Pertanika J. Sci. & Technol. 33 (S5): 19 - 42 (2025)

PERTANIKA JOURNALS

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Effect of Different Pre-treatments on Vacuum Oven Drying of Pegaga (*Centella Asiatica* L.) Leaves: Drying Kinetics, Nutritional Qualities, and Antioxidant Capacity

Nazurah Mohd Yunos[1], Siti Hajar Ariffin[1,2]*, Yus Aniza Yusof[1,2], Faiqa Shazeaa Mohd Salleh[1] and Rabitah Zakaria[1]

[1]Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[2]Laboratory of Halal Services, Halal Products Research Institute, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

ABSTRACT

Recent reports have indicated that a broad variety of phytochemicals, particularly those with antioxidant activity, can be found in fruits and vegetables, which has drawn considerable interest. However, due to its delicate texture and high water content, it is prone to damage and has a short shelf life. Drying is the most frequent practice for minimizing moisture content and, consequently, water activity to a safe level that extends longevity. The current commercial potential of pegaga, particularly in dried form, has not been adequately investigated. The effect of various pre-treatments (water blanching, steam blanching, vacuum blanching, and microwave blanching) on the vacuum oven drying of pegaga leaves was examined in this study. These pre-treatments were selected because they offer distinct advantages that can enhance the drying process and preserve the nutritional quality of the leaves. Pegaga leaves were vacuum oven-dried for 90 minutes at 60 °C at 0.01 MPa. The total phenolic content (TPC), total flavonoid content (TFC), and antioxidant activity of pegaga leaves were determined before pre-treatment, after pre-treatment, or before drying and after the drying process. Using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) test, the antioxidant activities of the methanolic extract solution were assessed. The Midilli Kucuk model was selected and fitted with the drying data to understand the drying kinetics of pegaga leaves. The results showed that vacuum blanching increased the TPC and TFC of pegaga leaves. The highest DPPH inhibition value was observed in control pegaga leaves after vacuum oven drying. Therefore, the combination of pre-treatments and

ARTICLE INFO

Article history:
Received: 13 February 2025
Accepted: 28 May 2025
Published: 10 July 2025

DOI: https://doi.org/10.47836/pjst.33.S5.02

E-mail addresses:
nazurahyunos@gmail.com (Nazurah Mohd Yunos)
hajarariffin@upm.edu.my (Siti Hajar Ariffin)
yus.aniza@upm.edu.my (Yus Aniza Yusof)
faiqazea@upm.edu.my (Faiqa Shazeaa Mohd Salleh)
rabitah@upm.edu.my (Rabitah Zakaria)
* Corresponding author

e-ISSN: 2231-8526

vacuum oven-dried pegaga leaves may retain their antioxidant and phenolic component content, which would be beneficial to local farmers and fresh produce industries by helping to minimize the loss of quality in dried pegaga leaf manufacturing.

Keywords: Antioxidant capacity, blanching pre-treatment, drying kinetics, nutritional properties, pegaga leaves, vacuum oven drying

INTRODUCTION

Pegaga (*Centella Asiatica* L.) leaves are a perennial herb belonging to the Apiaceae family (Idris et al., 2020). The plant has been widely recognized for its medicinal properties and is traditionally used in various culinary and therapeutic applications due to its antioxidant and pharmacological properties (Fadzil et al., 2020). Among its parts, the leaves of pegaga are particularly valued for their potential nutritional benefits (Rahim et al., 2021). They are high in bioactive substances, such as phenolic compounds and flavonoids, which contribute to their antioxidant behavior (Idris & Nadzir, 2021). However, keeping the nutritional value and antioxidant capacity of pegaga leaves throughout processing is quite difficult, especially during the drying phase, which is essential for increasing shelf life and retaining the medicinal properties of pegaga leaves.

In recent years, several pre-treatments have been explored to optimize the retention of bioactive compounds in various plant materials. Blanching is a common pre-treatment procedure that includes providing plant material with a short heat treatment to destroy the presence of enzymes, decrease the microbial load, and improve product stability (Tomar & Gururani, 2019). Pre-treatments, including steam, water, vacuum, and microwave blanching, are frequently used before drying to get around these restrictions. By lowering the starting moisture content and altering the tissue structure, these pre-treatments can improve drying efficiency and result in more consistent moisture removal. Additionally, they are essential for maintaining the physicochemical characteristics of dried products, such as their color, texture, and nutritional value (Deng et al., 2019). In contrast, microwave blanching can speed up the drying process by preheating the leaves, enhancing the overall quality of the dried product (Babu et al., 2018). For example, it has been discovered that steam blanching inactivates the enzymes that lead to browning (Xiao et al., 2017). The combination of these pre-treatments and vacuum oven drying can, therefore, greatly improve the efficacy and efficiency of the drying process while guaranteeing that the dried leaves maintain the appropriate quality characteristics.

Drying pegaga leaves is a widespread technique in certain cultures for traditional medicinal and culinary purposes. The benefit of drying pegaga leaves is that they preserve their beneficial characteristics for subsequent use. Drying pegaga leaves reduces the amount of moisture, which helps prevent microbial growth, mold, and other microorganisms that can cause deterioration. Because of the prolonged shelf life, the leaves may be preserved and

utilized for a longer period (Rahim et al., 2021). Pegaga leaves have a high concentration of active substances such as triterpenoids, flavonoids, and other phytochemicals (Zainol et al., 2009). The chemicals are concentrated when the leaves are dried, making them more effective. This is significant for their traditional medical use since the concentrated chemicals are thought to provide a variety of health advantages. While drying pegaga leaves can provide these benefits, the exact techniques and conditions of drying may influence the quality of the end products. To ensure that the leaves maintain as much of their color, taste, fragrance, and beneficial ingredients as possible, proper drying processes should be used (Babu et al., 2018). The preservation of these valuable compounds during pre-treatment and drying methods is crucial to retain the nutritional quality of pegaga leaves (Mohapatra et al., 2022).

The choice of drying method is equally important, as it directly influences the preservation of bioactive compounds in pegaga leaves (Márquez-Cardozo et al., 2021). Some researchers have performed drying of pegaga leaves using a tray and heat pump-assisted dehumidified drying (Trirattanapikul & Phoungchandang, 2014), hot air drying (Hiranvarachat et al., 2015; Zainol et al., 2009; Ng et al., 2020), freeze-drying (Rahim et al., 2021; Zainol et al., 2009), oven drying (Rahim et al., 2021; Zainol et al., 2009), dehydration drying (Rahim et al., 2021), vacuum oven (Tripathy & Srivastav, 2023) and microwave drying (Ng et al., 2020). However, there is limited research on the drying of pegaga leaves using a vacuum oven in terms of their nutritional content.

Vacuum oven drying, a low-temperature drying technique, has gained popularity due to its ability to maintain the nutritional content of heat-sensitive compounds compared to conventional drying methods (Hasan et al., 2019). Some types of green leaves have been dried in a vacuum oven. Dried products include collard leaves (Alibas, 2009), stevia leaves (Lemus-Mondaca et al., 2018), olive leaves (Şahin et al., 2018), lemon myrtle dried leaves (Saifullah et al., 2019), basil leaves (Telfser & Galindo, 2019), and Amaranthus leaves (Nighitha & Mathew, 2019). Vacuum oven drying has benefits, but it also has limitations. These include the need for longer drying periods and the possibility of uneven drying since moisture is removed more slowly at lower temperatures. This may lead to a final product that is not as good as it could be, especially in terms of color, texture, and ability to rehydrate (Zielinska et al., 2020).

Mathematical modeling is a useful technique for drying process simulation and gives optimal operating conditions for the equipment design of drying goods with higher rehydration qualities (Bishnoi et al., 2020). These fundamental models, also known as thin-layer models, are used to explore drying kinetics and predict mass transfer during drying (Lemus-Mondaca et al., 2021). Thus, the purpose of this study was to investigate the effect of vacuum oven drying pegaga leaves by modeling drying kinetics and assessing the effect of each pre-treatment.

The selection of a pre-treatment before drying can have a substantial impact on the drying kinetics as well as the antioxidant and nutritional content preservation. While a variety of drying techniques have been investigated, limited studies have been conducted on how diverse pre-treatments, such as microwave, steam, vacuum, and water blanching, combine with vacuum oven drying. Although the comparative effects of these pre-treatments are still unknown, they may change the microstructure of the leaves, improve drying efficiency, and retain nutritional characteristics.

This work aims to examine the effects of several pre-treatments on the vacuum oven drying process of pegaga leaves, emphasizing the drying kinetics, nutritional value, and antioxidant capacity. This study compares the water blanching, steam blanching, vacuum blanching, and microwave blanching methods systematically to determine which pre-treatment technique maximally preserves bioactive compounds during the drying process. Comprehending these impacts will yield significant knowledge for refining food and pharmaceutical industry processing methods, increasing the use of pegaga leaves as a functional component in a range of applications. Using common assays, the antioxidant activity in this study, as well as the drying behavior of pegaga leaves after each pre-treatment, and the retention of important nutritional elements, will be examined. As well as adding to our understanding of pegaga leaves, the results of this study will provide useful advice for producing high-quality dried goods that retain their beneficial qualities.

