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# Enhanced quality and bioactive preservation of dried mangoes through intermittent hot air drying: A comparative study with continuous hot air, vacuum, and freeze-drying techniques

**Saenmuang, S., Phothiset, S., Prommakool, A., Phattayakorn, K., Tayuan, C. and Sirijariyawat, A.***

Department of Food Technology and Nutrition, Faculty of Natural Resources and Agro-Industry, Kasetsart University Chalermphrakiat Sakon Nakhon Province Campus, Sakon Nakhon, 47000, Thailand.

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**Abstract** The impact of intermittent hot air drying on the quality of dried mangoes was evaluated. Three intermittent drying conditions (20, 30, and 40 minutes of heating with 5-minute intervals of no heating) were compared to continuous hot air drying, vacuum drying, and freeze drying. Intermittently dried mangoes exhibited hue values similar to fresh mangoes. The optimal drying condition was 40 minutes of heating with a 5-minute tempering time. Intermittent drying resulted in significantly higher phenolic content (224.60 mg/100 g), vitamin C content (64.38 mg/100 g), and antioxidant activity (79.40%) compared to continuous hot air drying ($p \leq 0.05$). Vitamin C content and antioxidant activity of the intermittent dried samples were comparable to vacuum-dried samples, while phenolic content was similar to freeze-dried samples ($p > 0.05$). Intermittent drying using an economical hot air dryer improved the quality of dried mangoes, with some attributes comparable to vacuum and freeze drying.

**Keywords:** Freeze drying, Hot air drying, Intermittent drying, Mango, Vacuum drying

## Introduction

Mango (*Mangifera indica* L.) is a very important and famous type of tropical fruit. It is abundant in fiber, vitamins B, A, C, and beta-carotene, which is a natural antioxidant. Thailand has exported mangoes in various forms such as fresh mangoes, dried mangoes, and frozen mangoes (Office of Agricultural Economics, 2023). Mangoes are seasonal fruit with short shelf life therefore mangoes need to be proceeded to extend shelf life.

Drying is a process of preserving and processing food by removing water in order to stop or slow down chemical changes and microbial growth. However,

* **Corresponding Author:** Sirijariyawat, A.; **Email:** arpassorn.s@ku.th

there are different methods for drying with different equipment and processing costs. Each drying method influences the appearance and quality of the dried product. Freeze drying is a drying method in which food is not exposed to heat and air. Therefore, dry food is of good quality, but the major constraint is expensive equipment. With vacuum drying, food is not exposed to air during drying. Therefore, the resulting product is of better quality than drying using hot air. However, the hot air-drying method is still popular due to its low equipment and maintenance cost. The proper study of the conditions used for hot air drying can help improve the quality of the dry product. Intermittent drying is one of many approaches to improve the quality of food that has been dried using hot air without increasing the cost of investment in the dryer. In addition, energy consumption can be reduced during the drying process. Intermittent drying is non-continuous drying in which there are changes in the conditions during drying such as temperature, humidity, and pressure during the drying process (Chandan and Karim, 2014). Intermittent drying is advantageous due to the repetitive nature of the process, involving surface moisture evaporation and displacement of inner moisture to the surface. This characteristic enables the reduction of overheating. Additionally, the short heating times contribute to the mitigation of oxidative and enzymatic processes, thereby preventing damage to heat-sensitive bioactive compounds (Duc Pham *et al*., 2019). Consequently, reports indicate that intermittent drying minimizes undesirable effects, thereby preserving crucial properties such as color and texture and extending the shelf life of dried berries (Pateiro *et al*., 2022). The influence of thermal intermittence drying on mango was found to impact the drying kinetics, resulting in notable reductions in the overall process time. Moreover, this intermittent drying method offers energy savings in comparison to continuous drying (Amado *et al*., 2021). Kowalski *et al*. (2013) reported drying with hot air at 70°C for 20 minutes intermission with an absence of hot air for 5 minutes of 9 cycles resulted in a higher amount of remaining beta-carotene and improvement in the color of the final product than using constant drying process. Vaquiro *et al*. (2009) investigated the drying process of mangoes Tommy Atkins varieties by dicing into a cube of 2.5 cm for each side and found that intermittent drying reduced the drying time by 3 - 11% and energy consumption in drying was reduced 9 - 23%. Increasing the rest or stopping time can increase energy savings, but the total drying time may increase. This additional total drying time may not be suitable for some products. The excessive increasing the length of time for stopping may cause the product to be hygroscopic and degrade the quality of the product (Kumar *et al*., 2014). Consequently, for dried mango, if appropriate intermittent hot air-drying conditions are studied, it is possible to produce good quality dried mango by using an affordable hot air dryer. The product is of better quality than continuous hot air drying and some qualities may be comparable to expensive drying tools such as vacuum dryer and freeze dryer.

