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Thin Layer Drying of Stinging Nettle (*Urtica Dioica*) Leaves in Cabinet Dryer and Selection of Appropriate Drying Model

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Abstract

The present study was conducted to examine the drying kinetics of stinging nettle (Urtica dioica) leaves, both pre-treated and untreated, in a cabinet dryer. The leaves were blanched at 90°C for one minute before drying at temperatures of 50, 55, or 60°C. The control group involved drying the leaves without any blanching. The drying of stinging nettle leaves followed only a falling rate period. Graphical and statistical analysis of the result showed that Midilli and Verma models were the best-fitted models for cabinet drying of stinging nettle leaves. The time required to dry unblanched leaves from an initial moisture content of ~8.54±0.86% db to a final moisture content of ~1.11±0.01% db was 90, 75, and 60 minutes at 50, 55, and 60°C, respectively. Similarly, the time required to dry blanched leaves was 75, 60, and 45 minutes at 50, 55, and 60°C respectively. The rehydration ratio of stinging nettle varied from 3.08±0.09 to 4.26±0.01 for unblanched and 3.40±0.15 to 4.52±0.07 for blanched product dried at 50-60°C. The D_{eff} of leaves was increased from 1.2-2.5×10-12m^2/s for unblanched leaves and 2-3.1×10-12m^2/s for blanched leaves as the drying temperature increased from 50-60°C. The activation energy was estimated to be 65.2 kJ/mol for unblanched leaves and 38.9 kJ/mol for blanched leaves. Drying (at 55°C) retained 43% and 31% of total chlorophyll and β-carotene respectively while drying with blanching retained 38% and 57% total chlorophyll and β-carotene respectively.

Keywords: *Stinging nettle leaves, Drying kinetics, Blanching, Rehydration, Chlorophyll, β-carotene*

INTRODUCTION

Stinging nettle, or *Urtica dioica* L., commonly known as Sishnu, an undervalued wild green vegetable can be found in hills and highlands of Nepal. Stinging nettles have been consumed by people since time immemorial. In the past, when grown vegetables were scarce, the leaves of this wild herbaceous plant were used to be eaten frequently by different ethnic groups as a part of cuisine prepared (Bhusal *et al*., 2022). In recent years, it has been preferred by elite groups to savor in form diets and capture the natural phytochemicals (Devkota et al., 2022). Stinging nettle has been gaining attention as a potential future crop due to its versatility and various applications (Di Virgilio et al., 2015).

Drying of stinging nettle can explore its potential application in the commercial world due to its extended shelf life, easy handling, reduced bulkiness, and low transportation and storage costs. There are several techniques for achieving drying but cabinet dryers are preferred over conventional sun drying and solar drying methods as they contribute to nutritional losses, leading to shortages (Kandonga, 2019). The major driving forces during drying are temperature difference, heat transfer, and mass transfer. The temperature difference, which is achieved by applying heat, causes a lot of physicochemical changes during thermal drying. Prolonged heating increases thermal intensity which deteriorates the desirable quality attributes. To minimize this effect, blanching, a short heat treatment, is applied to maintain the safety and quality characteristics of vegetables by inactivating enzymes such as lipoxygenase, polyphenol oxidase, polygalacturonase, and chlorophyllase before they are further subjected to harsher treatment like drying (Rukyat Busari et al., 2016; Stanley et al., 2017).

Mathematical models, more specifically, the drying models are tested to lower experimental error during real-life situations and thus are important tools for simulating and evaluating the efficiency, effectiveness, and economy of the drying process (Akter et al., 2022). The need to dry more food more quickly and sustainably while maintaining food quality and safety has led to the development of various novel drying technologies as well as advancements in food drying modeling approaches (Chen & Pan, 2023).

The nutritional benefits especially chlorophyll and β-carotene of stinging nettles are not fully explored and enjoyed throughout the year at all geographical locations due to their high perishability owing to high moisture content. Traditional solar drying techniques deliver poor quality to the finished product. Lack of understanding of drying characteristics, drying temperatures, and drying models in mechanical dryers (cabinet dryer) to local food processors are major problems for value addition in the food safety chain. Different methods of drying have been studied by researchers in recent years. Few studies are available about the drying kinetics of stinging nettle leaves (Kamwere et al., 2015; Lamharrar et al., 2017). The present study was done to study and model the thin layer drying of stinging nettle leaves in a cabinet dryer and evaluating the effect of blanching on the diffusion coefficient, activation energy, and quality attributes (chlorophyll, rehydration ratios, and β-carotene) of leaves. We aimed to enhance the efficiency of drying processes, addressing the gap in sustainable food preservation techniques. The justification for this research lies in the urgent need to reduce post-harvest losses and energy consumption, which has significant implications for food security.