MATERIALS AND METHODS

Plant Material and Preparation

Fresh pegaga leaves were obtained from Laman Sayur, Malaysia Agro Exposition Park Serdang (MAEPS), Selangor, Malaysia. The leaves were carefully selected, free from any visual defects or damage. They were then washed thoroughly with tap water to remove any dirt or impurities. The leaves were air-dried after rinsing to eliminate extra moisture. Figure 1 shows the flow chart of drying pegaga leaves with different pre-treatments.

Pre-treatments

The pre-treatments applied to the pegaga leaves included water blanching, steam blanching, vacuum blanching, and microwave blanching. The blanching parameters were fixed for all blanching techniques with minor modifications, as it obtained a green chlorophyll color and minimized the loss of soluble components (Minh, 2014). The following pre-treatments, which were altered from earlier research, were used to blanch around 10 g of pegaga leaves. The blanching process is conducted in a closed system. The following procedures were followed for each pre-treatment:

(i) Control leaves (CL): Leaves were washed and drained.

(ii) Water-blanched leaves (WB): Pegaga leaves were immersed in a 1 L beaker at

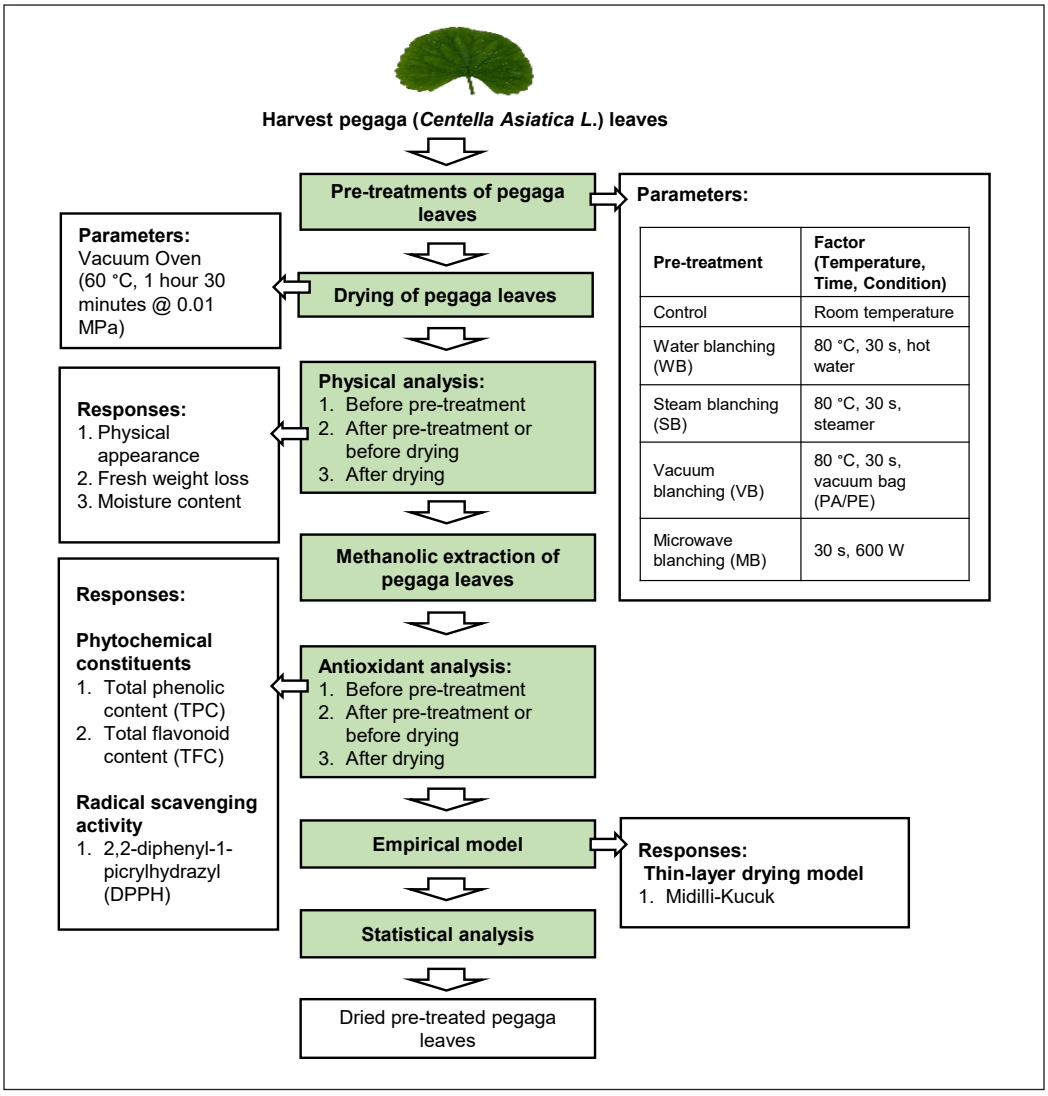

Figure 1. Flow chart of drying pegaga leaves with different pre-treatment

80 °C for 30 seconds on a hot plate. The blanched leaves were then drained and air-dried.

(iii) Steam-blanched leaves (SB): Pegaga leaves were placed in the steamer and steamed at 80 °C for 30 seconds by spreading a single layer of leaves in a steamer. The blanched leaves were then drained and air-dried.

(iv) Vacuum-blanched leaves (VB): Pegaga leaves were placed in a vacuum bag (polyamide/polyethylene). The bag was sealed, and vacuum pressure was applied. The bag with the leaves was then immersed at 80 °C for 30 seconds. The blanched leaves were removed from the bag, drained, and air-dried.

(v) Microwave-blanched leaves (MB): Pegaga leaves were microwaved at 600 W for 30 seconds. The microwaved leaves were drained and air-dried.

Drying Method

Vacuum oven drying (OV-12, Medline Scientific™ Jeio Tech, Malaysia) was employed to dry the pre-treated pegaga leaves. The pre-treated leaves were evenly spread on trays suitable for vacuum oven drying. The trays were then placed in a vacuum oven. The drying process was conducted at a temperature of 60 °C for 1 hour and 30 minutes under a vacuum pressure of 0.01 MPa. The drying parameters were used according to the method described by Şahin et al. (2018), Saifullah et al. (2019), and Nighitha and Mathew (2019) with slight modifications as it gives better preservation, reduced drying time at high temperature, retained higher phytochemical levels and antioxidant properties including ideal moisture content. The dried leaves were taken out of the oven and set aside to cool down at ambient temperature. The dried leaves were stored in airtight containers until further analysis.

Image Acquisition

An image of the samples was taken inside a black box (Figure 2). An LED ring light was placed on top of the box with the following settings: light, power 7-14W, and white color. Images were taken by using a digital camera with a fixed setting (Table 1). The images were taken before pre-treatment, after pre-treatment or before drying and after drying of Pegaga leaves. The physical appearance of the samples was observed.

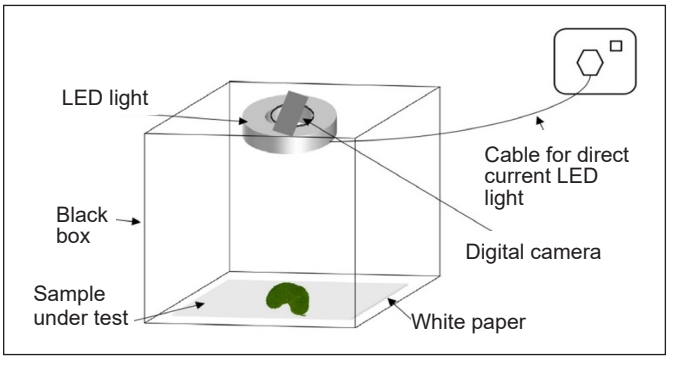

Figure 2. Conceptual design of the black box

Table 1
Digital camera setting for a physical image of pegaga leaves

Options	Settings
Megapixels	12 MP
Aperture size	F2.2
Focal length	29 m
Shutter speed	½ s
Flash	Off
Focus pixel	Autofocus

Moisture Content

The moisture content of pegaga leaves before pre-treatment, after pre-treatment or before drying and after vacuum oven drying was measured using a moisture analyzer (105 °C) (MX-50, AnD, Malaysia). The samples were placed on a small aluminum tray for testing. The time required for each sample to dry completely ranged from 4 to 20 minutes.

Fresh Weight Loss

After vacuum oven drying, pegaga leaves were weighed using an electronic weighing scale (SB12001, Mettler Toledo, Malaysia). Seven replications for each pegaga leaf used in this study were prepared. The percentage of fresh weight loss was calculated based on the initial weight of the pegaga leaves before drying and after pre-treatment (g) and the weight of the pegaga leaves after drying (g), as shown in Equation 1.

$$W_{loss} = \frac{W_{initial} - W_{final}}{W_{initial}} \times 100 \quad [1]$$

Moisture Ratio

The moisture ratio is calculated based on the moisture content at any random time, the equilibrium moisture content, and the initial moisture content, as shown in Equation 2.

