content at a given time

M_o = initial moisture content

2.10. Replication and Data Analysis

All experimental procedures and analyses were performed in triplicate (n = 3) unless otherwise stated, and the results were expressed as mean ± standard deviation (SD). Analytical instruments, including the analytical balance, spectrophotometer, and temperature sensors, were calibrated prior to measurement according to standard procedures. One-way Analysis of Variance (ANOVA) was performed to determine whether significant differences existed among the treatment groups followed with t-tests to identify specific differences. Statistical significance was evaluated at p < 0.05 using Microsoft Excel.

3. Results and Discussion

3.1. Drying Kinetics of Pineapple Slices

The drying behavior of the pineapple slices exposed to microwave, infrared, and oven drying was analyzed based on changes in moisture ratio and drying rate over time. The moisture ratio is a dimensionless quantity that are being used to represent the relative amount of moisture remained in a material compared to their initial and equilibrium moisture contents (Zeng et al., 2024). As presented in

Figure 3, the moisture ratio for all drying techniques consistently decreased over time. This indicates that a progressive moisture removal. Among all drying techniques, microwave drying demonstrated the most rapid reduction in moisture ratio where it reaches a near-equilibrium within approximately 85 minutes. This can be explained by microwaves' volumetric heating effect in which microwaves allow for internal

moisture movement. It also allows the heat to penetrate the material uniformly which delivers energy directly into the entire volume rather than relying on the surface-based conduction and convection (Parit et al., 2018). As for infrared drying, it shows a moderately fast decline in moisture ratio as it took around 130-150 minutes to reach the final moisture level.