Therefore, the study aimed to evaluate the effect of the intermittent hot air-drying methods on the quality of color, shrinkage, and antioxidant content of dried mango compared with the continuous hot air-drying method, vacuum drying, and freeze-drying method.

## Materials and methods

### *Sample preparation*

The mangoes used in this study were of the Kaew Khamin variety. Sample mangoes at the beginning of the ripening stage, exhibiting similar sizes, were selected. The total soluble solid contents of the mango samples ranged from 10 to 12 °Brix. Prior to the drying process, the mangoes were peeled and cut into small sizes of 2x4x1 cm.

### *Drying process*

A total of six drying methods were employed in this study. For the freeze-drying method, the mango pieces were initially frozen at -70°C and subsequently subjected to drying using a laboratory freeze dryer (Laboratory freeze dryer ALPHA 1-2 LDplus, Martin Christ, Germany). Vacuum drying involved drying the mango pieces in a vacuum oven (Vacuum drying oven VD 53, Binder, Germany) at a temperature of 60°C. Continuous hot air drying was performed using a tray dryer (Electric convection dryer KNT10, Kluoynamthai, Thailand) at 60°C. The three intermittent hot air-drying methods were also conducted using the same tray dryer at 60°C. In the first intermittent method (Hot air drying 20/5), the mango pieces were heated for 20 minutes, followed by a 5-minute intermission, and this cycle was repeated until the samples reached the desired water activity. Similarly, for the second intermittent method (Hot air drying 30/5), the mango pieces underwent heating for 30 minutes, followed by a 5-minute intermission, with repetitions until the required water activity was achieved. In the third intermittent method (Hot air drying 40/5), the mango pieces were heated for 40 minutes, interrupted for 5 minutes, and this process was repeated until the desired water activity was attained. All mango samples were dried until the water activity approached 0.6, at which point they were subjected to chemical and physical characterization to assess the influence of the drying methods.

***Beta-carotene***

The quantification of beta-carotene was performed using the high-performance liquid chromatography (HPLC) method (Sirijariyawat *et al*., 2018). A 0.5 g of sample was mixed with 10 mL mixed solvent used for extraction. Mixed solvent consisted of acetone and ethanol 1:1 ratio with 200 mg/L of Butylated hydroxytoluene (BHT). After mixing, supernatant and solid residue were separated by centrifuge (Universal Centrifuge Z326K, HERMLE Labortechnik GmbH, Germany) at 6,000 rpm for 10 minutes. The supernatant was collected to determine absorbance value at 470 nm with a microplate reader (Synergy™ HT Multi-Mode, BioTek Instruments Inc., USA). The absorbance value was compared with the known concentration of the standard beta-carotene then reported as mg/100g dry sample.

***Phenolic content***

Quantification method of total phenolic content was modified from Vinha *et al*. (2014). A 0.5 g of sample was mixed with 10 mL mixed solvent used for extraction. Mixed solvent consisted of methanol/water (80/20 v/v). Sample and mixed solvent were mixed at room temperature for 1 hour. After mixing, supernatant and solid residue were separated by centrifuge (Universal Centrifuge Z326K, HERMLE Labortechnik GmbH, Germany) at 6,000 rpm for 10 minutes. A 0.2 mL of supernatant was mixed with 0.5 mL of Folin-Ciocalteu reagent for 3 minutes at 25°C. Then, added 7.5% Sodium carbonate 0.2 mL and kept at room temperature for 120 minutes. The supernatant was collected to determine absorbance value at 725 nm with a microplate reader (Synergy™ HT Multi-Mode, BioTek Instruments Inc., USA). The absorbance value was compared with the known concentrations of gallic acid standard solution then reported as mg/100g dry sample.