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad [2]$$

Drying Kinetics and Modelling

The weight loss of the sample was recorded for seven intervals. The experiments were stopped when no weight loss was observed after three consecutive weighing. All the experiments were conducted in triplicate. The drying curves were fitted using a thin-layer model. The model is commonly used in most kinds of food and biological components (Zambra et al., 2021), specifically the Midilli Kucuk model. The drying kinetics of pegaga leaves were predicted using this model (Equation 3). The Midilli Kucuk model has been developed to accurately clarify the dehydration characteristics of several crops (Zambra et al., 2021). This model requires the calculation of the dimensionless moisture ratio from Equation 2.

$$Moisture\ Ratio\ (MR) = a\ exp(-kt)^n + bt \quad [3]$$

Where k is the kinetic parameter (min^{-1}); n, a, and b are empirical constants of the mathematical models.

SOLVER was used to do regression studies (MS Excel 2021, MS Office, USA). For the Midilli Kucuk model, the reduced chi-squared (χ^2) (Equation 4), the root mean square error (RMSE) (Equation 5) and the determination coefficient (R^2) were defined. Where N is the number of observations, z is the number of constants for each model, and $MR_{exp,i}$ and $MR_{pre,i}$ are the experimental data. The greatest R^2, lowest chi-square, and lowest RMSE values served as the selection criteria for the best-fit model (Hii & Ogugo, 2014). To obtain precise findings, the experiment was conducted three times.

$$\chi^2 = \left(\frac{\sum_{i=1}^{N} \left(MR_{pre,i} - MR_{exp,i} \right)^2}{N - z} \right) \quad [4]$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} \left(MR_{exp,i} - MR_{pre,i} \right)^2}{N}} \quad [5]$$

Nutritional and Antioxidant Properties

The dried leaves were ground separately into fine powder using a dry grinder. 10 g powder, dry pegaga leaves were immersed in 160 mL of 80% methanol and agitated for 2 hours at 50 °C in a water bath solution (Almey et al., 2010). Whatman No. 1 filter paper was used to filter the extract. The extracts were filled in the bottles and stored at 4 °C until further use.

Total Phenolic Content (TPC)

The TPC was measured using the Folin-Ciocalteu method with minor modifications (Bakar et al., 2022). 3.16 mL distilled water and 0.2 mL Folin-Ciocalteau reagent were dissolved together. Then, 0.6 mL of 20% sodium carbonate (Na_2CO_3) was mixed with 40 µl of pegaga extract. The tubes were incubated at room temperature for 2 hours. Absorbance was measured using a UV-Vis spectrophotometer (GENESYS™ 180 UV-Vis Spectrophotometer, Malaysia) at 765 nm using a mixture of distilled water, Folin-Ciocalteau reagent and sodium carbonate as the blank. The standard curve was constructed using gallic acid as the standard and represented as milligram gallic acid equivalent per gram of extract sample (mg GAE/g extract). All samples and readings have been obtained and evaluated in triplicate. The calibration curve equation was calculated based on the absorbance of light and the concentration of the compound, shown in Equation 6. The determination coefficient was $R^2 = 0.999$. Where Y was the absorbance of light, and X was the concentration of the compound.

$$Y = 0.004X + 0.021 \quad [6]$$

Total Flavonoid Content (TPC)

The TFC of pegaga extract was determined using a previously published technique with slight modifications (Mahirah et al., 2018). 1 mL of pegaga extract was mixed with 4 mL of distilled water. At zero time, 0.3 mL of 5% sodium nitrate ($NaNO_3$) was introduced to the test tubes, followed by 0.3 mL of 10% aluminum chloride ($AlCl_3$) after 5 minutes. After 1 minute, 2 mL of 1M sodium hydroxide (NaOH) was added, followed by 10 mL of distilled water. Absorbance was measured at 510 nm using a UV-Vis spectrophotometer

(GENESYS™ 180 UV-Vis Spectrophotometer, Malaysia). All samples and readings have been obtained and evaluated in triplicate. The standard curve was established using quercetin, and the results were represented as milligrams of quercetin equivalents per gram of extract sample (mg QUE/g extract). The calibration curve equation was calculated based on the absorbance of light and the concentration of the compound, as shown in Equation 7. The determination coefficient was $R^2 = 0.994$. Where Y was the absorbance of light, and X was the concentration of the compound.

$$Y = 0.001X + 0.013 \quad [7]$$

2, 2-diphenyl-1-picrylhydrazyl (DPPH) Assay

Pegaga extract was evaluated using the 2, 2-Diphenyl-1-picrylhydrazyl (DPPH) assay technique with minimal modifications (Almey et al., 2010). 250 µL of pegaga extract was combined with 5 mL of 0.1 mM DPPH solution and incubated in the dark for 30 minutes. The percentage inhibition of DPPH by extracts was calculated by UV-Vis spectrophotometer (GENESYS™ 180 UV-Vis Spectrophotometer, Malaysia), and its absorbance was recorded at 517 nm. All samples and readings have been obtained and evaluated in triplicate to ensure precise, reliable and consistent results. It offers a more comprehensive dataset for evaluating the antioxidant activity of pegaga leaves, which is essential for evaluating their possible uses and health advantages.

Statistical Analysis

Experiment data were analyzed using Microsoft Excel (MS Excel 2021, MS Office, USA) and Minitab version 21 software. Significant differences between samples for moisture content were analyzed using analysis of variance (ANOVA) and Tukey's multiple-range test ($P<0.05$). Data obtained were reported as mean ± standard deviation.

RESULTS AND DISCUSSION

Physical Image

Physical image is an important indicator that can be utilized to make quality inferences, which may subsequently be used to predict decisions (Makhal et al., 2021). In some cases, quality degradation results in a product being rejected, while in others, it decreases customer acceptability (Qin et al., 2014). Makhal et al. (2021) also stated that fresh vegetables are a good example of this because they are either offered loose or in clear packaging, leaving appearance as the primary criterion for determining quality. The physical images of pegaga leaves before pre-treatment, after pre-treatment or before and after drying in a vacuum drying oven are shown in Table 2. Steam blanching was able to retain its shape after drying

in a vacuum oven, whereas control, water blanching, vacuum blanching, and microwave blanching resulted in a smaller shape than the actual leaves. Shrinkage occurs after the leaves have been dried (Velić et al., 2007). Slices of red bell pepper that had been steam-blanching showed the least shrinkage (Jeevitha et al., 2013). The enhanced shrinkage may be attributed to moisture loss during blanching and the release of trapped oxygen in tissues after drying, resulting in cell structure breakdown in porous materials (Jeevitha et al., 2013). Velić et al. (2007) claimed that the blanching caused apples to shrink by about 23%. Microwave blanching caused *Moringa Oleifera* L. leaves to shrink the most (Champaneri et al., 2020). This might be because pre-treatment at a greater temperature raises contractile stress in the cellular structure, causing tissue shrinking (Srimagal et al., 2017). The bitter gourd samples used as controls showed the greatest shrinking (Srimagal et al., 2017).

Table 2
The physical image of pegaga leaves before pre-treatment, after pre-treatment or before drying and after drying in a vacuum drying oven

Drying Temperature	**60 °C**		
Drying Time	**1 hour 30 mins**		
Pre-treatment	**Before Pre-treatment**	**After Pre-treatment / Before Drying**	**After Drying**
Control			
Water Blanching			
Steam Blanching			
Vacuum Blanching			
Microwave Blanching			

Moisture Content

Fresh pegaga leaves had a wet basis moisture content of 84.37±0.01%. Table 3 presents the drying time, drying temperature, and moisture content of pegaga leaf samples vacuum-dried using various pre-treatment techniques. The results showed that pre-treatments have a significant impact on the ultimate moisture content of pegaga leaves after drying. The term "ultimate moisture content" describes the final moisture content of pegaga leaves during the drying process. After the leaves have completely dried, this is the amount of moisture that is still present. The moisture content of water-blanching pegaga leaves causes certain soluble components to leach, but it can also aid in lowering moisture content by weakening cell walls, which can promote faster drying (Sledz et al., 2016). Water-blanched leaves showed a decrease from 85.97±0.39% to 5.38±0.49% and showed a significant ($P<0.05$) decrease, which proved that certain soluble components are leaching from the pegaga leaves. In comparison to water blanching, steam blanching can conserve more nutrients because it causes less direct leaching and may result in a different moisture retention profile. Wickramasinghe et al. (2020) studied that steam blanching can more softly permeate plant tissues than water blanching, resulting in partial loss of moisture and heat-induced alterations. Steam blanching softens and improves the elasticity of plant material, allowing for improved moisture dispersion during drying (Wickramasinghe et al., 2020). Steam-blanched leaves showed a decrease from 85.79±0.01% to 8.86±0.09% and showed a significant difference ($P<0.05$), which proved that there is less direct leaching from the pegaga leaves compared to water blanching. Vacuum blanching can lower the required temperature and perhaps lead to a lower moisture content because of a faster rate of heat penetration and less cell damage (Xiao et al., 2017). Vacuum-blanched leaves showed a decrease from 84.66±0.14% to 9.21±0.24%, which was significant ($P<0.05$), resulting in lower moisture content compared to before drying. Microwave blanching is a highly quick and effective method; however, because of the rapid heating and loss of moisture, it may result in a reduced final moisture content.

