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Effectiveness of Drying Methods on The Quality and Physicochemical Characteristics of Dried Gac Fruit (*Momordica cochinchinensis* Spreng)

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Abstract

Gac fruit is renowned for its rich content of bioactive compounds, including lycopene, β-carotene, and vitamin E, which provide significant health benefits. However, due to its high moisture content, the fruit is highly perishable and requires proper postharvest handling to extend its shelf life. Drying is one of the most common preservation techniques employed to retain nutritional and functional qualities while reducing water activity. This study aims to evaluate the influence of different drying methods, specifically oven drying, vacuum drying, and sunlight drying. The results indicate that vacuum drying exhibits the highest IC50 inhibition compared to both solar and oven drying methods; however, there is no significant difference in inhibition between the solar and oven drying methods. In lightness (L value), sunlight and vacuum drying result in darker colors than oven drying. Still, there is no significant difference in brightness between sunlight and oven drying. The solar drying method exhibited the highest weight loss at 87.45%. However, there was no significant difference in the drying efficiency between the oven and vacuum oven methods. Microbial contamination under sunlight appears to be higher than in oven and vacuum drying; nonetheless, all methods remain acceptable as they fall below the safe limit. Based on these results, oven drying was selected for Gac fruit drying due to its favorable physicochemical outcomes and the shortest drying time. Additionally, oven drying proved to be the most balanced method, providing good retention of bioactive compounds, effective moisture removal, and acceptable microbial stability. Furthermore, oven drying produced the most visually appealing red hue, likely attributed to enhanced lycopene stability.

Keywords: Oven Drying, Perishable, Preservation Technique, Sun Drying, Vacuum Oven Drying

1. Introduction

Gac fruit (*Momordica cochinchinensis* Spreng.), a tropical species belonging to the Cucurbitaceae family, has long been used as both a food source and a traditional remedy in Thailand and several other Southeast Asian countries (Vuong et al., 2006; Auisakchaiyoung & Rojanakorn, 2015). In recent years, Gac has attracted significant attention from the food and nutraceutical industries due to its exceptional content of bioactive compounds, particularly carotenoids such as lycopene and β-carotene (Vuong et al., 2006). Like ginger, it is high in bioactive compounds (Farisi et al., 2025). These phytochemicals are primarily concentrated in the fruit's deep red arils. They are known for their antioxidant properties, which contribute to reducing oxidative stress and potentially mitigating the risk of chronic diseases (Kubola & Siriamornpun, 2011).

Despite its promising health benefits, the high moisture content of Gac fruit renders it highly perishable, making it susceptible to microbial spoilage and biochemical degradation. This characteristic poses a significant barrier to its commercialization and long-term storage. As a result, drying has emerged as a vital postharvest strategy to reduce moisture content and extend shelf life (Ratti, 2001; Mujumdar, 2007). Various drying techniques—such as sun drying, hot air drying, and freeze-drying—have been investigated for their impact on preserving Gac's nutritional and physicochemical qualities. However, each method

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presents inherent trade-offs between process efficiency, cost, and retention of sensitive bioactives (Doymaz, 2012).

Hot air drying is relatively economical and effective in reducing moisture, but can lead to thermal degradation of heat-sensitive compounds such as lycopene and β-carotene. Conversely, freeze-drying has been shown to better maintain the structural integrity, color, and antioxidant potential of the dried product, albeit at higher operational costs (Ratti, 2001) (Arslan & Özcan, 2010) Additionally, lycopene stability is particularly vulnerable to degradation during drying, affected by factors such as elevated temperature, light exposure, oxygen availability, and prolonged processing time. These factors promote lycopene isomerization and oxidation, which diminishes its nutritional efficacy (Vongsawasdi et al., 2007; Pinthong et al., 2019).

Thus, optimizing the drying process is crucial to preserving the functional attributes of Gac fruit. Careful selection of drying methods that minimize nutrient loss while ensuring food safety and quality can support the development of Gac-based functional food products and improve postharvest value chains. Due to the fruit's short postharvest life and seasonal availability, drying has emerged as a promising preservation technique to extend shelf life and facilitate its use in functional food formulations (Phongpaichit et al., 2020).