MATERIALS AND METHODS

Materials

Fresh and young stinging nettle leaves were collected randomly from the area of Khokana, Nepal in July and August. The leaves were sorted and washed with water to remove adhered dust and foreign materials. The thickness and area of leaves were measured by a micrometer screw gauge.

Drying

Stinging nettle leaves (weighing 60g) were placed in a mesh tray in a drying unit, being the tray was placed in the middle of the drying unit and dried at 50, 55 or 60℃ with and without blanching (for control). The dryer was heated for 10 min after reaching its final temperature for equilibrium. The leaves were dried in a cabinet dryer continuously till the moisture content of the product reached a constant weight. The moisture content of the leaves was determined during and after drying. Dried samples were stored in zip lock bags at -18°C for further analysis. The experiment was performed three times.

Modeling of drying kinetics

Seven semi-empirical thin-layer drying models given in Table 1 have been taken into account in this study. MR is the moisture ratio calculated as,

$$MR=\frac{M_t-M_e}{M_i-M_e}\text{--------------------(i)}$$

where,

M_t = moisture content (% dry basis) at any time t (min)

M_i = initial moisture content (% d.b)

M_e = equilibrium moisture content (% d.b)

Table 1 Mathematical model

S. No.	Model	Model equation	Reference
1	Newton	$MR=\exp(-kt)$	(Lewis, 1921)
2	Page	$MR=\exp(-ktn)$	(Najla & Bawatharani, 2020)
3	Two-term	$MR = a\exp(-k_0t) + b\exp(-k_1t)$	(Onwude et al., 2016)
4	Logarithmic	$MR= a\exp -kt+c$	(Onwude et al., 2016)
5	Henderson and Pabis	$MR = a\exp(-kt)$	(Panchariya et al., 2002)
6	Midilli	$MR = a\exp(-kt^n) + bt$	(Midilli et al., 2002)
7	Verma	$MR = a\exp(-kt) + (1-a)\exp(-gt)$	(Li et al., 2021)

Non-Linear regression analysis of these equations was made by using MS Excel and graph was made in Graphpad prism The models' capacity to explain drying kinetics was determined using the quantitative error parameters. The error function such as sum of square error (SEE), coefficient of determination (R^2) and root mean square error (RMSE) are given below;