***Vitamin C***

Quantification of vitamin C was modified from Vinha *et al*. (2014). A 0.5 g of sample was mixed with 10 ml of 0.1 g/L metaphosphoric acid then mixed at room temperature for 45 minutes. After mixing, supernatant and solid residue were separated by centrifuge (Universal Centrifuge Z326K, HERMLE Labortechnik GmbH, Germany) at 6,000 rpm for 10 minutes. Supernatant 200 μL was collected and mixed with 100 μL of 2,6-dichlorophenolindophenol at room temperature. The supernatant was collected to determine absorbance value at 515 nm with a microplate reader (Synergy™ HT Multi-Mode, BioTek

Instruments Inc., USA). The absorbance value was compared with known concentrations of ascorbic acid standard solution then reported as mg ascorbic acid/100g dry sample.

***Antioxidant activity by DPPH method***

Antioxidant activity was evaluated by DPPH method (Vinha *et al*., 2014). A 0.25 g of sample was mixed with 10mL of methanol then stir for 60 minutes at room temperature. After separating solid residue and supernatant by centrifuge (Universal Centrifuge Z326K, HERMLE Labortechnik GmbH, Germany) at 6,000 rpm for 10 minutes, a 30 µL of supernatant was mixed with DPPH (60 µmol/L) 270 µL and stir to well mixed. The supernatant was collected to determine absorbance value at 515 nm with a microplate reader (Synergy™ HT Multi-Mode, BioTek Instruments Inc., USA) to identify %Radical scavenging activity (%RSA) from the following equation.

$$\%RSA = [(ADPPH - AS)/ADPPH] \times 100$$

AS represents absorbance value of sample mixed DPPH and ADPPH represents absorbance value of DPPH solution.

***Color***

Color of samples was determined quantitatively by color measurement instrument (Mini scan XE plus, Hunter Associates Laboratory Inc., USA) with color system CIE L*a*b*. Hue value can be calculated from

$$Hue = \text{arctangent}\ (b^*/a^*)$$

in which Hue value = 0° or 360° represents red, Hue value = 270° represents blue, Hue value = 180° represent green and Hue value = 90° represents yellow (Argyropoulos and Muller, 2011).

***Shrinkage degree***

Shrinkage degree was determined by volume replacement approach (Zielinska *et al*., 2015) with

$$S = (1 - V/V_0) * 100$$

in which S represent shrinkage degree, V is volume ($cm^3$) of dried sample ($cm^3$), and $V_0$ represents volume ($cm^3$) of sample before drying process.

### *Statistical analysis*

The experiment was replicated three times. The data collected from different studies were analyzed to determine their statistical significance using one-way analysis of variance (ANOVA) with the SPSS software. Significance was tested at a level of $p \leq 0.05$, and differences among means were assessed using Duncan's New Multiple Range Test.

## Results

### *Duration of hot air drying*

Mangoes were subjected to hot air drying at a temperature of 60°C until the water activity ($a_w$) reached a level below 0.6. This specific water activity level was targeted to ensure the storage of dried mangoes free from microbial growth. It should be noted that variations in drying conditions led to varying drying times, as illustrated in Table 1.

Intermittent drying exhibited a longer total drying time compared to continuous drying, particularly in the case of the intermittent method involving 20 minutes of heating and 5 minutes of tempering, as well as 30 minutes of heating and 5 minutes of tempering, which resulted in an additional drying time of 60-75 minutes. Conversely, the intermittent method with 40 minutes of heating and 5 minutes of tempering only increased the heating time by 15 minutes. Despite the longer overall drying time of the intermittent method compared to continuous drying, the heating time was shorter.