Champaneri et al. (2020) claimed that microwave blanching resulted in the lowest moisture content of *Moringa Oleifera* L. leaves (6.78%), a difference from the result shown in Table 3. This may be due to the changes in humidity during drying and pre-treatment. The moisture content of the *Moringa Oleifera* L. leaves dropped as the power level increased, which might be due to moisture evaporation caused by microwave volumetric heating (Champaneri et al., 2020). Heat-induced alterations in plant tissues can occur when microwave or other heat treatments are used prior to drying (Gonzalez & Barrett, 2010). These changes include the enlargement of air spaces inside the tissue, which can aid in the evaporation of moisture during drying. Due to localized heating, microwaves can also cause some water to evaporate inside the tissues, enabling moisture removal during the subsequent drying stage (Ni et al., 1999).

Table 3
Moisture content remained of pegaga leaves before pre-treatment, after pre-treatment or before drying, and after drying in a vacuum drying oven

Drying Temperature	**60 °C**		
Drying Time	**1 hour 30 mins**		
Treatment	**Before Pre-treatment (%)**	**After Pre-treatment / Before Drying (%)**	**After Drying (%)**
Control	84.37±0.01	84.37±0.44	11.74±0.57
Water Blanching		85.97±0.39	5.38±0.49
Steam Blanching		85.79±0.01	8.86±0.09
Vacuum Blanching		84.66±0.14	9.21±0.24
Microwave Blanching		83.71±0.01	8.53±0.09

Pre-treatments can change moisture content scientifically by influencing water movement, diffusion, and evaporation during drying. This pre-treatment may damage cell walls and enhance cell membrane permeability, allowing for quicker water removal during drying (Ando et al., 2016). Except for the control samples, the moisture content of the dried pegaga leaves was less than 10%. 'T Hag et al. (2020) asserted, however, that the microbiological safe moisture level of Native African leafy vegetables (ALVs) was less than 14% on a dry basis. Dried vegetables must contain no more than 8% water (Food Regulations, 1985). Drying reduced the moisture content of *Moringa oleifera* L. leaves from 80% to less than 10%, allowing the leaves to be stored without infection by microbes (Nobosse et al., 2017). Mold should develop quickly when the moisture concentration is greater than 11%, and color loss should occur when the moisture content is less than 4% (Anoraga et al., 2018). From the results obtained, it was verified that drying conditions for pegaga leaves were 60 °C and 1 hour and 30 minutes.

Fresh Weight Loss

Figure 3 shows the percentage of fresh weight loss after drying in a vacuum drying oven for control, water blanching, steam blanching, vacuum blanching, and microwave blanching of pegaga leaves. All the samples were dried until they reached a constant weight, and the drying time for each treatment was recorded. It was noticed that the percentage fresh weight loss of all pre-treated pegaga leaves showed an increasing trend with the increment of drying time. The moisture content of plant leaves can be affected by biological and processing factors (Żbik et al., 2023). Żbik et al. (2023) reported that the weight loss differences between species are caused by differences in the leaf tissue morphology, which is most likely due to structural changes that facilitate water transport in the tissues or differences in epidermal permeability (Żbik et al., 2023). Indeed, various pre-treatment procedures can cause structural changes in pegaga leaves, which can have a major impact on their future drying behavior and final attributes.

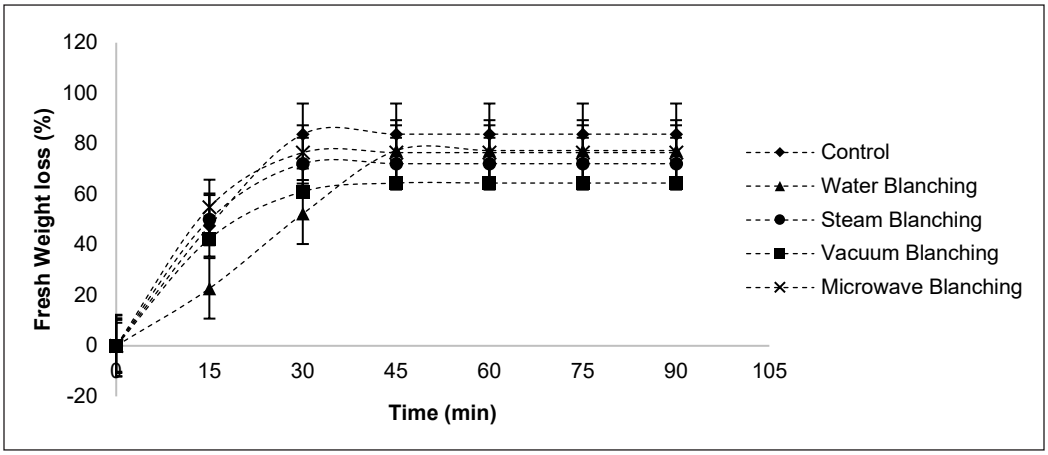

Figure 3. Percentage of fresh weight loss after drying in a vacuum drying oven for control, water blanching, steam blanching, vacuum blanching, and microwave blanching of pegaga leaves

These variations are caused by the unique processes involved in each pre-treatment approach. The maximum weight loss (66.61%) was shown by the pegaga leaves sample treated with no pre-treatments, followed by microwave blanching (62.46%), steam blanching (58.61%), and water blanching (54.87%). Pegaga leaves stay mainly intact when there are no pre-treatments on the leaves. Cell walls, cell membranes, and cellular components are undamaged, and the leaves retain their original qualities (Thamkaew et al., 2021). At the same time, the least weight loss (51.57%) was exhibited by the vacuum-blanched pegaga leaves. Vacuum blanching is the process of applying a vacuum to plant material while it is exposed to steam. Because the decreasing pressure reduces the boiling point of water, moisture evaporates even at lower temperatures. This combination of steam and lowered pressure can result in faster and more regulated cell expansion and moisture removal, resulting in structural changes that are a mix of steam and vacuum effects.

Drying Kinetics and Modelling

The coefficient of determination (R^2) and drying rate (k) values for the models are shown in Table 4. Figure 4 shows the comparison of experimental data and predicted moisture ratio using the Midilli Kucuk Model for pegaga leaves. The greatest R^2, lowest χ^2 and RMSE values for the Midilli Kucuk model varied throughout all trials by vacuum-blanched pegaga leaves. The Midilli Kucuk model, in particular, was found adequate to represent the vacuum-drying behavior of pegaga leaves. Similarly, Bialik et al. (2020) in the article on vacuum-dried kiwi berry, green seaweed (*Ulva spp.*) (Vega-Gálvez et al., 2022) *Stevia rebaudiana* leaves (Hidar et al., 2020), *Kageneckia oblong* leaves (Zambra et al., 2021), and golden berries (Kipçak, 2023), as well as many other researchers, concluded that the Midilli-Kucuk model satisfactorily describes the drying behavior of food products.

Table 4
Kinetics parameters for drying kinetics of pegaga leaves using the Midilli Kucuk model

Pre-treatment	Model Coefficients		Statistical Parameters		
		a	R^2	χ^2	RMSE
Control	a	451.9760	0.9672	4.001×10^{-3}	2.858×10^{-3}
	k	4.0832			
	n	0.1531			
	b	0.0001			
Water Blanching	a	2.1703	0.9504	3.960×10^{-3}	2.829×10^{-3}
	k	0.1724			
	n	0.7473			
	b	0.0006			
Steam Blanching	a	445.3704	0.9630	2.666×10^{-3}	1.904×10^{-3}
	k	4.0560			
	n	0.1621			
	b	0.0001			
Vacuum Blanching	a	438.9299	0.9990	0.0807×10^{-3}	0.0576×10^{-3}
	k	4.0865			
	n	0.1598			
	b	0			
Microwave Blanching	a	2.9134	0.9754	2.066×10^{-3}	1.476×10^{-3}
	k	0.2383			
	n	0.6624			
	b	0.0009			