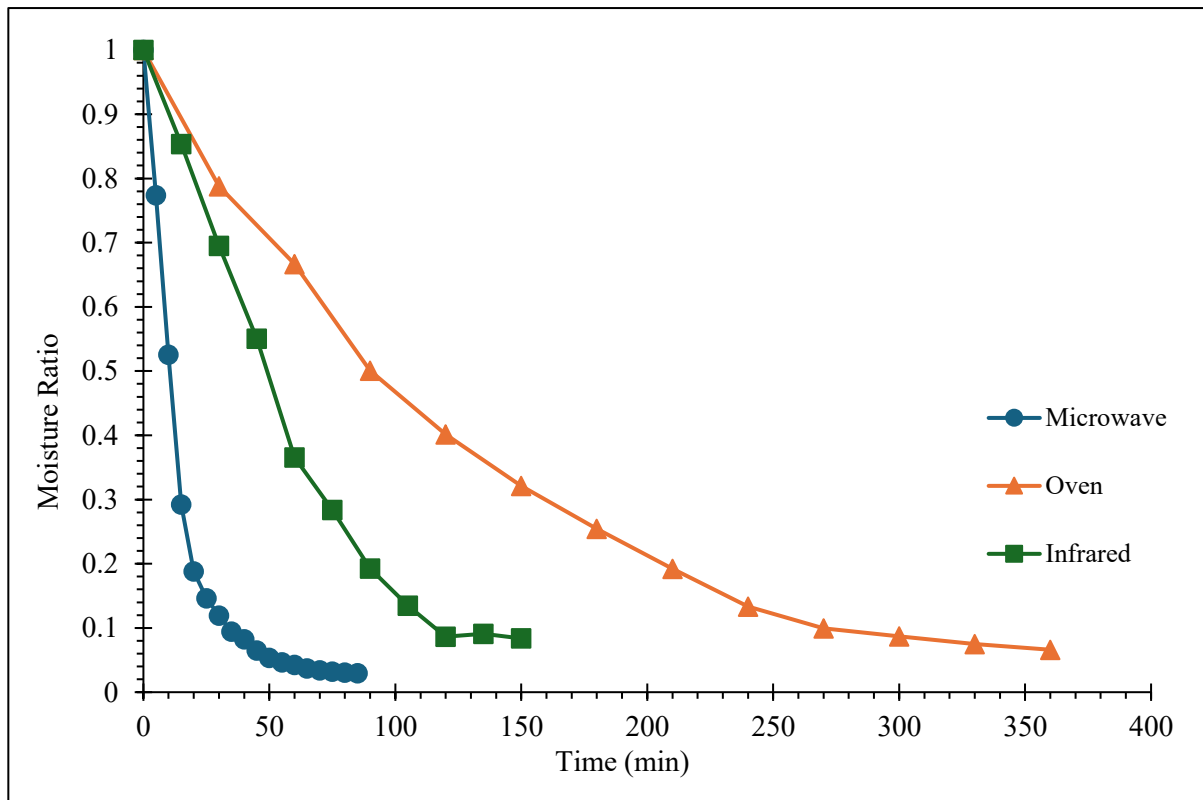


Figure 3. Effect of Different Drying Method on Moisture Ratio Over Time

In contrast to oven drying that took the longest time. According to (El-Mesery & Elabd, 2021) oven drying relies on convective heat transfer in which the heat is supplied from the hot air to the surface of the material. Then, the moisture must diffuse from the interior to the surface before evaporating resulting in a relatively slow process as the internal moisture must travel through the material by diffusion. It was the slowest as the moisture ratio gradually decreased over more than 350 minutes where it indicates slower moisture removal due to its reliability on external convective heat transfer.

The drying rate profiles of pineapple slices subjected to microwave, infrared, and hot-air oven drying are presented in Figure 4. All three

drying techniques operated entirely within the falling rate regime without displaying a constant rate phase, confirming that moisture removal was governed primarily by internal mass transfer resistance. However, the magnitude and kinetics of moisture evaporation differed substantially among the methods. Microwave drying exhibited an exceptionally high initial drying rate, reaching a maximum peak of 29.8 g H₂O/ g dry matter . min within the first 5 minutes of processing. This dramatic initial surge reflects rapid internal dielectric energy conversion, which induces prompt phase change and vigorous vaporization of unbound water molecules. Following this peak, the microwave drying rate declined abruptly as

free moisture was depleted, shifting the process toward the removal of bound water. This rapid drop further demonstrates the efficiency of volumetric heating in accelerating moisture migration and hastening the transition through the falling rate period (Ma et al., 2023).

In contrast, infrared drying exhibited a more moderate and steady drying rate profile. As illustrated in Figure 4, infrared drying lacked the pronounced initial spike observed in microwave drying, starting at 10.0 g H₂O/ g dry matter . min and reaching a secondary peak of 7.8 g H₂O/ g dry matter . min at 30 minutes while maintaining consistent drying

momentum over a longer duration. According to Ismail et al. (2018), the absence of a sharp initial surge during infrared drying reflects surface-dominated heat absorption and steadier moisture evaporation over time. Wang and Sheng (2006) noted that because infrared energy is primarily absorbed at the material surface and conducted inward, it facilitates controlled water removal rather than rapid internal moisture expulsion. The gradual decline in the infrared drying rate indicates a smooth transition from unbound to bound water removal (Delfiya et al., 2022), which can minimize structural collapse in the fruit matrix.

