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Vacuum drying as a natural preservation method of post-harvest lemon might accelerate drying duration and produce the high-quality of dried lemon slices

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Abstract

Lemon (*Citrus limon* B.) is one of the local fruits abundant in Indonesia. The dried lemon fruit was required for storage, extended shelf-life, minimizing decay, and simple distribution. This research applied vacuum drying to lemon slice dehydration in order to achieve quick times and preserve product quality. Vacuum drying with combinations of temperature (40, 50, 60 °C) and vacuum pressure (-38 and -69 cmHg) was applied to drying lemon slices until the final moisture content (9-11% w.b) was reached. The color, hardness value, and vitamin C content were analyzed on dried lemon slices. As a result, 60 °C with -38 cmHg indicates the fastest time to achieve a dry lemon slice and the highest hardness value. The 40 °C with -69 cmHg indicated the best vitamin C content of 76.40 (mg/100 g dw) and color value of L* (64.35 ± 0.57), H (77.0 ± 0.78), a*(6.43 ± 0.55), b*(27.92 ± 1.87), and c* (28.65 ± 1.91). The higher vacuum pressure accelerated the drying time and preserved the quality of the dried lemon slice. The higher temperatures led to the quality deterioration though also accelerate drying time. Experiment with more enhanced vacuum pressure and decreased temperature on lemon drying was required.

Keywords: vacuum drying; lemon fruit; temperature; pressure; vitamin C.

Practical Application: The vacuum drying (40 °C, -38 cmHg) accelerates the dried lemon slice with the best hardness, color, and vitamin C value.

1 Introduction

Lemon (*Citrus limon* B.) is one of the local fruits in Indonesia that has the potential to be developed in economic value with attractive color, nutrition including citric acid, ascorbic acid, and minerals (Lorente et al., 2014; Tolangara et al., 2020). Lemon contains a large amount of ascorbic acid. Men should consume as much as 90 mg per day and 75 mg per day for women. In humans, citrus ascorbic acid provides many health benefits such as prevention of scurvy and cancer, relief of the common cold, stimulation of collagen synthesis, and improvement of the wound healing process (Kabasakalis et al., 2000; Naidu, 2003). Lemons harvested at the optimal ripening stage marked with slightly yellowed skin have the highest content of ascorbic acid or vitamin C, antioxidant activity and physicochemical characteristics (Matteo et al., 2021).

Color is one of the most important quality properties as it is the first quality judgment made by a consumer and it influences consumers' food choices, perceptions, and purchased behavior (Nourian et al., 2003). When citrus fruits are not immediately consumed or processed into food products, their nutritional content and physicochemical characteristics will decrease and lead to spoilage, which can be detrimental to citrus farmers. Therefore, lemons that have been harvested need to be dried to extend shelf life, prevent spoilage or rapid deterioration of nutrients, and directly minimize losses for citrus farmers.

Fruit drying can be carried out by various processes, such as convective drying, vacuum drying, and freeze drying. However, during processing, undesirable changes in the sensory and nutritional properties of the product usually occur. Convective drying is relatively inexpensive and widely used to dehydrate fruits and vegetables. However, long drying times and relatively high air drying temperatures cause product shrinkage and can impair the sensory and nutritional properties of the product (Roratto et al., 2021). Ripe lemons contain 90% moisture content. However, the high moisture content leads to microbial growth, which ultimately shortens the overall shelf life of lemons. Therefore, drying serves as a preservation method by removing the water from the lemons to extend their shelf life (Lee et al., 2015). So far, various drying methods have been used to dry lemon peels and slices, such as closed-type sun drying (Chen et al., 2005); Pulsed vacuum drying (Wang et al., 2018); hot air drying (Torki-Harchegani et al., 2015) and microwave drying (Sadeghi et al., 2013). Ozay-Arancioglu et al. (2022) investigated the impact of different drying methods (vacuum drying, freeze drying, hot air drying, and ultrasound-assisted vacuum drying) on the drying kinetics, color, total bioactive compound, and microstructural properties of pomegranate arils. These drying methods significantly affect all parameters.