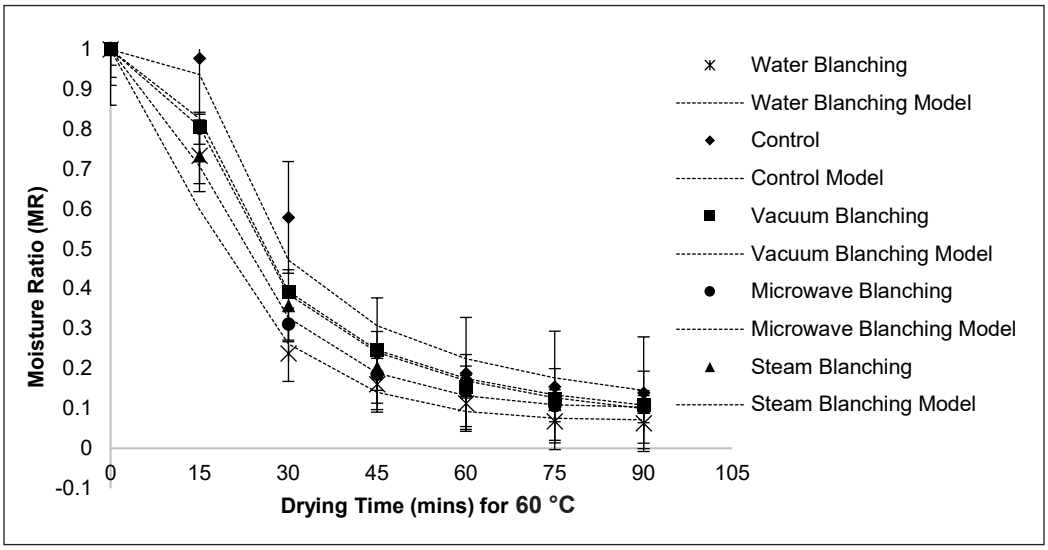

Figure 4. Comparison of experimental data and predicted moisture ratio using the Midilli Kucuk Model for pegaga leaves

Nutritional and Antioxidant Properties

Effect of Different Pre-treatments on Total Phenolic Content (TPC)

The major component of pegaga leaves is phenolic compounds (Bakar et al., 2022). The total phenolic content (TPC) in fresh pegaga was 0.02 mg GAE/g extract (Figure 5), which changed differently with varying pre-treatments. Among the pre-treated dried pegaga leaves, vacuum blanching of dried pegaga leaves had the highest TPC (0.09 mg GAE/g extract), followed by steam blanching (0.08 mg GAE/g extract), water blanching (0.07 mg GAE/g extract), microwave blanching (0.06 mg GAE/g extract) and control leaves (0.05 mg GAE/g extract). The vacuum blanching method prevented direct contact of the pegaga leaves with boiling water, whereas the water blanching, steam blanching, microwave blanching, and control leaf samples were all directly contacted with pre-treatments. However, the change in TPC observed following vacuum blanching and subsequent drying can be due to various metabolic events that occur throughout these procedures. Phenolic compounds are a type of secondary metabolite found in plants that are recognized for their antioxidant and health-promoting qualities (Nurzyńska-Wierdak, 2023). Certain phenolic compounds can degrade at high temperatures, even under low pressure (Minatel et al., 2017). Minatel et al. (2017) reported that some phenolics may undergo chemical modifications that alter their structure and limit their detection during TPC analysis, depending on the temperature and period of vacuum blanching. The concentration of phenolic chemicals in the residual tissue rises when water is removed from the plant material during drying (Chua et al., 2019). While the absolute number of water-soluble chemicals may decrease, phenolic compounds become more

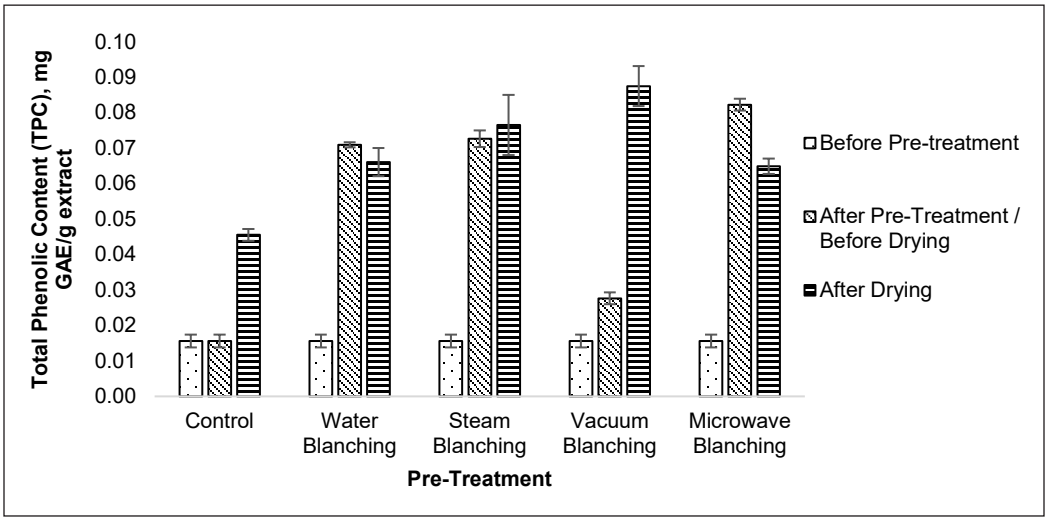

Figure 5. Total phenolic content (TPC) of pegaga leaves before pre-treatment, after pre-treatment or before drying, and after drying in a vacuum drying oven

concentrated in dried material, perhaps contributing to an increase in TPC (Hapsari et al., 2022). The rise in TPC during the pre-treatment process may be attributed to the higher temperature, as boiling water increases the permeability of the cell membrane, allowing bioactive compounds to be released during heat contact (Klungboonkrong et al., 2018). The TPC results of vacuum blanching pre-treated dried pegaga leaves in this investigation were consistent with the findings of Borines et al. (2020), who stated that vacuum-drying onion leaves gave the greatest TPC. Long-term exposure to air and light may accelerate the oxidation of several phenolic compounds, as previously noted in the literature (Klungboonkrong et al., 2018). Longer drying times decreased TPC in olive (*Olea europaea* L.) leaves (Filgueira-Garro et al., 2022).

Effect of Different Pre-treatments on Total Flavonoid Content (TFC)

The effect of pre-treatment and drying processes on the total flavonoid content (TFC) of pegaga leaves is depicted in Figure 6. The vacuum oven drying procedures had nearly the same effect on the TFC as they did on the TPC of the pegaga leaves. The TFC in fresh pegaga was 0.44 mg QUE/g extract, which changed differently with varying pre-treatments. Among the pre-treated dried pegaga leaves, vacuum blanching of dried pegaga leaves had the highest TFC (2.22 mg QUE/g extract), followed by microwave blanching (2.04 mg QUE/g extract), water blanching (1.95 mg QUE/g extract), steam blanching (1.62 mg QE/g extract) and control leaves (1.17 mg QUE/g extract). The observed phenomenon in which the initial Total Flavonoid Content (TFC) of pegaga leaves was low after vacuum blanching but increased significantly after vacuum oven

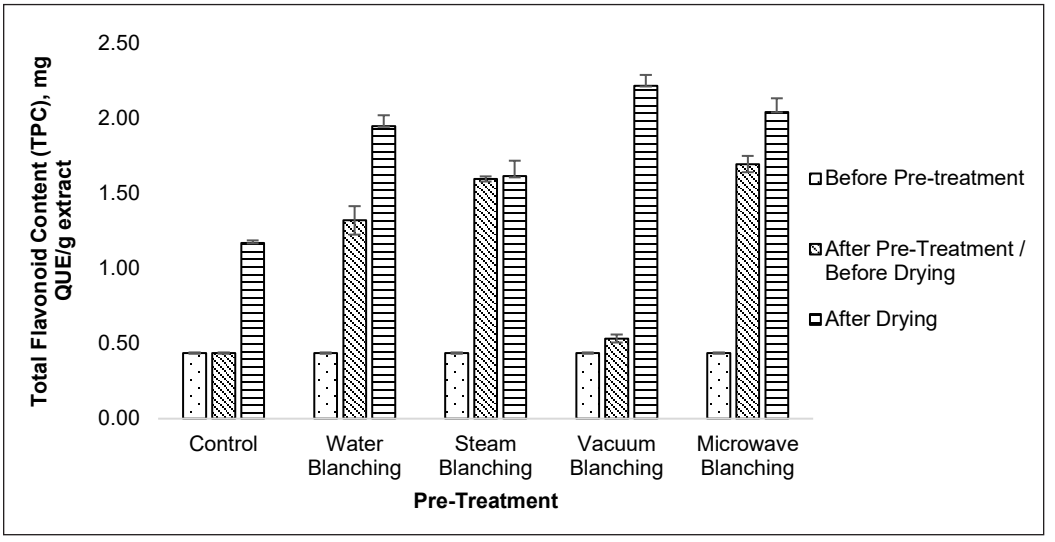

Figure 6. Total flavonoid content (TFC) of pegaga leaves before pre-treatment, after pre-treatment or before drying and after drying in a vacuum drying oven

drying can be explained by several factors related to the effects of vacuum blanching and subsequent vacuum oven drying on the flavonoid content and the chemistry of the plant material. Vacuum blanching can enhance the loss of volatile substances such as flavonoids (Xiao et al., 2017). Flavonoids are a class of bioactive chemicals that are heat, steam, and vacuum-sensitive (Tacer-Caba et al., 2015). Due to the presence of steam and the lower-pressure environment, certain flavonoids with smaller molecular weights or structures that are more prone to vaporization may be lost during vacuum blanching (ElGamal et al., 2023).