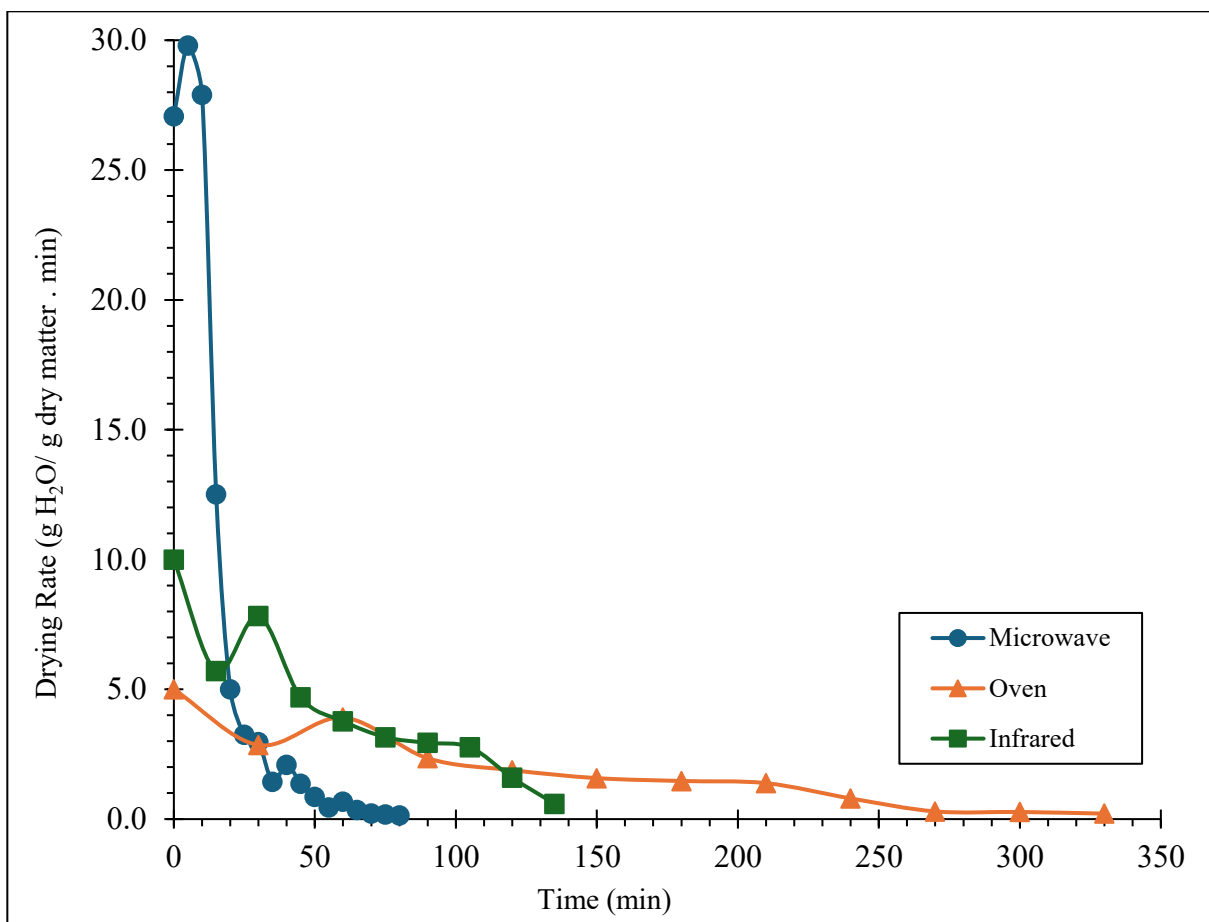


Figure 4. Drying Rate Profiles of Pineapple Slices Using Different Drying Methods

Meanwhile, hot-air oven drying exhibited the lowest initial drying rate of 5.0 g H₂O/ g dry matter . min and the most prolonged drying trajectory overall. The rate in oven drying declined steadily without any notable peaks, indicating slow heat penetration due to reliance on external convective air circulation (Norhadi et al., 2020). Consequently, internal moisture migration to the fruit surface was less

efficient, leading to extended drying times. Overall, the drying rate profiles demonstrate that microwave drying is the most energy-intensive and rapid technique, infrared drying offers a balanced and moderately efficient alternative, and oven drying is the least effective method for promoting moisture transfer.

Across all evaluated drying techniques, no constant rate period was observed in the drying curves (Figure 3 and Figure 4). According to Chokngamvong and Suvanjumrat (2023), the absence of a constant rate phase indicates that the rate of moisture supply to the sample surface was insufficient to maintain steady surface evaporation. Consequently, the drying process was governed entirely by the falling rate period, where mass transfer is dictated by internal moisture diffusion rather than surface evaporation. This behavior is characteristic of biological tissue like pineapple, where surface moisture evaporates rapidly during initial heating, leaving bound internal water that migrates slowly toward the surface via diffusion. Unlike materials with free surface water that sustain constant evaporation rates until surface moisture is depleted (He et al., 2021), the cellular matrix and sugar-rich structure of pineapple restrict internal moisture mobility, thereby prolonging the falling rate phase (Muyonga et al., 2021). Ultimately, the exclusive presence of a falling rate period confirmed that internal moisture diffusion was

the primary rate limiting mechanism controlling moisture removal across all three drying methods.

3.2. Antioxidant Activity

The antioxidant properties of the dried pineapple samples were evaluated through Total Phenolic Content (TPC) and DPPH radical scavenging capacity assays. These analyses provide critical insights into the retention of bioactive compounds particularly phenolics which contribute significantly to antioxidant potential but are highly susceptible to thermal degradation. Among the three drying techniques evaluated, microwave drying resulted in the highest retention of both TPC and DPPH radical scavenging activity, followed by infrared drying, while hot-air oven drying yielded the lowest values across both assays. One-way ANOVA confirmed that all three drying methods differed significantly from one another ($p < 0.05$) in both TPC and DPPH values, as shown in Table 1 and illustrated in Figure 5.

Table 1. Effect of drying methods on Total Phenolic Content (TPC) and DPPH radical scavenging activity of pineapple slices.