Drying methods and the difference in temperature treatment affect the main characteristics of dried foods, including volume

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and shape changes (Panyawong & Devahastin, 2007). Vacuum drying has some operating conditions, including higher drying rate, lower drying temperature, and oxygen-deficient processing. These methods aim to improve the quality and nutritive value of dried products (Arévalo-Pinedo & Murr, 2006). In the working principle of vacuum drying, the pressure in the drying chamber is lower than atmospheric pressure. When the drying mechanism takes place, the water vapor in the material will come out of its environment due to the difference in water vapor pressure, where the water vapor pressure in the material is greater than the water vapor pressure in the environment. If the drying chamber is in a vacuum, it will encourage the evaporation process to take place more easily because there is a decrease in the boiling point of water (Bazyma et al., 2006). This study aims to determine the effect of differences in temperature (40 °C, 50 °C, and 60 °C) and pressure (-68 cmHg and -48 cmHg) on the mass reduction, moisture content, vitamin C content, color differences, and hardness values.

2 Materials and methods

2.1 Tools and materials

The tools used in this research include oven, vacuum drying, penetrometer, color reader, analytical balance, digital scale, slicer, and sample cup. The material used in this research is lemon (*Citrus limon B*).

2.2 Sample preparation

Fresh lemon (cultivated in Malang, Indonesia, cultivar: unknown) were purchased from a local market and stored at 6 °C before the experiment started, the storage time was not more than 12 h until processing. The average amount of lemon in each sample was 100 ± 4 g. The initial moisture content of the sample was determined to be 88.5% on a wet basis according to the oven method, drying at 105 °C for 12 h (Association of Official Analytical Chemists, 1995).

2.3 Drying experiment

Lemon was cut into round-shaped slices and had a 2 ± 0.1 mm thickness before processing. Drying experiments were carried out using vacuum drying with a water jet system. The tube where the material uses a double jacket system with used cooking oil insulator and used automatic temperature regulation system. The vacuum drying chamber was preheated for 2 h before the drying experiments started to obtain a stable drying temperature. Drying experiments were carried out at 40, 50, and 60 °C and vacuum pressure at -68 cmHg and -48 cmHg. The choice of air-drying temperature (40, 50, and 60 °C) was made based on the methods by Garau et al. (2007). Drying was carried out until a moisture content of about 10% was obtained by measuring the mass reduction of the material every 1 h with triplicate.

2.4 Analysis of moisture content, color, hardness value, and vitamin C

The average moisture content of each sample during drying was calculated from the sample weight recorded each hour. The moisture ratio (MR) of the sample was determined by the following equation (Equation 1):

$$MR = \frac{(M - M_e)}{(M_0 - M_e)} \quad (1)$$

where M is the average moisture content of a lemon at any time of the drying process, M_0 and M_e for the initial and equilibrium moisture content, respectively.

The color of fresh and dried lemon slices was determined by using a CR-200 Minolta Colorimeter calibrated with a white standard tile. The results were expressed as Hunter color values of L, a, and b, where L was used to denote lightness, redness, and greenness, and b yellowness and blueness. Hue angle (H^0) is investigated as the most visual color parameter (Zea et al., 2013).

2.5 Hardness value

The testing of hardness value of lemon using a penetrometer according to Teh et al. (2020).

2.6 Vitamin C

Analysis of vitamin C content followed the Medina-Lozano method. Briefly, samples (1.0 g) were ground into a homogenate with 10 mL of 5% oxalic acid, then centrifuged at 2000 g for 5 min at 4 ∘ C. The supernatant (1 mL) was added with the solution of 0.1% methyl viologen (2 mL) and 2 mol/L NaOH (2 mL), shook, and let stand for 2 min. OD value was determined at 600 nm with a UV-Spectrophotometer, and the VC content was calculated based on the standard curve (Medina-Lozano et al., 2021).