**Table 1.** Total drying time and heating time of continuous and intermittent hot air drying

| Hot air drying method | Total drying time (min) | Heating time (min) |
|---|---|---|
| Continuous | 520 | 520 |
| 20/5 | 595 | 480 |
| 30/5 | 580 | 500 |
| 40/5 | 535 | 480 |

### *Beta-carotene content*

Beta-carotene, a compound present in various fruits and vegetables, including mangoes, exhibited a content of 26.90 mg/100g in fresh mango samples (Figure 1). Upon subjecting the mangoes to different drying methods, the remaining beta-carotene content varied, as depicted in Figure 1. Freeze drying yielded the highest retention of beta-carotene in dried mangoes, with a value of 83.79%. Continuous and intermittent hot air-drying methods exhibited comparable levels of remaining beta-carotene content (p>0.05), ranging from 35.24% to 44.50%. In contrast, vacuum drying resulted in a higher remaining beta-carotene content in dried mangoes compared to hot air drying.

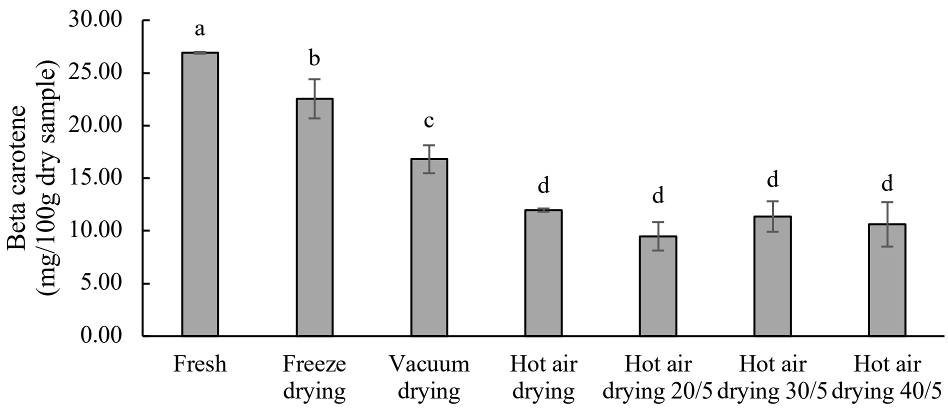


**Figure 1.** Beta-carotene content of fresh and dried mangoes by various drying methods

* Different letters on the bar mean significant difference (p≤0.05)

### *Phenolic content*

Phenolic compounds, known for their natural antioxidant properties, are commonly found in fruits and vegetables. Fresh mangoes exhibited a phenolic compound content of 282.31 mg/100g in dry samples. Drying processes led to a reduction in phenolic compounds in mangoes, as depicted in Figure 2. Freeze drying resulted in significantly higher phenolic content in dried mangoes (p ≤ 0.05) compared to vacuum drying and continuous hot air drying, which exhibited similar phenolic content (p>0.05). Intermittent drying using a heating period of 40 minutes and tempering for 5 minutes resulted in significantly higher phenolic content in dried mangoes compared to other hot air-drying methods (p≤0.05). Interestingly, the phenolic content in mangoes subjected to this intermittent drying condition was comparable to that of mangoes dried using the freeze drying method, as shown in Figure 2.

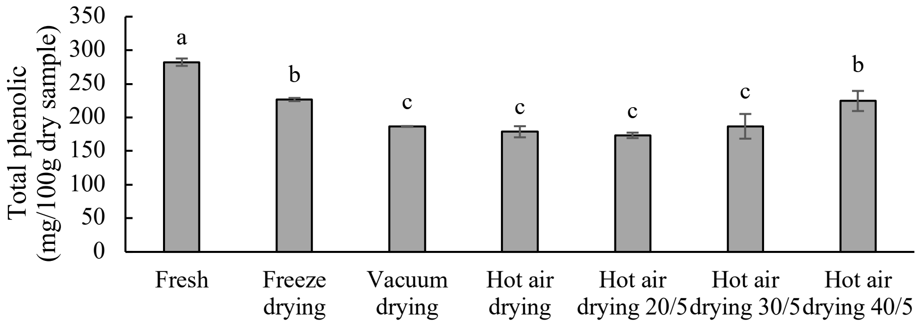


**Figure 2.** Total phenolic content of fresh and dried mangoes by various drying methods

* Different letters on the bar mean significant difference (p≤0.05)