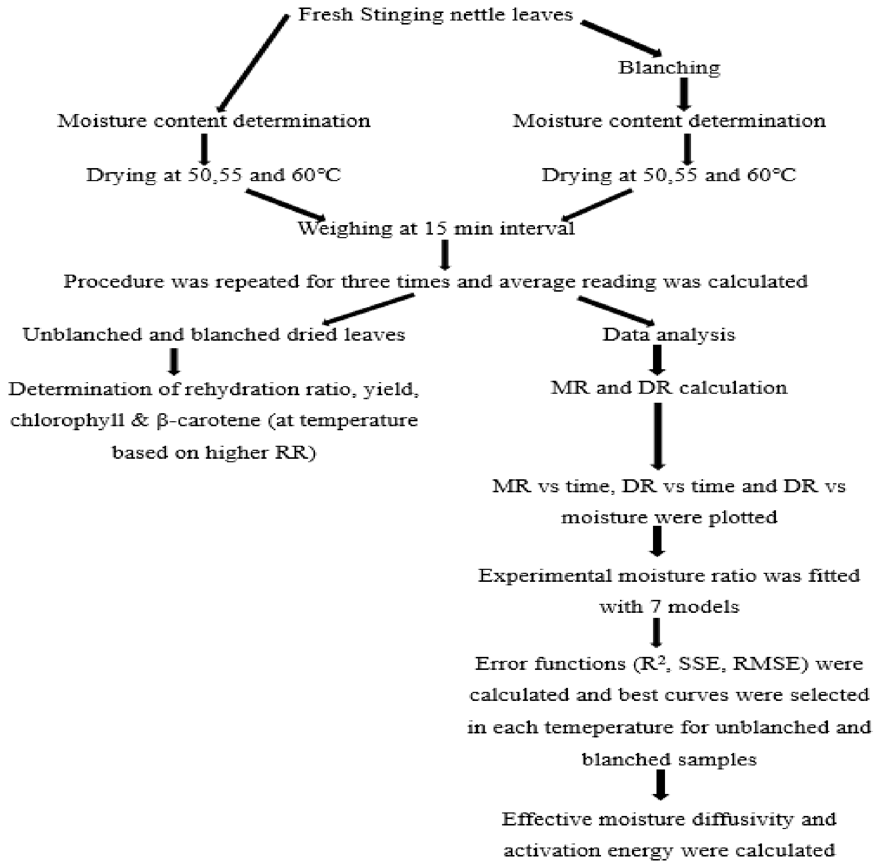

Figure 1: Experimental Protocol

Table 2 Error function

Error function	Equations	Reference
SSE	$\sum_{i=1}^{N} (MR_{exp,i}-MR_{pre,i})^2$	(Okonkwo et al., 2022)
R^2	$\frac{\sum_{i=1}^{N}\left(MR_{exp,i}-MR_{pre,i}\right)^2-\sum_{i=1}^{N}(MR_{exp,i}-MR_{pre,i})^2}{\sum_{i=1}^{N}(MR_{exp,i}-MR_{pre,i})^2}$	(Shafaei et al., 2016)
RMSE	$\sqrt{\frac{1}{N}\sum_{i=1}^{N}(MR_{exp,i}-MR_{pre.i})^2}$	(Nayi et al., 2023)

Effective moisture diffusivity and activation energy

The simplified form of Fick's second law of diffusivity is given as,

$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \frac{\pi^2 D_{eff}}{4(h)^2} \times t$---------------------(ii)

Plotting the experimental drying data in terms of Ln (MR) with time yields the diffusion coefficient. When Ln(MR) is plotted against time, a straight line with a slope is obtained as,

$\text{Slope}(m) = \frac{\pi^2 D_{eff}}{4(h)^2}$-----------------(iii)

The Arrhenius equation was used to describe the relationship between the effective

diffusivity and drying temperature and is given as,

$D_{eff} = D_0 \exp\frac{E_a}{RT}$------------------(iv)

Activation energy is determined by plotting the experimental drying data in terms of Ln

(D_{eff}) versus 1/Temperature (K). The value of R is 8.3143 KJ/molK.

Drying rate

$$\text{Drying rate} = \frac{\text{Amount of moisture content(gm)}}{\text{Bone dry weight(gm)}\times\text{Time(min)}}\text{-----------------(v)}$$

Rehydration ratio

A sample (1 g) i.e., initial weight, of dried nettle leaves was put in a beaker containing 150 ml of boiling distilled water (100°C) for 5 min (Maharaj, 2000). After the completion of rehydration, the excess surface water was blotted with blotting paper, and the final weight was taken. The rehydration ratio can be calculated as follows as described by Phahom et al. (2017);

$$\text{Rehydration Ratio} = \frac{\text{Weight of rehydrated sample}}{\text{Weight of dried material}}\text{-------------(vi)}$$

Chlorophyll and beta-carotene

For every sample, one gram was weighed, chopped into small pieces, and ground using a mortar and pestle. After adding 20 milliliters of 80% acetone, the mixture was carefully ground once again. The combination was then allowed to sit at 4ºC for three hours. After centrifuging the mixture for five minutes at 2500 rpm, the supernatant was poured into a 100 ml volumetric flask, and 80% acetone was added to get the volume up to 100 ml. This solution was then used to estimate the amount of chlorophyll. Digital colorimeter (400-700 nm) Model 1311, manufactured by ESICO International, India was used for the analysis. The 80% acetone solution was used as a blank to measure the absorbance of the solutions at 645 and 663 nm (Stewart & Globig, 2011, Gogoi & Basumatary, 2018). Using the following formulas, the contents of chlorophyll a, b, and total chlorophyll were determined.

$$\text{Chlorophyll a (mg/g)}=(12.7\times A_{663}-2.69\times A_{645})\frac{V}{1000\times W}\text{--------------(vii)}$$

$$\text{Chlorophyll b (mg/g)}=(22.9\times A_{645}-4.68\times A_{633})\frac{V}{1000\times W}\text{--(viii)}$$

$$\text{Total chlorophyll (mg/g)}=(20.2\times A_{645}+8.02\times A_{633})\frac{V}{1000\times W}\text{---------------(xi)}$$

where A is the absorbance at a specific wavelength, V is the final volume of chlorophyll extract in 80% acetone and W is fresh weight of tissue extracted.