2.7 Statistical analysis

All experiments were done in triplicate. Results are expressed as mean values ± standard deviation (Medina-Lozano et al., 2021). All the statistical analysis and data were fitted to models using Minitab 18 software. Furthermore,a key test with $p < 0.05$ revealed a significantly different.

3 Results and discussion

3.1 Drying characteristic

Drying temperature affects physicochemical and structural shape attributes of material (Shishir & Chen, 2017). Figure 1 shows the decreased moisture content rate with drying time for lemon slices at 40 °C, 50 °C, and 60 °C at slices thickness 2 ± 0.1 mm and vacuum pressure at -69 cmHg and -48 cmHg. The drying temperature and vacuum pressure increased with decreasing the drying time. Chen et al. (2022) explored the temperature effect of oven drying on the drying property and quality of Xuan-Mugua fruit; Ataides et al. (2022) dried epicarps of araticum fruits at different temperatures with oven drying; and Silva et al. (2022) dried Brazil nuts with a forced ventilation oven. Their results revealed the higher temperature the quicker the drying time that corresponds to a recent research result. Total drying time from the initial moisture content to the final 9-11% (wet basis) were 16 h, 18 h, 11 h, 13 h, 9 h, and 11 h for samples dried at 40, 50, 60 °C, with -38 cmHg and -69 cmHg,