***Vitamin C content***

Vitamin C, also known as ascorbic acid, is a water-soluble vitamin that is susceptible to degradation caused by oxidation, both enzymatic and oxygen-induced. Fresh mangoes exhibited an approximate vitamin C content of 109.81 mg/100 g in dry samples (Figure 3). Freeze drying proved to be the most effective method in preserving the remaining vitamin C content, as illustrated in Figure 3. Regarding intermittent hot air drying, it was found that heating the mangoes for 40 minutes followed by a 5-minute tempering period resulted in a higher remaining vitamin C content compared to continuous hot air drying ($p \leq 0.05$). Furthermore, there was no significant difference in the remaining vitamin C content between intermittent hot air drying and vacuum drying ($p > 0.05$). The degradation of vitamin C during the drying process can be attributed to the combination of temperature and exposure time to heat and air.

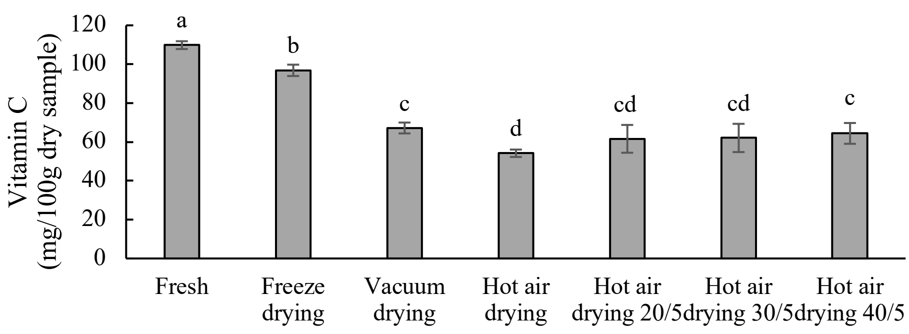


**Figure 3.** Vitamin C content of fresh and dried mangoes by various drying methods

* Different letters on the bar mean significant difference (p≤0.05)

### *Antioxidant activity*

The antioxidant activity of mangoes dried using different methods was assessed through the DPPH assay, and the results are presented as the percentage of Radical Scavenging Activity (%RSA) in Table 2. The study revealed that mangoes dried using the freeze-drying method exhibited the highest antioxidant activity. Vacuum dried mangoes exhibited higher antioxidant activity compared to mangoes dried using the continuous hot air-drying method ($p \leq 0.05$). These findings align with the levels of phytochemicals, including beta-carotene, phenolic compounds, and vitamin C, detected in the dried mango samples.

Intermittent hot air drying yielded dried mangoes with higher antioxidant activity compared to the continuous hot air-drying method, as indicated in Table 2. Specifically, mangoes dried by heating for 40 minutes, followed by a 5-minute pause, exhibited the highest antioxidant activity ($p \leq 0.05$) among the samples dried using hot air. Furthermore, this sample displayed antioxidant activity similar to mangoes dried using the vacuum drying method.

### *Sample shrinkage*

During drying, water was eliminated from the food cells thus pressure of the fluid inside the food cells decreased and caused food to shrink. Freeze dried mango had the lowest shrinkage percentage ($p \leq 0.05$) as shown in Table 2. While vacuum drying and hot air drying of both continuous and intermittent resulted in mango had the same percentage shrinkage ($p > 0.05$).

**Table 2.** Antioxidant activity and shrinkage value of dried mangoes with different drying methods

| **Drying method** | **%RSA** | **%Shrinkage** |
|---|---|---|
| Freeze drying | $84.64^{a} \pm 0.75$ | $17.35^{b} \pm 2.95$ |
| Vacuum drying | $77.89^{b} \pm 1.04$ | $69.49^{a} \pm 1.90$ |
| Hot air drying | $71.25^{d} \pm 0.69$ | $72.33^{a} \pm 2.63$ |
| Hot air drying 20/5 | $74.00^{c} \pm 0.06$ | $69.08^{a} \pm 1.30$ |
| Hot air drying 30/5 | $73.43^{cd} \pm 0.94$ | $69.35^{a} \pm 2.56$ |
| Hot air drying 40/5 | $79.40^{b} \pm 2.35$ | $68.24^{a} \pm 1.18$ |