Drying methods significantly influence the physical quality and retention of sensitive compounds in fruits. For example, freeze drying better preserves thermolabile nutrients and color pigments than hot air or sun drying (Quach et al., 2015). However, it is cost-intensive and not always feasible for large-scale or low-cost applications. In contrast, hot air drying is more economically viable but can lead to oxidative degradation and color darkening due to high temperatures (Kha et al., 2010). These processing-induced changes may reduce the nutritional and commercial value of the final dried product.

The growing interest in obtaining sufficient levels of natural phytochemicals from plants, especially gac fruits, leads researchers to search for the optimal and efficient drying method to produce a consistent source of plant materials with maximum benefits and desired qualities.

2. Material and Methods

2.1. Plant Materials

The experimental study was conducted from January to July 2023 in Tanjung Morawa, with geographical coordinates of approximately 3.53° North latitude and 98.79° East longitude, with an average elevation of about 25 meters (82 feet) above sea level. North Sumatra, Indonesia, where the average ambient temperature was approximately 30°C and relative humidity ranged between 70% and 80%. Gac fruits (*Momordica cochinchinensis* Spreng.) were harvested using sterilized secateurs. Upon harvesting, the initial temperature of the fruit samples was recorded at 32°C. The fruits were rinsed under running tap water to remove surface contaminants before being transported to the Postharvest Laboratory, Faculty of Agriculture, Muhammadiyah University of North Sumatra (UMSU) for further processing.

The fruits were cut into uniform pieces measuring approximately 1–2 cm in the laboratory. The prepared samples were then divided into four treatment groups corresponding to three different drying methods: oven drying, vacuum oven drying, and sun drying. Each treatment consisted of four replicates, each containing 200 g of sample. The samples were analyzed for physicochemical properties and microbial contamination after the drying treatments.

2.2. Drying Procedures

2.2.1. Oven drying

For oven drying, five replicates of 200 g Gac fruit pieces were spread on aluminum trays (600 mm × 700 mm × 400 mm) to a thickness of 5–7 cm and dried in a Memmert ULM 500 oven (Germany) set to 50°C. The oven operates with horizontal airflow and has a maximum power output of 1250 W at 2450 MHz. The samples were periodically flipped to ensure uniform drying during the drying process. The process continued over three days until the moisture content stabilized at 15–20%, and the samples could be easily crushed manually.

2.2.2. Vacuum oven drying

Vacuum drying was performed similarly using five replicates of 200 g samples, placed on aluminum trays with the same thickness (5–7 cm). Samples were dried in a vacuum oven set at 50°C, using horizontal airflow. The drying duration was five days, and the samples were intermittently turned to ensure consistent drying. The endpoint was reached when a constant weight was achieved at a final moisture content of 15–20%.

2.2.3. Sun Drying

Sun drying was conducted at the Faculty of Agriculture. Five replicates of 200 g of Gac fruit were evenly spread over stainless steel trays lined with brown paper to a 5–7 cm thickness. The samples were exposed to direct sunlight and stirred twice daily. Drying continued for approximately 10 days until a constant moisture level of 15–20% was obtained and the samples became brittle and crushable by hand.

2.3. Determination of Physicochemical Characteristics

2.3.1. IC 50

A total of 2 grams of Gac powder was weighed and dissolved in 100 mL of methanol. The mixture was placed in a sealed container covered with aluminum foil to prevent light exposure and agitated using a mechanical shaker for 2 hours. After shaking, the solution was filtered to obtain a clear extract. The filtrate was re-covered with aluminum foil and allowed to stand overnight at room temperature.

A mixture of DPPH solution and methanol (as a blank) was added to a microplate for the antioxidant activity analysis. The prepared samples were incubated in the dark for 30 minutes. The absorbance of the solution was measured at a wavelength of 370 nm using a UV-Visible spectrophotometer (Sánchez-Rangel, JS, & Ornelas-Paz, JJ, 2020).