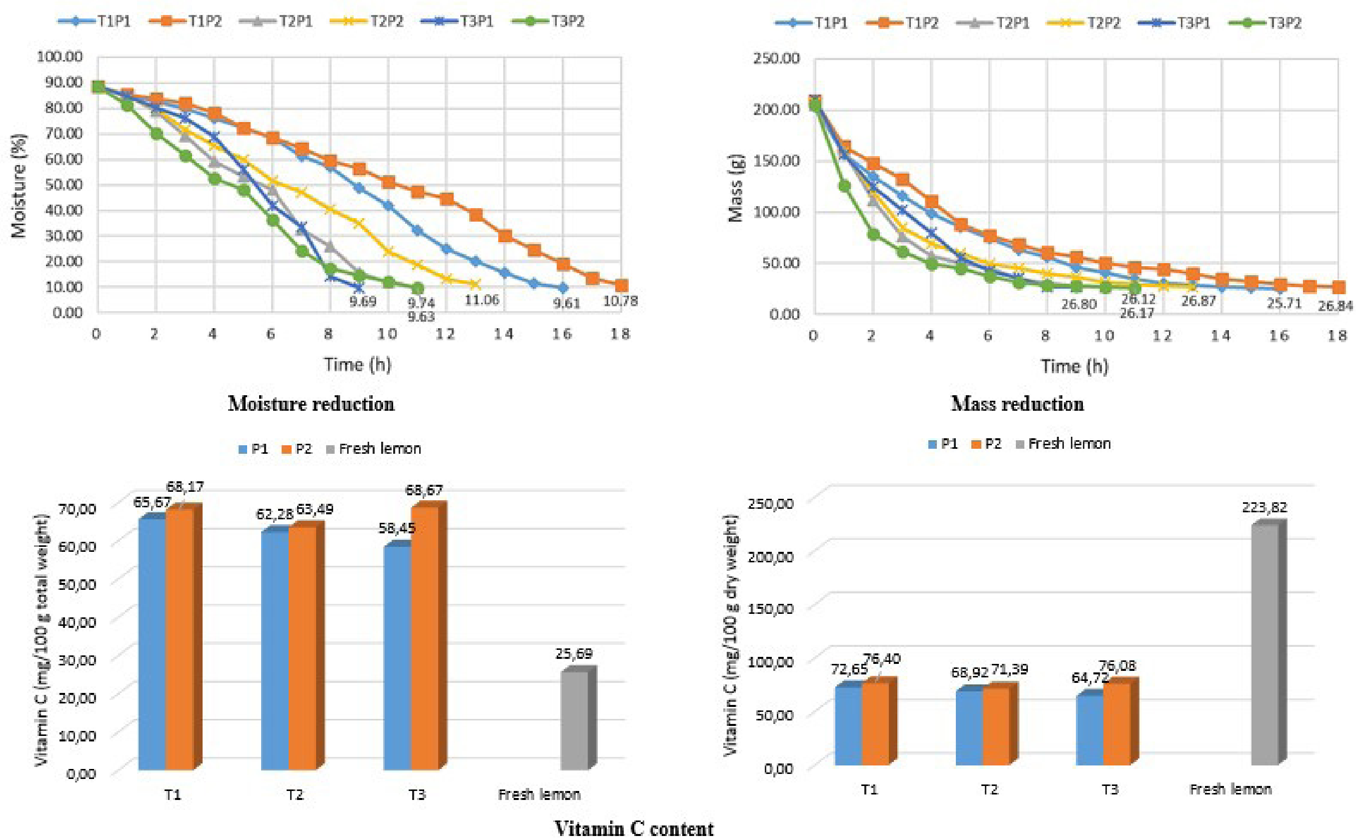

Figure 1. The vacuum drying effect of lemon fruit (*Citrus limon* B.) on their mass and moisture reduction, and vitamin C content (per total weight and dry weight). T1P1 = Temperature 40 °C, Pressure - 38 cmHg; T1P2 = Temperature 40 °C, Pressure - 69 cmHg; T2P1 = Temperature 50 °C, Pressure - 38 cmHg; T2P2 = Temperature 50 °C, Pressure - 69 cmHg; T3P1 = Temperature 60 °C, Pressure - 38 cmHg; T3P2 = Temperature 60 °C, Pressure - 69 cmHg.

respectively. The temperature of 60 °C with vacuum pressure -38 cmHg possesses the fastest drying time (9 h) with the dried lemon slice containing a moisture content of 9.69 ± 0.52% w.b. The temperature 40 °C with vacuum pressure -69 cmHg exhibited the slowest drying time of 10.78% ± 0.69 w.b. Figure 1 indicates a decrease in mass during drying time with the same temperature and pressure treatment. The temperature of 60 °C with vacuum pressure -38 cmHg possesses the fastest drying time (9 h) with the dried lemon slice containing 26.80 g. The temperature of 40 °C with a vacuum pressure of -69 cmHg exhibited the slowest drying time. The higher both temperature and vacuum pressure the faster the drying time to obtain dried lemon slices with final moisture content and mass reduction. During the drying process, increasing the vacuum pressure increases the drying rate. This occurs because as the vacuum pressure increases, there is an accelerated removal of the moisture build-up in the chamber, thereby improving the drying process. This is in accordance with research by Salehi & Kashaninejad (2018). The quality of dried products using vacuum drying is due to the combined effect of the increased pressure gradient between the inner and outer layers of the lemon and the low temperature maintained during the drying process. The vacuum pressure in the drying chamber increases moisture content transfer during the drying process (Xie et al., 2017). In vacuum drying the contact between the product being dried and the oxygen is limited. Due to the reduced pressure, effective drying can be obtained at low temperatures (Nawirska et al., 2009). Recently, much research investigated similar occurrences during drying of lemon slices such as vacuum drying, freeze drying, air drying (Papoutsis et al., 2017), pulsed vacuum drying (Wang et al., 2018), and oven drying (Torki-Harchegani et al., 2016). Torki-Harchegani et al. (2016) stated that the difference in the period of rate moisture content during the whole drying process may be due to the different drying temperatures used.