* Different letters within the same column mean significant difference ($p \leq 0.05$)

### *Color*

The drying method exerted a noticeable influence on the color characteristics of the dried mangoes, as illustrated in Table 3. Freeze-dried samples exhibited similar lightness (L*) compared to the fresh samples, whereas the redness (a*) and yellowness (b*) values decreased. The freeze-dried sample had a higher Hue value (88.68) than the fresh sample, indicating a more pronounced yellow tone. Conversely, vacuum drying and continuous hot air drying, which involved heating during the drying process, resulted in lower lightness (L*) and yellowness (b*) values, lower Hue values, and higher redness (a*) values compared to the fresh sample ($p \leq 0.05$). The samples subjected to vacuum drying and continuous hot air drying exhibited a red-yellow color.

**Table 3.** Color value of fresh and dried mangoes with different drying methods

| Treatment | L* | a* | b* | Hue value |
|---|---|---|---|---|
| Fresh | $70.42^{a} \pm 5.42$ | $8.68^{b} \pm 3.39$ | $60.11^{a} \pm 3.88$ | $81.88^{b} \pm 2.65$ |
| Freeze drying | $72.06^{a} \pm 5.69$ | $1.06^{c} \pm 0.43$ | $45.93^{c} \pm 1.09$ | $88.68^{a} \pm 0.56$ |
| Vacuum drying | $51.62^{b} \pm 4.88$ | $10.11^{ab} \pm 0.82$ | $46.61^{bc} \pm 4.27$ | $77.68^{c} \pm 2.05$ |
| Hot air drying | $59.11^{b} \pm 0.46$ | $13.64^{a} \pm 1.49$ | $52.64^{b} \pm 1.43$ | $75.49^{c} \pm 1.14$ |
| Hot air-drying 20/5 | $56.24^{b} \pm 2.61$ | $7.52^{b} \pm 0.92$ | $49.02^{bc} \pm 0.62$ | $81.27^{b} \pm 1.16$ |
| Hot air-drying 30/5 | $58.52^{b} \pm 0.76$ | $7.66^{b} \pm 0.59$ | $52.51^{b} \pm 0.45$ | $81.71^{b} \pm 0.56$ |
| Hot air-drying 40/5 | $53.71^{b} \pm 0.17$ | $6.68^{b} \pm 0.37$ | $47.50^{bc} \pm 0.28$ | $81.99^{b} \pm 0.49$ |

* Different letters within the same column mean significant difference ($p \leq 0.05$)

Intermittent drying conditions yielded dried mangoes with color values closer to those of fresh mangoes. Notably, the Hue values of the dried mangoes under all three intermittent drying conditions did not significantly differ ($p > 0.05$) and ranged from 81.27 to 81.99. These Hue values were also not significantly different from those of the fresh mangoes ($p > 0.05$). However, a significant reduction in Hue value (75.49) was observed in the continuous hot air-drying method ($p \leq 0.05$).

## Discussion

### *Duration of hot air drying*

Intermittent drying proved advantageous for samples undergoing the falling rate period of drying. During this stage, the diffusion of heat and moisture within the sample controlled the drying rate. The tempering period facilitated heat diffusion into the sample, while moisture diffused onto the sample surface. As moisture migrated to the surface and water distribution within the food pieces became more uniform, the drying rate increased during the heating period. Consequently, the surface temperature of the sample and the duration of heat exposure were reduced. As a result, the quality of the product obtained through intermittent drying surpassed that of continuous hot air drying (Chua *et al*., 2003). Váquiro *et al*. (2009) reported intermittent mango drying reduced the drying time and energy consumption and improve quality of the final product. Intermittent drying resulted in a lower surface temperature of mangoes than that of continuous drying. Due to the increased amount of moisture on the surface, heat from the hot air transferred to the sample surface was used to evaporate the water from the sample surface more than to increase in surface temperature. After each resting period, the water at the surface of the sample was rapidly removed thus drying rate was high after each resting period. Mabrouk *et al.* (2012) reported intermittent drying improved the quality of sliced apples and reduced the drying time. Kowalski *et al*. (2013) reported an intermittent hot air drying by 30 minutes heating alternating with 5 minutes tempering for carrot yielded the shortest drying time. Increasing the duration of the resting period resulted in a longer drying time. Kowalski and Szadzińska (2014) studied continuous and intermittent hot air drying of cherries at 60°C found that intermittent drying (5 minutes heating and 30 minutes tempering) reduced overall drying time.