2.3.2. Vitamin C Content

Vitamin C concentration was measured using UV-Vis spectrophotometry within the 530–590 nm wavelength range. The absorbance of the reacted sample was recorded and plotted against a standard calibration curve using the linear regression equation Y=ax+bY = ax + bY=ax+b, from which the vitamin C content was calculated by Desai & Desai (2019)

2.3.3. Flavonoid Content

Flavonoid content was determined using quercetin as a standard. Ten grams of Gac powder were extracted in 100 mL of methanol and allowed to stand overnight. The solution was filtered, brought to volume, and incubated for 30 minutes. Absorbance was measured at 370 nm using a UV-Vis spectrophotometer as conducted by Sánchez-Rangel & Ornelas-Paz (2020).

2.3.4. Moisture Loss

Fresh samples were weighed before drying and again after drying in a conventional oven at 60°C until a constant weight was achieved. Moisture loss was calculated to evaluate water reduction.

2.3.5. Color Measurement

Color properties were assessed using a colorimeter, applying the CIE L*a*b* color space system. This method quantifies lightness (L*), red-green value (a*), and yellow-blue value (b*) as perceived by the human visual system.

2.3.6. Total Plate Count (TPC)

The total microbial load was determined using a modified version of the AOAC Official Method 997.02 (2000). A 1-gram portion of the sample was aseptically transferred into a sterile test tube containing 9.0 mL of sterile distilled water to create a stock solution, which was then thoroughly mixed. Serial 10-fold dilutions were prepared up to 10^{-5} for each sample. All dilution tubes were shaken 15 times before plating.

From each dilution, 100 µL was aseptically pipetted and plated in duplicate on appropriately labeled Petri dishes containing solidified growth media. The samples were uniformly spread using a sterile glass spreader, and the plates were incubated at 35 °C. Bacterial colonies were enumerated after 48 hours of incubation, whereas fungal colonies were assessed after 96 hours. Results were expressed as colony-forming units (CFU) per gram and calculated from plates showing colony counts between 30 and 300. Plates exhibiting excessive colony growth were recorded as “too numerous to count” (TNTC).

2.4. Research Flow chart

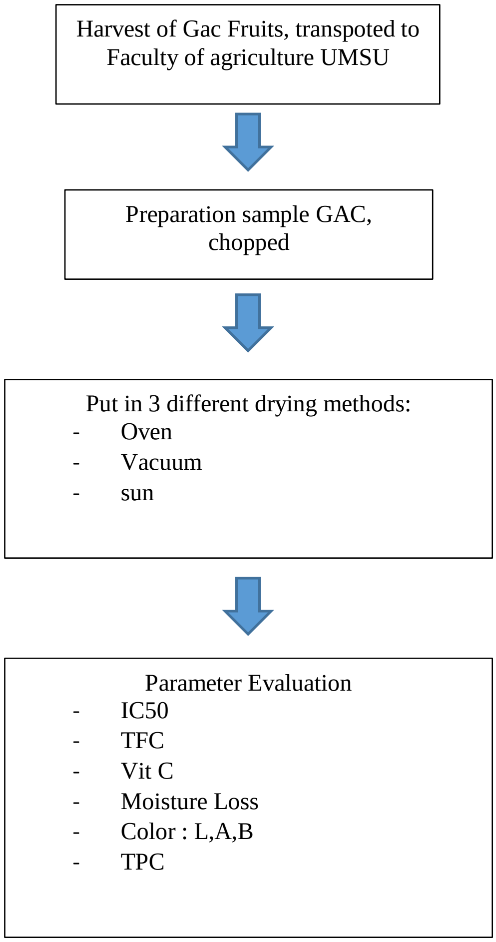

Figure 1. Research flow diagram

2.5. Data Analysis

The experimental design followed a Completely Randomized Design (CRD) with a one-factor layout consisting of three drying treatments (oven, vacuum oven, and sun drying) and five replications per treatment. The data were analyzed using analysis of variance (ANOVA) under the General Linear Model (PROC GLM). Significant differences among means were evaluated using Duncan’s Multiple Range Test (DMRT) at a 5% significance level. All statistical analyses were performed using the Statistical Analysis System SAS software, version 9.4.

3. Results and Discussion

The results of the research and statistical tests indicated that vacuum drying exhibited the highest IC_{50} inhibition value compared to sun drying and oven drying methods. However, there was no statistically significant difference between the sun and oven drying treatments, as shown in Table 1. Interestingly, the vitamin C content was highest in samples subjected to sun drying, although no significant differences were observed between the oven and vacuum drying methods. These findings align with Garau et al. (2007), who reported that prolonged drying durations and lower drying temperatures reduce antioxidant activity, a trend that corresponds with the present study.