3.2 Physical properties of dried lemon slices

Color

Color is commonly used to analyze the quality of dried products. During drying, volume of the sample decreases and due to moisture loss, and the surface area also at the same time shrink, which significantly affects the drying process and the product's quality parameters such as rehydration capability and texture (Koua et al., 2019). Color is one of the most important sensory evaluation attributes for dried lemon slices; a yellowish-brown color can severely restrict its acceptability and value. The color parameters L*, a*, b*, ΔE, and H^0 of dried lemon slices under different drying temperatures and vacuum pressure are summarized in Table 1. Hue angle (H^0) is investigated as the most visual color parameter among others (Bai, 2014). Table 1 shows the highest L* and H values at the temperature of 40 °C with vacuum pressure -38 cmHg. Allowable drying time with low temperature could retain color quality degradation in food products (Chua et al., 2000). The best preservation of color values a*, b*, and c* were shown by the temperature of 40 °C with a vacuum pressure of -69 cmHg. It can be seen in Figure 2, that the dried lemon slice color the strongest yellowness, the lowest redness, and the strongest chroma. Low L* values show a dark color and are mainly related to non-enzymatic browning reactions (Pathare et al., 2013).

Hardness value

The texture is a sensory quality attribute that affects the food. Hardness measurements showed three periods in texture development: (1) softening, (2) uniform hardness, and (3) hardening (Martynenko & Janaszek, 2014). The effect of different temperatures and vacuum pressure on the hardness of dried lemon shown in Table 1 indicates that the highest hardness value of lemon dried slice is possessed by temperature 60 °C vacuum pressure -38 cmHg. After this, the second hardest dried slice is achieved at a temperature of 40 °C with vacuum pressure -38 cmHg. similar that the high value of the texture of the dried sample may be related to the high drying time, which consequently leads to higher hardness values (Sabarez et al., 2012). This can be seen in Figure 1 that a temperature of 40 °C vacuum pressure -38 cmHg has a longer drying time, consequently leading to a higher hardness value.

Vitamin C content

The effect of drying temperature and vacuum pressure on the degradation of vitamin C was determined and compared with the fresh samples. The vitamin C content in lemon slices dried at different temperatures and pressure conditions was calculated and summarized in Figure 1. Figure 1 showed the higher temperature, the lower of vitamin C. In contrast, the higher the vacuum pressure the higher the vitamin C content. The temperature 40 °C vacuum pressure -69 cmHg exhibited the highest vitamin C content (76.40 g/100 g dry weight). Drying lemon slices at a low temperature could preserve a high amount of vitamin C during the drying process and at the optimum vacuum pressure could retain vitamin C (Lee et al., 2021). The results conducted by Pal et al. (2008) support that lower temperature with high vacuum conditions can retain vitamin C content, when the effect of drying temperature conditions on the reservation of vitamin C in green sweet pepper was studied. Severe degradation of vitamin C in 50 °C and 60 °C vacuum oven-dried lemon slices could be due to the composition of thermal and oxidative degradations of vitamin C. The minimum oxidative degradation of vitamin C during the drying process was conducted under high vacuum conditions. Vitamin C can be easily reduced, depending on many parameters such as temperature, light, pH, presence of enzymes, oxygen, and metallic catalyzers (Zempleni et al., 2013).

Figure 1, vitamin C content in mg/100 g total weight calculates that dried lemon slices are higher than fresh lemon. However, they lower in case mg/100 g dry weight. In mg/100 g dry weight, the dried lemon slices of all treatments contained