At lower temperatures, the vacuum atmosphere allows for the release of volatile chemicals, which can include flavonoids (Żbik et al., 2023). Lower pressure settings may allow for more effective and gentle extraction of flavonoids from plant material during drying (Jha & Sit, 2022). The value of TFC reported for vacuum oven-dried Ocimum basilicum leaves with methanol extract is high (Mahirah et al., 2018) compared to the experiment. According to Mahirah et al. (2018), flavonoids having a benzo-γ-pyrone structure form a significant category of polyphenolic chemicals found in plants. The presence of flavonoids contributes to the high antioxidant activity of green leafy vegetables (Hue et al., 2012). Consumption of flavonols, namely quercetin, found in onions, lowers the risk of diseases (Ribeiro et al., 2023). Total phenolic content (TPC) and TFC assay results followed a similar trend, with the vacuum oven-dried sample for pegaga leaves having the highest TPC and TFC, and the control leaves having the least TPC and TFC. The most frequent kind of plant phenol is flavonoid (Mahirah et al., 2018). Do et al. (2014) reported a significant relationship (0.923) between the polyphenolic contents (TPC and TFC) of the *Limnophila aromatica* plant. The results of this study supported the conclusion that flavonoid is the most common chemical in the phenolic category.

Effect of Different Pre-treatments on 2,2-diphenyl-1-picrylhydrazyl (DPPH) Assay

2,2-diphenyl-1-picrylhydrazyl (DPPH) assay of fresh pegaga leaves is 0.53%, but it decreased after pre-treatment and vacuum-drying of pegaga leaves. These results agree with Filgueira-Garro et al. (2022), where vacuum-drying olive leaves reduced DPPH. This reduction in DPPH might have been produced by polyphenol oxidases (PPO) that were active during vacuum drying. According to Filgueira-Garro et al. (2022), the presence of apparent browning in vacuum-dried olive leaves could mean that PPO activity has reduced the phenolic component and its antioxidant properties. The greatest proportion of DPPH was found in control leaves (0.30%), followed by water blanching (0.05%), vacuum blanching (0.05%), microwave blanching (0.05%), and steam blanching (0.04%) (Figure 7). Antioxidants counteract the damaging effects of free radical damage in our surroundings, where it is commonly found in herbal remedies and traditional treatments. (Bakar et al., 2022).

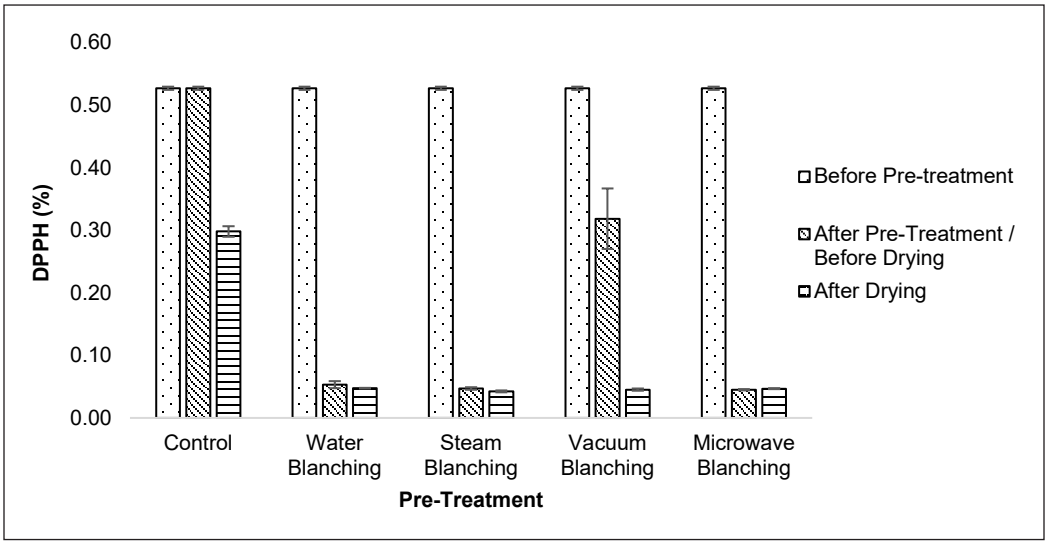

Figure 7. DPPH scavenging activity of pegaga leaves before pre-treatment, after pre-treatment or before drying and after drying in a vacuum drying oven

CONCLUSION

The drying properties of pegaga leaves were tested using a vacuum oven at 60 °C for 1 hour and 30 minutes under 0.01 MPa. During the decrease in rate period, the drying process happened, but not during the steady rate period. R^2, χ^2, and RMSE were used to assess the quality of fit of the experimental data to the thin layer drying model. The Midilli Kucuk model can appropriately represent the thin-layer drying behavior of pegaga leaves, according to the results. The most appropriate pre-treatment for drying pegaga leaves based on the above analysis was found to be vacuum blanching, microwave blanching, steam blanching, control, and water blanching, respectively.

In general, it was found that the pre-treatment before drying pegaga leaves significantly affected the nutritional qualities and antioxidant activities of the pegaga leaves. Vacuum blanching resulted in relatively high TPC (0.09 mg GAE/g extract) and TFC (2.22 mg QUE/g extract) while decreasing the 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay value (0.05%) after vacuum oven drying. Thus, the vacuum blanching and vacuum oven drying method is the best method to preserve or enhance the nutritional content of pegaga leaves based on this study. Improved pre-treatments and drying techniques can lead to more uniform quality in terms of appearance, phytochemicals, and antioxidant properties, which are crucial for marketability, customer acceptability, and applications in functional foods, supplements, and herbal products. Utilizing more of the pegaga leaves efficiently and minimizing waste may be achieved by maximizing the drying process to avoid over- or under-drying. The research might lead to improvements in food processing and

preservation methods by providing fresh perspectives on the efficacy of various drying and pre-treatment methods. However, the specific phenolic compounds or other substances responsible for the antioxidant capabilities of the extracts are yet unclear. Since previous and present research suggests that pegaga leaves offer potential as natural antioxidant sources, additional study is needed to identify and describe antioxidant compounds from extracts that may be contributing to the high antioxidant properties. The findings may serve as a basis for further investigation into formulation strategies, extraction processes, and novel applications related to the processing of pegaga leaves. Thus, this study can enhance the utilization of pre-treated dried pegaga leaves as a valuable natural resource in various applications.

ACKNOWLEDGEMENTS

The authors thank Geran Inisiatif Putra Muda (GP-IPM/2020/9689800) for funding the project and the facilities provided by Universiti Putra Malaysia to conduct research activities.

REFERENCES

Alibas, I. (2009). Microwave, vacuum, and air drying characteristics of collard leaves. *Drying Technology*, *27*(11), 1266–1273. https://doi.org/10.1080/07373930903267773

Ando, Y., Maeda, Y., Mizutani, K., Wakatsuki, N., Hagiwara, S., & Nabetani, H. (2016). Impact of blanching and freeze-thaw pretreatment on drying rate of carrot roots in relation to changes in cell membrane function and cell wall structure. *LWT-Food Science and Technology*, *71*, 40–46. https://doi.org/10.1016/j.lwt.2016.03.019

Anoraga, S. B., Sabarisman, I., & Ainuri, M. (2018). Effect of different pretreatments on dried chilli (*Capsicum annum* L.) quality. *IOP Conference Series: Earth and Environmental Science*, *131*(1), Article 012014. https://doi.org/10.1088/1755-1315/131/1/012014

Almey, A. A. A., Khan, C. A. J., Zahir, I. S., Suleiman, K. M., Aisyah, M. R., & Rahim, K. K. (2010). Total phenolic content and primary antioxidant activity of methanolic and ethanolic extracts of aromatic plants' leaves. *International Food Research Journal*, *17*(4), 1077–1084.

Babu, A. K., Kumaresan, G., Raj, V. A. A., & Velraj, R. (2018). Review of leaf drying: Mechanism and influencing parameters, drying methods, nutrient preservation, and mathematical models. *Renewable and Sustainable Energy Reviews*, *90*, 536–556. https://doi.org/10.1016/j.rser.2018.04.002

Bakar, I. N. A., Ibrahim, M. F., Hakiman, M., Abd-Aziz, S., Prasongsuk, S., Tin, L. C. Y., & Jenol, M. A. (2022). Characterization of asiaticoside concentration, total phenolic compounds, and antioxidant activity of different varieties of *Centella asiatica* (L.) and essential oil extraction using hydro-distillation with enzyme assisted. *Biocatalysis and Agricultural Biotechnology*, *44*, Article 102474. https://doi.org/10.1016/J.BCAB.2022.102474

Bialik, M., Wiktor, A., Witrowa-Rajchert, D., Samborska, K., Gondek, E., & Findura, P. (2020). Osmotic dehydration and freezing as a suitable pretreatment in the process of vacuum drying kiwiberry: Drying

kinetics and microstructural changes. *International Agrophysics*, *34*(2), 265–272. https://doi.org/10.31545/INTAGR/118859

Bishnoi, S., Chhikara, N., Singhania, N., & Ray, A. B. (2020). Effect of cabinet drying on nutritional quality and drying kinetics of fenugreek leaves (*Trigonella foenum-graecum* L.). *Journal of Agriculture and Food Research*, *2*, Article 100072. https://doi.org/10.1016/j.jafr.2020.100072

Borines, M. G., Demafelis, R. B., Capunitan, J. A., Stephanie, L., Dizon, H., Joyce, R., Landoy, B., & Rodriguez, R. C. (2020). Effects of dehydration on the bioactive compounds of waste onion leaves. *Philippine Journal of Crop Science*, *45*(1), 21–33.