Drying Method	Total Phenolic Content (mg GAE/100g)	DPPH Radical Scavenging (% Inhibition)
Microwave	729.41±12.35	56.03±1.12
Infrared	516.28±9.84	44.03± 0.95
Oven	331.37±8.15	40.20± 0.88

The superior antioxidant preservation in microwave-dried samples aligns with findings by Joseph Bassey et al. (2024) and Wang and Sheng (2006), who reported enhanced bioactive retention in microwave-treated fruits compared to conventional thermal methods despite variations in sample matrices or process scale. Similarly, Zulkipli et al. (2024) observed significantly higher phenolic preservation and radical scavenging capacity in microwave-dried plant materials relative to

oven drying. The moderate retention observed during infrared drying and the severe losses in oven drying further demonstrate that bioactive preservation is inversely related to the duration of thermal and oxidative stress during drying (Athira et al., 2022). These observations agree with Si et al. (2015), who found that infrared drying retained significantly higher phenolic content (123.22 g GAE/kg dry weight) at 70 °C than conventional convective drying.

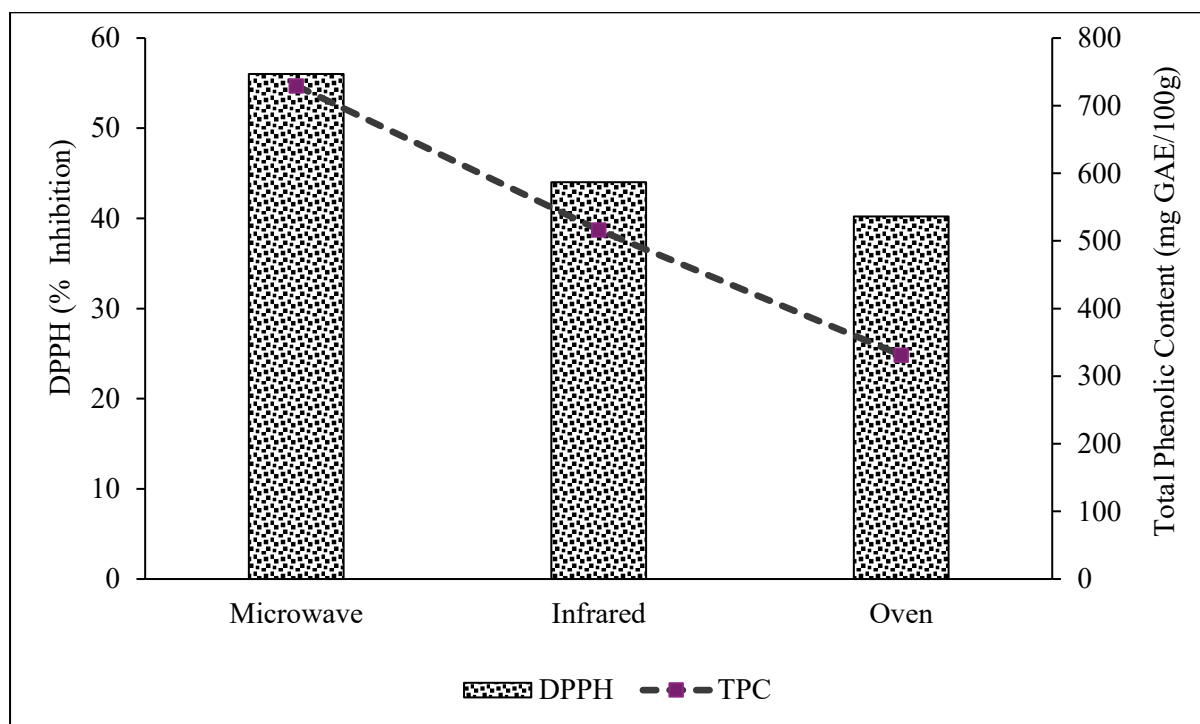


Figure 5. Effect of Different Drying Methods on Antioxidant Activity and Total Phenolic Content

Although drying kinetics dictate physical moisture removal rates, bioactive degradation is governed by chemical breakdown pathways influenced by heat intensity and oxygen exposure (Toydemir, 2016). The enhanced retention in microwave dried pineapple stems directly from its volumetric dielectric heating mechanism. Microwave radiation directly excites dipolar water molecules throughout the fruit matrix simultaneously, generating a steep internal vapor pressure gradient that rapidly drives moisture outward. This substantial reduction in total drying duration minimizes heat accumulation at the surface and limits exposure to atmospheric oxygen, thereby suppressing the thermal oxidation and cleavage of phenolic structures (Toydemir, 2016). Furthermore, rapid dielectric heating rapidly inactivates endogenous oxidative enzymes, such as polyphenol oxidase (PPO) and peroxidase (POD), halting enzyme catalyzed phenolic degradation early in the process. In contrast, infrared and convective oven drying rely on surface heat absorption followed by inward thermal conduction. This creates prolonged thermal stress and sustained exposure to elevated temperatures and atmospheric oxygen at the surface layer, accelerating the oxidative breakdown of heat-sensitive flavonoids and phenolics.