The variation in IC$_{50}$ inhibition may be attributed to the differential accumulation and formation of phytochemical compounds that exhibit diverse antioxidant properties. These compounds may exert synergistic or antagonistic interactions with each other or with other extract constituents. Ultimately affecting the overall antioxidant capacity (Zielinski & Kozlowska, 2000).

Table 1. Mean Effect of drying methods on IC 50, Vitamin C, and Flavonoid content in Gac fruit

Drying Methods	IC50 mg/l	Vitamin C mg/l	Flavonoid Content mg/l
Sun	34.205 ± 1.48 b	308.40 ± 2.02 a	237,933 ± 1.12 a
Oven	47.48 ± 0.55 b	290,708 ± 1.52 b	230.223 ± 2.02 a
Vacuum	65,016 ± 0.52 a	292,962 ± 1.48 b	212,377 ± 0.39 b

Notes: For each factor, means within a column followed by the same letter are not significantly different by DMRT at $P \leq 0.05$

Flavonoids are well-recognized as potent plant-derived antioxidants (Matahari et al., 2011). The total flavonoid content (TFC) was higher in samples treated with sun and oven drying methods than in those treated with vacuum drying. However, no significant difference was found between sun and oven drying (Table 1). (Youssef & Mokhtar, 2014) Similarly, results were observed in Portulaca oleracea leaves dried in an oven at 50 °C, where total phenolic content (TPC) and TFC were highest. This may be due to the rapid moisture removal and inactivation of oxidative enzymes during oven drying, which facilitates better retention of phytochemicals (Ji et al., 2012).

Furthermore, drying stabilizes plant materials and helps preserve and enhance their antioxidant properties and bioactive compound content (Dorta et al., 2012). In this study, the antioxidant potential of Gac fruit may also be linked to its essential oils, saponins, and polyphenolic flavonoids, which are known to contribute significantly to oxidative stress reduction. These findings underscore the importance of selecting appropriate drying methods to maximize the retention of functional compounds in plant-based food products.

Color is a crucial quality attribute in dried fruit products, significantly influencing consumer perception and acceptability. The color parameters measured in this study included L* (lightness), a* (red-green coordinate), and b* (yellow-blue coordinate). According to the results (Table 2), Gac fruits dried under vacuum and sun drying conditions exhibited lower L* values, indicating a darker appearance than samples dried using the conventional oven method. However, no significant difference in lightness was observed between vacuum and sun drying methods. This may be attributed to the prolonged drying duration and exposure to ambient oxygen in both treatments, which can promote non-enzymatic browning and pigment degradation (Chen & Mujumdar, 2020).

In terms of a* values, which reflect redness, oven-dried samples exhibited deeper red hues than those dried under vacuum or sunlight. The darker red coloration could be associated with a more stable lycopene retention under controlled thermal conditions. However, Sun-dried samples appeared pinker, possibly due to pigment degradation from prolonged exposure to sunlight and oxygen. For b* values (yellow-blue), no significant differences were detected among the three drying methods, suggesting comparable stability in yellow pigments, such as β-carotene, across treatments.

These findings are consistent with observations by Di Cesare et al. (2023), who reported that oven-dried basil leaves maintained color characteristics closer to their fresh counterparts than those dried under ambient air. On the other hand, Othman and Sopian (2021) argued that solar drying is the only method capable of preserving the natural color of certain botanical products. However, Arslan and Özcan (2020) found that rosemary leaves subjected to oven drying appeared darker than those sun-dried, likely due to thermal degradation of heat-sensitive compounds, including proteins and carbohydrates, under high temperatures.

The results of this study emphasize the importance of selecting appropriate drying methods to preserve the color quality and visual appeal of Gac fruit. Color changes during drying are mainly attributed to the degradation of natural pigments such as lycopene and β-carotene. Lycopene, in particular, is highly susceptible to oxidative degradation and isomerization under heat and light exposure (Pinthong et al., 2019). Therefore, balancing drying efficiency with minimal pigment loss remains challenging in Gac fruit processing.