Champaneri, D. D., Mayani, J. M., Pancholi, H. N., Patel, J. B., & Bangoria, U. V. (2020). Effect of different blanching methods on physical and colour characteristics of *Moringa Oleifera* L. dry leaf powder. *International Journal of Latest Trends in Engineering and Technology* , *16*(1), 34–37. http://dx.doi.org/10.21172/1.162.03

Chua, L. Y. W., Chua, B. L., Figiel, A., Chong, C. H., Wojdyło, A., Szumny, A., & Choong, T. S. Y. (2019). Antioxidant activity, and volatile and phytosterol contents of strobilanthes crispus dehydrated using conventional and vacuum microwave drying methods. *Molecules*, *24*(7), Article 1397. https://doi.org/10.3390/molecules24071397

Deng, L. Z., Mujumdar, A. S., Zhang, Q., Yang, X. H., Wang, J., Zheng, Z. A., Gao, Z. J., & Xiao, H. W. (2019). Chemical and physical pretreatments of fruits and vegetables: Effects on drying characteristics and quality attributes–a comprehensive review. *Critical Reviews in Food Science and Nutrition*, *59*(9), 1408–1432. https://doi.org/10.1080/10408398.2017.1409192

Do, Q. D., Angkawijaya, A. E., Tran-Nguyen, P. L., Huynh, L. H., Soetaredjo, F. E., Ismadji, S., & Ju, Y. H. (2014). Effect of extraction solvent on total phenol content, total flavonoid content, and antioxidant activity of Limnophila aromatica. *Journal of Food and Drug Analysis*, *22*(3), 296–302. https://doi.org/10.1016/j.jfda.2013.11.001

ElGamal, R., Song, C., Rayan, A. M., Liu, C., Al-Rejaie, S., & ElMasry, G. (2023). Thermal degradation of bioactive compounds during drying process of horticultural and agronomic products: A comprehensive overview. *Agronomy*, *13*(6), Article 1580. https://doi.org/10.3390/agronomy13061580

Fadzil, N. F., Bakar, M. F. A., Yusop, M. H. M., & Bakar, F. I. A. (2020). Sensorial and physicochemical characteristics of herbal noodle enriched with centella asiatica. *Food Research*, *4*(4), 1030–1037. https://doi.org/10.26656/fr.2017.4(4).408

Filgueira-Garro, I., González-Ferrero, C., Mendiola, D., & Marín-Arroyo, M. R. (2022). Effect of cultivar and drying methods on phenolic compounds and antioxidant capacity in olive (*Olea europaea* L.) leaves. *AIMS Agriculture and Food*, *18*(1), 250–264. https://doi.org/10.3934/agrfood.2022016

Food Regulations (1985). *Food regulations 1985*. International Law Book Services.

Gonzalez, M. E., & Barrett, D. M. (2010). Thermal, high pressure, and electric field processing effects on plant cell membrane integrity and relevance to fruit and vegetable quality. *Journal of Food Science*, *75*(7), R121-R130. https://doi.org/10.1111/j.1750-3841.2010.01763.x

Hapsari, S., Yohed, I., Kristianita, R. A., Jadid, N., Aparamarta, H. W., & Gunawan, S. (2022). Phenolic and flavonoid compounds extraction from Calophyllum inophyllum leaves. *Arabian Journal of Chemistry*, *15*(3), Article 103666. https://doi.org/10.1016/j.arabjc.2021.103666

Hasan, M. U., Malik, A. U., Ali, S., Imtiaz, A., Munir, A., Amjad, W., & Anwar, R. (2019). Modern drying techniques in fruits and vegetables to overcome postharvest losses: A review. *Journal of Food Processing and Preservation*, *43*(12), Article e14280. https://doi.org/10.1111/jfpp.14280

Hidar, N., Ouhammou, M., Mghazli, S., Idlimam, A., Hajjaj, A., Bouchdoug, M., Jaouad, A., & Mahrouz, M. (2020). The impact of solar convective drying on kinetics, bioactive compounds and microstructure of stevia leaves. *Renewable Energy*, *161*, 1176–1183. https://doi.org/10.1016/j.renene.2020.07.124

Hii, C. L., & Ogugo, J. F. (2014). Effect of pre-treatment on the drying kinetics and product quality of star fruit slices. *Journal of Engineering Science and Technology*, *9*(1), 122–134.

Hiranvarachat, B., Devahastin, S., & Soponronnarit, S. (2015). Comparative evaluation of atmospheric and vacuum microwave-assisted extraction of bioactive compounds from fresh and dried *Centella asiatica* L. leaves. *International Journal of Food Science and Technology*, *50*(3), 750–757. https://doi.org/10.1111/ijfs.12669

Hue, S. M., Boyce, A. N., & Somasundram, C. (2012). Antioxidant activity, phenolic and flavonoid contents in the leaves of different varieties of sweet potato (Ipomoea batatas). *Australian Journal of Crop Science*, *6*(3), 375–380.

Idris, F. N., & Nadzir, M. M. (2021). Comparative studies on different extraction methods of centella asiatica and extracts bioactive compounds effects on antimicrobial activities. *Antibiotics*, *10*(4), Article 457. https://doi.org/10.3390/antibiotics10040457

Idris, F. N., Nadzir, M. M., & Abd Shukor, S. R. (2020). Optimization of solvent-free microwave extraction of Centella asiatica using Taguchi method. *Journal of Environmental Chemical Engineering*, *8*(3), Article 103766. https://doi.org/10.1016/j.jece.2020.103766

Jeevitha, G. C., Hebbar, H. U., & Raghavarao, K. S. M. S. (2013). Electromagnetic radiation-based dry blanching of red bell peppers: A comparative study. *Journal of Food Process Engineering*, *36*(5), 663–674. https://doi.org/10.1111/jfpe.12030

Jha, A. K., & Sit, N. (2022). Extraction of bioactive compounds from plant materials using combination of various novel methods: A review. *Trends in Food Science & Technology*, *119*, 579–591. https://doi.org/10.1016/J.TIFS.2021.11.019

Kıpçak, E. (2023). The investigation of oven and vacuum oven drying kinetics and mathematical modelling of golden berries. *Journal of the Turkish Chemical Society Section B: Chemical Engineering*, *6*, 1–8. https://doi.org/10.58692/jotcsb.1190201

Klungboonkrong, V., Phoungchandang, S., & Lamsal, B. (2018). Drying of Orthosiphon aristatus leaves: Mathematical modeling, drying characteristics, and quality aspects. *Chemical Engineering Communications*, *205*(9), 1239–1251. https://doi.org/10.1080/00986445.2018.1443080

Lemus-Mondaca, R., Vega-Gálvez, A., Rojas, P., Stucken, K., Delporte, C., Valenzuela-Barra, G., Jagus, R. J., Agüero, M. V., & Pasten, A. (2018). Antioxidant, antimicrobial and anti-inflammatory potential of

Stevia rebaudiana leaves: Effect of different drying methods. *Journal of Applied Research on Medicinal and Aromatic Plants*, *11*, 37–46. https://doi.org/10.1016/j.jarmap.2018.10.003

Lemus-Mondaca, R., Zura-Bravo, L., Ah-Hen, K., & Di Scala, K. (2021). Effect of drying methods on drying kinetics, energy features, thermophysical and microstructural properties of Stevia rebaudiana leaves. *Journal of the Science of Food and Agriculture*, *101*(15), 6484–6495. https://doi.org/10.1002/jsfa.11320

Mahirah, Y. S., Rabeta, M. S., & Antora, R. A. (2018). Effects of different drying methods on the proximate composition and antioxidant activities of ocimum basilicum leaves. *Food Research*, *2*(5), 421–428. https://doi.org/10.26656/fr.2017.2(5).083

Makhal, A., Robertson, K., Thyne, M., & Mirosa, M. (2021). Normalising the "ugly" to reduce food waste: Exploring the socialisations that form appearance preferences for fresh fruits and vegetables. *Journal of Consumer Behaviour*, *20*(5), 1025-1039. https://doi.org/10.1002/cb.1908

Márquez-Cardozo, C. J., Caballero-Gutiérrez, B. L., Ciro-Velázquez, H. J., & Restrepo-Molina, D. A. (2021). Effect of pretreatment and temperature on the drying kinetics and physicochemical and techno-functional characteristics of pumpkin (Cucurbita maxima). *Heliyon*, *7*(4), Article e06802. https://doi.org/10.1016/j.heliyon.2021.e06802

Minatel, I. O., Borges, C. V., Borges, C. V., Alonzo, H., Hector, G., Gomez, G., Chen, C. O., Chen, C. O., Pace, G., & Lima, P. (2017). Phenolic compounds: Functional properties, impact of processing and bioavailability. In M. Soto-Hernandez, M. Palma-Tenango & M. D. R. Garcia-Mateos (Eds.) *Phenolic compounds - Biological activity* (pp. 1–24). IntechOpen. https://doi.org/10.57772/66368

Minh, N. P. (2014). Effects of blanching and drying treatment on extraction of soluble components from dried Centella asiatica. *International Journal of Multidisciplinary Research and Development, 1*(2), 77–82.