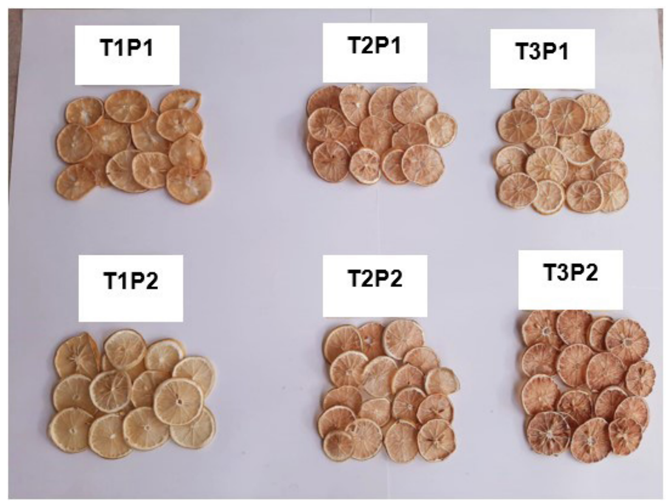

Figure 2. The vacuum drying effect on the color image of dried lemon slice (*Citrus limon* B.). T1P1 = Temperature 40 °C, Pressure - 38 cmHg; T1P2 = Temperature 40 °C, Pressure - 69 cmHg; T2P1 = Temperature 50 °C, Pressure - 38 cmHg; T2P2 = Temperature 50 °C, Pressure - 69 cmHg; T3P1 = Temperature 60 °C, Pressure - 38 cmHg; T3P2 = Temperature 60 °C, Pressure - 69 cmHg.

Table 1. The vacuum drying effect of lemon fruit (*Citrus limon* B.) on their hardness and colour value.

Temperature and Pressure	Hardness (Kgf)	Colour value				
		L	*a*	*b*	*c*	Hue
T1P1	0.23 ± 0.01 bc	62.29 ± 0.12 d	6.80 ± 0.50 ab	29.75 ± 0.45 ab	30.51 ± 0.56 ab	77.1 ± 0.74 ab
T1P2	0.16 ± 0.01 d	64.35 ± 0.57 bc	6.43 ± 0.55 ab	27.92 ± 1.87 ab	28.65 ± 1.91 ab	77.0 ± 0.78 ab
T2P1	0.21 ± 0.01 c	67.12 ± 0.48 a	5.11 ± 1.73 b	24.44 ± 1.86 b	25.00 ± 2.11 b	78.3 ± 3.23 a
T2P2	0.21 ± 0.02 c	65.31 ± 0.75 b	9.52 ± 1.31 a	30.93 ± 1.30 a	32.37 ± 1.62 a	73.0 ± 1.56 b
T3P1	0.28 ± 0.01 a	65.95 ± 0.66 ab	9.06 ± 1.51 a	29.71 ± 2.81 ab	31.07 ± 3.11 ab	73.1 ± 1.32 b
T3P2	0.25 ± 0.01 b	62.84 ± 0.90 cd	9.99 ± 1.64 a	33.40 ± 3.27 a	34.87 ± 3.60 a	73.4 ± 1.07 b
Fresh lemon	0.23 ± 0.01	50.64 ± 0.37	0.82 ± 0.27	16.04 ± 1.02	16.06 ± 1.04	87.1 ± 0.77

T1P1 = Temperature 40 °C, Pressure - 38 cmHg; T1P2 = Temperature 40 °C, Pressure - 69 cmHg; T2P1 = Temperature 50 °C, Pressure - 38 cmHg; T2P2 = Temperature 50 °C, Pressure - 69 cmHg; T3P1 = Temperature 60 °C, Pressure - 38 cmHg; T3P2 = Temperature 60 °C, Pressure - 69 cmHg. The mean is followed by the different letters in each column to indicate a significantly different ($P < 0.05$).

vitamin C lower compared to fresh lemon, their vitamin C content decreasing by approximately 67%. This is in agreement with results reported by Mohammadi et al. (2020), vitamin C content in dried fruits (orange, carrot, and broccoli) decreased by 50-67% toward the content in fresh fruits, which are dependent on dehydration methods. Accordingly, breakage of vitamin C in lemon dehydration with vacuum drying was probably. However, the value of vitamin C for the dried lemon slices in this study was all higher than the USDA-suggested value. USDA recommended that vitamin C content minimum is 59,1 mg/100 g portion of raw orange (United States Department of Agriculture, 2019).

4 Conclusion

With both the higher temperature and vacuum pressure the faster-dried lemon slice was achieved, consequently leading to it being harder. However, the best color parameters (L*, H, a*, b*, c*), and vitamin C content were possessed by a temperature of 40 °C and vacuum pressure of -38 cmHg. The higher temperature could cause color and vitamin C deterioration in dried lemon slices. An experiment with more enhanced vacuum pressure and decreased temperature on lemon drying was required.

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