Garau et al. (2007) noted that prolonged drying time at low temperatures can reduce antioxidant activity, aligning with the present study's findings. This reduction may result from the breakdown or transformation of phytochemicals such as flavonoids and phenolics. Zielinski and Kozlowska (2000) suggested that these variations might stem from forming different phytochemical compounds, which could either enhance or antagonize antioxidant activity through synergistic interactions.

Flavonoids, known for their antioxidant properties, are commonly found in plant materials (Matahari et al., 2011). In this study, sun-drying and oven drying resulted in higher flavonoid content than vacuum drying, although the differences between sun and oven drying were not statistically significant. Youssef and Mokhtar (2014) observed similar results with Portulaca oleracea leaves dried at 50°C, attributing the higher flavonoid retention to rapid moisture removal and the inactivation of oxidative enzymes, which prevent phytochemical degradation (Ji et al., 2012).

Dorta et al. (2012) further emphasized that drying stabilizes plant materials and enhances their bioactive compound retention and antioxidant capacity, thus improving the functional properties of the final dried product.

Table 2. Mean Effect of drying methods on IC 50, Vitamin C, and Flavonoid content in Gac fruit

Drying Methods	**Color**		
	L	**a**	**b**
Sun	20.92 ± 0.56 a	-8.76 ± 0.51 b	8.99 ± 0.38 a
Oven	20.76 ± 0.55 b	-8.56 ± 0.33 a	9.04 ± 0.56 a
Vacuum	20.90 ± 0.52 a	-8.67 ± 0.34 ab	9 ± 0.56 a

Notes: For each factor, means within a column followed by the same letter are not significantly different by DMRT at P ≤ 0.0

Significant differences in moisture loss were observed among the three drying methods applied to Gac fruit (Figure 2). The sun-dried samples retained the highest moisture content, with values 6.74% higher than those subjected to oven drying and 5.4% higher than those dried using vacuum drying. This outcome suggests that sun drying, although cost-effective and environmentally friendly, may be less efficient in removing moisture than controlled thermal techniques such as oven or vacuum drying.

The higher residual moisture content in sun-dried samples can be attributed to several factors, including fluctuating ambient temperatures, lower and inconsistent drying rates, exposure to environmental humidity, and limited airflow during the drying process. These limitations often result in incomplete dehydration, particularly in fruits with dense or waxy tissues like Gac (Ratti, 2001; Doymaz, 2012).

In contrast, oven and vacuum drying facilitate more uniform and controlled heat transfer, enabling effective moisture evaporation and better reduction of water activity. The lower moisture content in these treatments contributes to enhanced microbial stability and extended shelf life (Mujumdar, 2007). Vacuum drying, in particular, operates under reduced pressure, allowing moisture to be removed at lower temperatures, thereby minimizing the risk of thermal degradation while maintaining effective water removal (Ahmed et al., 2013).

Moisture content is a critical parameter in dried fruit quality because it influences microbial stability and shelf life, the final product’s texture, rehydration ability, and overall acceptability (Chakraborty et al., 2011). High residual moisture, as observed in sun-dried samples, may promote microbial growth, enzymatic activity, and degradation of sensitive bioactive compounds such as vitamin C and lycopene during storage (Garau et al., 2007).

Previous studies support these findings. For example, Arslan and Özcan (2010) noted that oven-dried fruits generally exhibited lower moisture levels than those dried under ambient conditions. Similarly, Erbay and Icier (2010) emphasized that drying methods and conditions directly impact dehydration efficiency and the preservation of quality attributes.

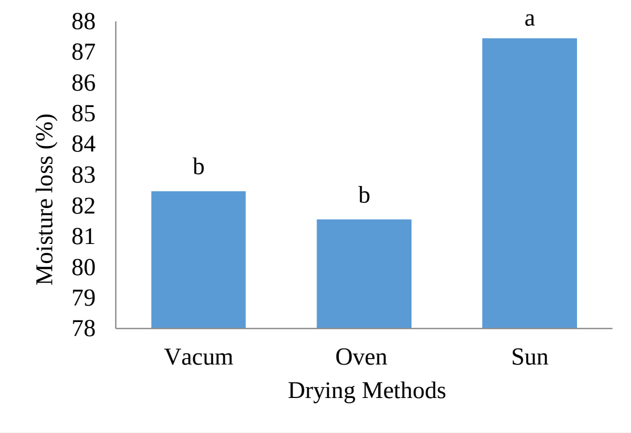

Figure 2. Mean Effect of drying methods on Moisture Loss, Vitamin C and Flavonoid content in Gac fruit, For each factor, means within a column followed by the same letter are not significantly different by DMRT at P ≤ 0.0