Whereas TPC reflects the overall concentration of phenolic compounds, the DPPH assay measures their functional radical-scavenging activity. The lower DPPH inhibition observed in infrared and oven dried samples indicates that prolonged thermal exposure not only reduces phenolic quantity but also compromises their functional radical-neutralizing efficiency due to structural alterations (Toydemir, 2016). The consistent parallel trend between TPC and DPPH across all treatments (Figure 5) supports the interpretation that drying method plays an important role not only in the retention of antioxidants but also in maintaining the chemical integrity of bioactive phenolic compounds.

4. Conclusion

This study evaluated the impact of microwave, infrared, and hot-air oven drying on the moisture removal kinetics and antioxidant retention of pineapple slices under standardized thermal conditions. Across all three drying techniques, moisture removal occurred entirely within the falling rate period without exhibiting a constant rate phase, confirming that the drying process was governed by internal moisture diffusion. Among the evaluated methods, microwave

drying achieved the fastest moisture removal kinetics and shortest overall drying duration, whereas convective oven drying was the slowest and least efficient. Antioxidant evaluation through Total Phenolic Content (TPC) and DPPH radical scavenging activity demonstrated that microwave drying preserved significantly higher ($p < 0.05$) levels of bioactive compounds compared to infrared and oven drying. This superior retention is directly attributed to the volumetric dielectric heating mechanism of microwave energy, which generates rapid internal vapor pressure gradients and shortens drying time. By substantially reducing total thermal exposure and limiting contact with atmospheric oxygen, microwave drying minimizes thermal degradation, cleavage, and oxidative breakdown of heat sensitive phenolics. These results demonstrate that microwave drying is the most effective technique for preserving antioxidant quality in pineapple under the evaluated conditions. However, future investigations evaluating multi-factor operating parameters (e.g., variable temperatures and power levels) are recommended to establish fully optimized processing conditions for industrial scaling. However, a limitation of this study is the investigation of a single drying temperature (80 °C) and fixed microwave power setting (300 W). Future investigations evaluating multi-factor operating parameters (e.g., variable temperatures, power densities, and wavelengths) are recommended to establish fully optimized processing conditions for industrial scaling.

5. References

- Athira, V. A., Gokulvel, E., Nandhu Lal, A. M., Venugopalan, V. V., Rajkumar, R., & Venkatesh, T. (2022). Advances in drying techniques for retention of antioxidants in agro produces. *Critical Reviews in Food Science and Nutrition*, 63(31), 10849–10865.
- Bassey, E. J., Cheng, J. H., & Sun, D. W. (2024). Comparative elucidation of bioactive and antioxidant properties of red dragon fruit peel as affected by electromagnetic and conventional drying approaches. *Food Chemistry*, 439, Article 137030.
- Chaudhuri, D., Chatterjee, A., Das, A., & Mandal, N. (2012). Study of antioxidant and reactive oxygen species scavenging activity of the edible tuber of greater yam (*Dioscorea alata* L.) from North-East India. *Asian Journal of Pharmaceutical and Clinical Research*, 5(3), 74–77.
- Chauhan, A., Singh, S., Dhar, A., & Powar, S. (2021). Optimization of pineapple drying based on energy consumption, nutrient retention, and drying time through multi-criteria decision-making. *Journal of Cleaner Production*, 292, Article 125973.
- Chokngamvong, S., & Suvanjumrat, C. (2023). Study of drying kinetics and activation energy for drying a pineapple piece in the crossflow dehydrator. *Case Studies in Thermal Engineering*, 49, Article 103351.
- Delfiya, D. S. A., Prashob, K., Murali, S., Alfiya, P. V., Samuel, M. P., & Pandiselvam, R. (2022). Drying kinetics of food materials in infrared radiation drying: A review. *Journal of Food Process Engineering*, 45(6), Article e13934.
- El-Mesery, H. S., & Elabd, M. A. (2021). Effect of microwave, infrared, and convection hot-air on drying kinetics and quality properties of okra pods. *International Journal of Food Engineering*, 17(11), 909–926.
- Harith, N. S., Rahman, N. A., Zamanhuri, N. A., & Hashib, S. A. (2023). Microwave-based antioxidant extraction from pineapple peel waste. *Materials Today: Proceedings*, 87, 126–131.
- He, C., Wang, H., Yang, Y., Huang, Y., Zhang, X., Arowo, M., Ye, J., Zhang, N., & Xiao, M. (2021). Drying behavior and kinetics of drying process of plant-based enteric hard capsules. *Pharmaceutics*, 13(3), Article 335.
- Izli, N., Izli, G., & Taskin, O. (2018). Impact of different drying methods on the drying kinetics, color, total phenolic content, and antioxidant capacity of pineapple. *CyTA – Journal of Food*, 16(1), 213–221.
- Ma, Y., Tian, X., Wang, Y., Zhao, H., & Song, J. (2023). Comparative study on drying characteristics and quality of apple cubes