Mohapatra, P., Ray, A., Jena, S., Nayak, S., & Mohanty, S. (2022). Influence of various drying methods on physicochemical characteristics, antioxidant activity, and bioactive compounds in *Centella asiatica* L. leaves: A comparative study. *Biotechnologia*, *103*(3), 235–247. https://doi.org/10.5114/bta.2022.118666

Ng, Z. X., Yong, P. H., & Lim, S. Y. (2020). Customized drying treatments increased the extraction of phytochemicals and antioxidant activity from economically viable medicinal plants. *Industrial Crops and Products*, *155*, Article 112815. https://doi.org/10.1016/j.indcrop.2020.112815

Ni, H., Datta, A. K., & Torrance, K. E. (1999). Moisture transport in intensive microwave heating of biomaterials: A multiphase porous media model. *International Journal of Heat and Mass Transfer*, *42*(8), 1501–1512. https://doi.org/10.1016/S0017-9310(98)00123-9

Nighitha, M. T., & Mathew, S. M. (2019). The effect of drying on the shelflife amaranthus leaves. *International Research Journal of Engineering and Technology, 6*(2), 219–222.

Nobosse, P., Fombang, E. N., & Mbofung, C. M. F. (2017). The effect of steam blanching and drying method on nutrients, phytochemicals and antioxidant activity of moringa (*Moringa oleifera* L.) leaves. *American Journal of Food Science and Technology, 5*(2), 53-60. https://doi.org/10.12691/ajfst-5-2-4

Nurzyńska-Wierdak, R. (2023). Phenolic compounds from new natural sources—Plant genotype and ontogenetic variation. *Molecules*, *28*(4), Article 1731. https://doi.org/10.3390/molecules28041731

Qin, Y., Wang, J., & Wei, C. (2014). Joint pricing and inventory control for fresh produce and foods with quality and physical quantity deteriorating simultaneously. *International Journal of Production Economics*, *152*, 42-48. https://doi.org/10.1016/j.ijpe.2014.01.005

Rahim, M. S. A. A., Baharudin, N. A., Nazri, I. A. A., Mohamad, S., & Muazzam, K. A. A. R. (2021). Effect of different drying methods on the antioxidant properties of leaves of Centella asiatica. *IOP Conference Series: Earth and Environmental Science*, *756*(1), 6–13. https://doi.org/10.1088/1755-1315/756/1/012054

Ribeiro, T. B., Melo, A., Vilas-Boas, A. A., & Pintado, M. (2023). Flavonoids. In M. Carocho, S. A. Heleno & L. Barros (Eds.) *Natural secondary metabolites: From nature, through science, to industry* (pp. 73–105). Springer. https://doi.org/10.1007/978-3-031-18587-8_4

Şahin, S., Elhussein, E., Bilgin, M., Lorenzo, J. M., Barba, F. J., & Roohinejad, S. (2018). Effect of drying method on oleuropein, total phenolic content, flavonoid content, and antioxidant activity of olive (Olea europaea) leaf. *Journal of Food Processing and Preservation*, *42*(5), Article e13604. https://doi.org/10.1111/jfpp.13604

Saifullah, M., McCullum, R., McCluskey, A., & Vuong, Q. (2019). Effects of different drying methods on extractable phenolic compounds and antioxidant properties from lemon myrtle dried leaves. *Heliyon*, *5*(12), Article e03044. https://doi.org/10.1016/j.heliyon.2019.e03044

Sledz, M., Wiktor, A., Rybak, K., Nowacka, M., & Witrowa-Rajchert, D. (2016). The impact of ultrasound and steam blanching pre-treatments on the drying kinetics, energy consumption and selected properties of parsley leaves. *Applied Acoustics*, *103*, 148–156. https://doi.org/10.1016/j.apacoust.2015.05.006

Srimagal, A., Mishra, S., & Pradhan, R. C. (2017). Effects of ethyl oleate and microwave blanching on drying kinetics of bitter gourd. *Journal of Food Science and Technology*, *54*(5), 1192–1198. https://doi.org/10.1007/s13197-017-2518-7

Tacer-Caba, Z., Nilufer-Erdil, D., & Ai, Y. (2015). Chemical composition of cereals and their products. In P. C. K. Cheung & B. M. Mehta (Eds.) *Handbook of food chemistry* (pp. 301-330). Springer. https://doi.org/10.1007/978-3-642-36605-5_33

Telfser, A., & Galindo, F. G. (2019). Effect of reversible permeabilization in combination with different drying methods on the structure and sensorial quality of dried basil (*Ocimum basilicum* L.) leaves. *LWT*, *99*, 148–155. https://doi.org/10.1016/j.lwt.2018.09.062

Thamkaew, G., Sjöholm, I., & Galindo, F. G. (2021). A review of drying methods for improving the quality of dried herbs. *Critical Reviews in Food Science and Nutrition*, *61*(11), 1763–1786. https://doi.org/10.1080/10408398.2020.1765309

Tomar, M. S., & Gururani, P. (2019). Microwave assisted blanching of fruits and vegetables : A mini review. *Octa Journal of Biosciences, 7*(2), 105–107.

Tripathy, S., & Srivastav, P. P. (2023). Effect of dielectric barrier discharge (DBD) cold plasma-activated water pre-treatment on the drying properties, kinetic parameters, and physicochemical and functional properties of Centella asiatica leaves. *Chemosphere*, *332*, Article 138901. https://doi.org/10.1016/J.CHEMOSPHERE.2023.138901

Trirattanapikul, W., & Phoungchandang, S. (2014). Microwave blanching and drying characteristics of *Centella asiatica* (L.) urban leaves using tray and heat pump-assisted dehumidified drying. *Journal of Food Science and Technology*, *51*(12), 3623–3634. https://doi.org/10.1007/s13197-012-0876-8

'T Hag, L. V., Danthe, J., Handschin, S., Mutuli, G. P., Mbuge, D., & Mezzenga, R. (2020). Drying of African leafy vegetables for their effective preservation: The difference in moisture sorption isotherms explained by their microstructure. *Food and Function*, *11*(1), 955–964. https://doi.org/10.1039/c9fo01175g

Vega-Gálvez, A., Uribe, E., Gómez-Pérez, L. S., García, V., Mejias, N., & Pastén, A. (2022). Drying kinetic modeling and assessment of mineral content, antimicrobial activity, and potential α-glucosidase activity inhibition of a green seaweed (Ulva spp.) subjected to different drying methods. *ACS Omega*, *7*(38), 34230–34238. https://doi.org/10.1021/acsomega.2c03617

Velić, D., Bilić, M., Tomas, S., Planinić, M., Bucić-Kojić, A., & Aladić, K. (2007). Study of the drying kinetics of "Granny Smith" apple in tray drier. *Agriculturae Conspectus Scientificus*, *72*(4), 323–328.

Wickramasinghe, Y. W. H., Wickramasinghe, I., & Wijesekara, I. (2020). Effect of steam blanching, dehydration temperature & time, on the sensory and nutritional properties of a herbal tea developed from moringa oleifera leaves. *International Journal of Food Science, 2020*(1), Article 5376280. https://doi.org/10.1155/2020/5376280

Xiao, H. W., Pan, Z., Deng, L. Z., El-Mashad, H. M., Yang, X. H., Mujumdar, A. S., Gao, Z. J., & Zhang, Q. (2017). Recent developments and trends in thermal blanching – A comprehensive review. *Information Processing in Agriculture*, *4*(2), 101–127. https://doi.org/10.1016/j.inpa.2017.02.001

Zainol, M. K. M., Abdul-Hamid, A., Bakar, F. A., & Dek, S. P. (2009). Effect of different drying methods on the degradation of selected flavonoids in Centella asiatica. *International Food Research Journal*, *16*(4), 531–537.

Zambra, C., Hernández, D., Reyes, H., Riveros, N., & Lemus-Mondaca, R. (2021). Kageneckia oblonga leaves subjected to different drying methods: Drying kinetics, energy consumption and interesting compounds. *Frontiers in Sustainable Food Systems*, *5*, Article 641858. https://doi.org/10.3389/fsufs.2021.641858

Żbik, K., Górska-Horczyczak, E., Onopiuk, A., Kurek, M., & Zalewska, M. (2023). Vacuum and convection drying effects on volatile compounds profile and physicochemical properties of selected herbs from Lamiaceae family. *European Food Research and Technology*, *249*(10), 2569-2581. https://doi.org/10.1007/s00217-023-04309-7

Zielinska, M., Ropelewska, E., Xiao, H. W., Mujumdar, A. S., & Law, C. L. (2020). Review of recent applications and research progress in hybrid and combined microwave-assisted drying of food products: Quality properties. *Critical Reviews in Food Science and Nutrition*, *60*(13), 2212–2264. https://doi.org/10.1080/10408398.2019.1632788