Figure 3 showed that microbial contamination was higher in Gac fruit subjected to sun drying than in those dried using vacuum and conventional oven. Although all values remain below the safety threshold and are still considered acceptable for consumption, this finding highlights the critical role of drying methods in microbial control during postharvest processing.

Higher microbial load in sun-dried samples may be attributed to the prolonged exposure to ambient conditions, where fluctuations in temperature and humidity can provide a conducive environment for microbial growth (Arslan & Özcan, 2010). Moreover, incomplete moisture removal during sun drying often results in higher water activity, which supports the survival and proliferation of microorganisms such as molds, yeasts, and bacteria (Müller & Heindl, 2016).

Moisture reduction is pivotal in extending shelf life and maintaining the safety of dried plant materials. The World Health Organization recommends that medicinal and herbal products be dried to a 7–10% moisture content to ensure microbial stability and preserve chemical markers important for therapeutic efficacy (WHO, 2007). Drying methods that allow precise temperature control, such as vacuum or hot-air oven drying, are more effective in reaching and maintaining this critical humidity threshold.

Additionally, microorganisms tend to thrive at relative humidity (RH) levels exceeding 70%, which correlates with increased water activity (aw). Since enzymatic and microbial activities are significantly elevated at higher aw, it is recommended that RH levels be kept below 60% during storage to minimize degradation of bioactive compounds and maintain the microbiological quality of herbal products (Müller & Heindl, 2016; Ratti, 2001).

Vacuum drying, in particular, promotes moisture removal at lower temperatures and reduces oxygen availability, thus limiting the growth of aerobic microorganisms (Ahmed et al., 2013). These advantages suggest that controlled drying technologies are preferable for preserving Gac fruit's microbial and biochemical integrity during postharvest processing.

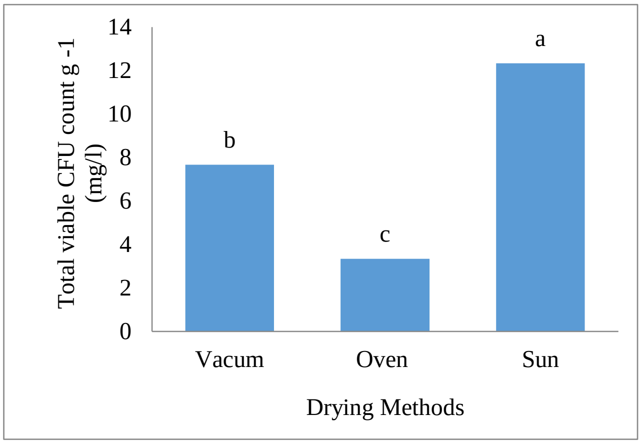

Figure 2. Mean Effect of drying methods on Microbial Contamination, Vitamin C and Flavonoid content in Gac fruit, For each factor, means within a column followed by the same letter are not significantly different by DMRT at P ≤ 0.0.

4. Conclusion

The study deduces the following conclusion:

1. The optimal approach for preserving Gac fruit is oven drying, as it effectively maintains a desirable equilibrium between the retention of bioactive compounds, color consistency, and microbial safety.
2. The process of sun drying is known to retain the highest levels of vitamin C. Still, it also leads to increased moisture and microbial presence, rendering it less suitable for prolonged preservation.
3. The process of vacuum drying efficiently reduces moisture, but it also results in a decline in antioxidant activity and the degradation of phytochemicals.
4. It is suggested that controlled drying techniques, such as oven or vacuum drying, be used instead of sun drying to achieve the best possible preservation of Gac fruit's nutritional, visual, and microbial properties.

Hence, it is suggested that controlled drying techniques, such as oven or vacuum drying, be employed to achieve the most effective retention of antioxidant properties, visual quality, and microbiological safety in Gac fruit.

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