- dried in two different microwave dryers. *Foods*, 12(4), Article 870.
- Mohd Ali, M., Hashim, N., Abd Aziz, S., & Lasekan, O. (2020). Pineapple (*Ananas comosus*): A comprehensive review of nutritional values, volatile compounds, health benefits, and potential food products. *Food Research International*, 137, Article 109675.
- Muyonga, J. H., Natocho, J., Kigozi, J., Baidhe, E., & Nansereko, S. (2021). Drying behaviour and optimization of drying conditions of pineapple puree and slices using refractance window drying technology. *Journal of Food Science and Technology*, 59(7), 2794–2804.
- Norhadi, N., Akhir, A. M., Rosli, N. R., & Mulana, F. (2020). Drying kinetics of mango fruit using tray and oven dryer. *Malaysian Journal of Chemical Engineering & Technology*, 3(2), 51–59.
- Parit, R. K., Uttam, D., & Bombale, L. (2018). Microwave system for fruit drying. *International Journal of Electrical and Electronics Research*, 6(5), 15–20.
- Samad, N. A., Zaidel, D. N. A., Yunus, N. A., Muhamad, I. I., Jusoh, Y. M. M., Dailin, D. J., & Sulistyo, J. (2024). Kinetics modelling of *Moringa oleifera* leaves using microwave drying. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 113(1), 167–175.
- Si, X., Zhou, L., Chen, Q., Bi, J., Wu, X., Yi, J., & Li, Z. (2015). Comparison of different drying methods on the physical properties, bioactive compounds and antioxidant activity of raspberry powders. *Journal of the Science of Food and Agriculture*, 95(5), 895–903.
- Sun, G. M., Zhang, X. M., Soler, A., & Marie-Alphonsine, P. A. (2015). Nutritional composition of pineapple (*Ananas comosus* (L.) Merr.). In M. S. J. Simmonds & V. R. Preedy (Eds.), *Nutritional composition of fruit cultivars* (pp. 609–637). Academic Press.
- Toydemir, G. (2016). A review on the effect of drying on antioxidant potential of fruits and vegetables. *Turkish Journal of Agriculture – Food Science and Technology*, 4(12), 1134–1140.
- Vidinamo, F., Fawzia, S., & Karim, M. A. (2022). Investigation of the effect of drying conditions on phytochemical content and antioxidant activity in pineapple (*Ananas comosus*). *International Journal of Food Properties*, 25(1), 2147–2161.
- Wang, J., & Sheng, K. (2006). Far infrared and microwave drying of peach. *LWT – Food Science and Technology*, 39(3), 247–255.
- 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.
- Zaki, N. A. M., Rahman, N. A., Zamanhuri, N. A., & Hashib, S. A. (2017). Ascorbic acid content and proteolytic enzyme activity of microwave-dried pineapple stem and core. *Chemical Engineering Transactions*, 56, 1369–1374.
- Zeng, Z., Han, C., Wang, Q., Yuan, H., Zhang, X., & Li, B. (2024). Analysis of drying characteristic, effective moisture diffusivity and energy, exergy and environment performance indicators during thin layer drying of tea in a convective-hot air dryer. *Frontiers in Sustainable Food Systems*, 8, Article 1312335.
- Zulkipli, N. N., Norasmadi, I. N. S., Lob, S., Wan Sembok, W. Z., Suhaimi, N. I., & Mubarak, A. (2024). Effect of different drying methods on retention of colour, total phenolic content, flavonoid content and antioxidant activity in *Pereskia bleo* leaves. *Malaysian Applied Biology*, 53(3), 83–93.

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