***Beta-carotene content***

Previous studies have consistently demonstrated that freeze drying retains a higher amount of beta-carotene in dried food products compared to other drying methods. Vacuum drying has also been shown to result in greater beta-carotene residue compared to hot air drying. For instance, Suvarnakuta *et al*. (2005) reported that vacuum-dried carrots had higher beta-carotene residues than samples dried using hot air. The breakdown of beta-carotene is caused by oxidation, which is influenced by factors such as heating time, temperature, and oxygen content. Hot air drying, being an air-exposure method, leads to a higher breakdown of beta-carotene due to oxygen exposure compared to other drying techniques. Chen *et al*. (2007) found that mangoes dried using hot air at 60 °C had lower total carotenoid content than freeze-dried mangoes. Similarly, Kumar and Sagar (2014) reported that osmodehydrated mangoes dried using a vacuum dryer had higher remaining beta-carotene content compared to samples dried using hot air. Furthermore, Sogi *et al*. (2013) observed that hot air and vacuum air-drying methods resulted in the breakdown of carotenoids, while freeze-dried samples exhibited the highest carotenoid content.

Regarding the impact of intermittent drying, studies have shown that this method can lead to an increase in beta-carotene content. Pan *et al*. (1998) reported that the intermittent drying method preserved up to 87.2% of the original beta-carotene content in squash fruit, while continuous drying only yielded a final content of 61.5%. Similarly, Kowalski *et al*. (2013) found that intermittent hot air drying reduced the degradation of beta-carotene in carrots. The remaining beta-carotene content after intermittent drying may vary depending on several factors, including the specific sample characteristics, drying temperature, heating period, and tempering period.

***Phenolic content***

Regarding the phenolic content, our findings align with prior research, demonstrating that freeze-dried products possess higher phenolic content compared to those dried using hot air and vacuum methods. Korus (2011) reported that freeze drying yielded higher total phenolic content in dried kale compared to hot air drying at 55°C. Phenolic compounds are known to contribute to the antioxidant activity of plants but are susceptible to oxidation. Hot air drying, relying on direct air exposure, can directly impact the phenolic content. Heat can degrade naturally occurring antioxidants while potentially generating Maillard reaction products, which possess antioxidant properties. These factors may influence the overall antioxidant activity of the samples (Anese *et al*., 1999). In line with this, Sogi *et al*. (2015) reported that freeze-dried mangoes exhibited higher total phenolic content compared to samples dried using hot air and vacuum methods at 60°C. Mangoes subjected to hot air drying and vacuum drying demonstrated similar phenolic content.

Our findings revealed that the phenolic content within mangoes exposed to the intermittent drying using a heating period of 40 minutes and tempering for 5 minutes was similar with that of mangoes dried using the freeze-drying method. The heat applied during the drying process led to the breakdown of phenolic compounds. However, intermittent drying, characterized by alternating heating and tempering periods, reduced the overall heating duration and internal temperature compared to continuous drying. Consequently, intermittent drying exhibited superior preservation of phenolic compounds when compared to continuous hot air drying. A study conducted by Kowalski and Szadzinska (2014) found that intermittent drying reduced color changes in dried cherries, attributed to the retention of anthocyanins in the samples. However, in the present study, intermittent drying methods involving a heating period of 20 minutes and tempering for 5 minutes, as well as 30 minutes of heating with 5 minutes of tempering, resulted in similar phenolic content compared to continuous drying.

This similarity may be attributed to the relatively short heating durations employed in these intermittent conditions. Consequently, the total drying times were extended, exposing the products to air for longer periods and increasing the probability of oxidation. These findings highlight the importance of optimizing heating and tempering durations to achieve the desired phenolic compound content and overall product quality.

### *Vitamin C content*

Previous research by Jiang *et al*. (2014) highlighted the easily of ascorbic acid to degradation from light, heat, and oxygen. Freeze drying resulted in a slight reduction in ascorbic acid content in bananas, retaining approximately 80.29% of the original content found in fresh bananas. Gumusay *et al*. (2015) similarly found that freeze drying yielded the highest vitamin C content in dried tomatoes, followed by vacuum drying, while the hot air-drying method exhibited the lowest content due to the effects of oxygen and heat, which degrade vitamin C.

Intermittent drying, characterized by periodic heating and stopping, reduced the overall exposure time of the mangoes to heat. As a result, intermittent drying exhibited better preservation of vitamin C content compared to continuous hot air drying. This finding aligns with the study by Kumar *et al*. (2014), which reported that intermittent drying reduced the degradation of vitamin C during the drying process.

### *Antioxidant activity*

Antioxidants in fruits and vegetables tend to lose their activity when exposed to heat. Previous research by Sogi *et al*. (2013) reported that freeze-dried mango peel and kernels exhibited the highest antioxidant activity. Thermal drying methods led to a decline in antioxidant activity due to oxidation reactions affecting phenolic compounds, ascorbic acid, and carotenoids. Gumusay *et al*. (2015) also reported that freeze drying resulted in higher antioxidant activity in tomatoes and ginger compared to other drying methods, such as vacuum drying and hot air drying. In the same study, the authors demonstrated a correlation between antioxidant activity, vitamin C content, and phenolic acid content in tomatoes and ginger samples. As for the hot air drying, prolonged and continuous exposure to heat resulted in a decrease in antioxidant value in mango samples. In contrast, the intermittent hot air-drying method limited the contact time between the mangoes and heat, thereby preserving the antioxidant activity of the mangoes to a greater extent compared to the continuous hot air-drying method.

### *Sample shrinkage*

The shrinkage of the samples depended on the amount of water that has been removed. In addition, drying method also affected the shrinkage of the dried food. The results of our study were consistent with previous research reports which found that freeze drying caused less shrinkage of the dry product (Nawirska *et al*., 2009; Calin-Sanchez *et al*., 2015).

### *Color*

Hot air drying produced more pigment than freeze drying due to a browning reaction, which was accelerated by the hot air-drying method. While freeze drying method was performed at low temperatures, thus browning reaction was retard. In the context of pineapple drying, a decline in the hue angle was observed in tray and vacuum dried samples at temperatures of 50 and 60 °C. This decrease indicated a significant reduction in yellow color intensity and the emergence of an orange-red color (Ahmad and Zaiki, 2022). In the investigation of cherry quality during drying (Uribe *et al*., 2023), five different techniques were employed, namely freeze-drying (FD), convective drying (CD), vacuum drying, infrared radiation (IRD), and solar drying. Notably, the FD samples exhibited the smallest total color change. Chen *et al*. (2007) found that freeze-dried mangoes had higher lightness, but lower redness and yellowness values compared to mangoes dried using the hot air-drying method.

Regarding intermittent drying, Kowalski *et al*. (2013) observed that carrots subjected to intermittent hot air drying exhibited less color change and minimized beta-carotene decomposition. Similarly, Kowalski and Szadzińska (2014) found that intermittent drying methods, such as heating for 5 minutes followed by a 30-minute heat interruption, reduced the drying time and total color difference ($\Delta E$) in cherries compared to continuous hot air drying, thereby preserving the natural color of the fruit.

In conclusion, the optimization of hot air-drying conditions through intermittent drying proved beneficial in enhancing the quality of dried mangoes. Mangoes subjected to three different intermittent hot air-drying conditions exhibited color characteristics comparable to those of fresh mangoes, superior the continuous hot air-drying samples. Specifically, intermittent drying with a 40-minute heating period followed by a 5-minute interruption resulted in a minimal increase in the overall drying time while minimizing the exposure to heat. The total phenolic content of the intermittently dried samples was found to be similar to that of samples obtained through freeze drying. Furthermore, the vitamin C content and antioxidant activity of the intermittently dried samples were comparable to those of samples obtained through vacuum drying. However, there were no significant differences observed in terms of sample shrinkage and beta-carotene content compared to the continuous hot air-drying method.

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