Few crystals of anhydrous sodium sulfate were observed when a 2 g sample, with minimal alterations from Bishnoi et al. (2020), was ground in 10–15 ml of acetone. The extraction process was performed twice after the supernatant was collected separately following decantation. 10 milliliters of petroleum ether (boiling point 70–80°C) were combined with supernatant in a separating funnel. The upper layer was collected in a 100 ml volumetric flask and the lower layer was discarded after thorough mixing. The optical density was measured at 450 nm following the creation of the volume using petroleum ether. In order to extract, two samples were obtained.

$$\beta\text{-carotene (mg/100g)}=\frac{OD\times 13.9\times 1000\times 100\times 100}{W\times 560\times 1000}\text{- --------(x)}$$

where, W is weight of sample taken and OD is optical density at 450 nm.

RESULT AND DISCUSSION

Drying characteristics

The moisture content of fresh stinging nettle leaves was found to be 8.91±1.04% db in an average of 18 batches. As the samples dried, their weight gradually decreased due to evaporation or moisture loss. Drying stinging nettle leaves required 90, 75, and 60 minutes at 50, 55, and 60°C without pre-treatment, and 75, 60, and 45 minutes with pre-treatment. Drying time varied significantly ($p \leq 0.05$) with temperature. As the drying temperature increased, the moisture on the capsules' surface evaporated quickly, while the moisture inside the capsules and on the surface generated a huge gradient, accelerating moisture transfer. According to Latiff et al. (2020), drying the sample at lower temperatures took longer because there was insufficient heat to vaporize moisture from the surrounding air.

The blanching decreased the drying time by 16.66-25% compared to unblanched stinging nettle. Blanching may have reduced drying time because it ruptured the cell structure of leaves during blanching, allowing moisture to be removed from them more quickly. Blanching caused the cells in produce to lose their wall integrity, resulting in faster loss of bound water after drying than when unblanched (Waldron et al., 2003). Reduction in drying time as compare to unblanched one was also found in beetroot leaves (Kakade & Hathan, 2014) and aonla shreds (Gupta et al., 2014). However, in Moringa leaves, the drying time was more in blanched sample (Wickramasinghe et al., 2020) and in water yam slices (Fatimat Okeleye et al., 2021). This might be due to available of excess surface water before drying. According to Garba et al., (2015), blanching of black carrot slices did not cause any effect on drying time.

Figure 1 and 2 shows the relationship between moisture ratio versus time and drying rate versus time respectively. During a constant rate period, heat transfer caused water evaporation. The temperature difference between the air and the surface served as the driving force for heat transmission. The rate of water removal was proportional to the rate of mass transfer. Mass transfer was driven by the difference between the vapor pressure of water at the surface temperature and the partial pressure of water vapor in the air stream. During the falling rate period, the drying rate began to slow significantly. Then, the rate of drying was determined by the flow of liquid or vapor within the solid matrix. Water vapor diffused from the inside to the surface of a solid substance, causing heat and mass transfer.

The moisture ratio, which compares the initial moisture content to the moisture content at a certain drying period, has a major impact on the drying rate. The drying rate was faster in the early stages with high moisture ratios because of the significant difference in moisture content between the leaves and the drying medium. As the drying process progressed and the moisture ratio lowered, the drying rate slowed and approached equilibrium between the leaves. During the falling-rate drying period with low moisture ratios, the drying rate slowed even further as moisture movement became increasingly difficult.

According to Premi et al. (2010), a continual reduction in moisture ratio suggested that diffusion had governed internal mass transport. A greater drying air temperature reduced the moisture ratio faster because it increased the rate of air heat delivery to the leaves and accelerated moisture migration. The moisture ratio declined fast during the early stages of drying before gradually decreasing in the late stages. Coriander leaves (Silva et al., 2008), soursop leaves (Nhi et al., 2020), and thyme leaves (Turan & Firatligil, 2019) all had similar results.

Fitting of Drying Models

Measured and predicted moisture ratio (best fit model) vs time at 60°C for blanched samples was shown in figure 3. The empirical drying constants at different temperature are given in Table.3 The coefficients of determination (R^2) for the drying rate constants of all drying models were above 0.90, indicating a good fit. For Unblanched leaves dried at 50°C, the value of R^2 obtained for the Midilli model was higher i.e., 0.9989 and SSE and RMSE were lower i.e., 0.0031 and 0.0108 respectively than other models. For blanched one, Midilli model had higher R^2 i.e., 0.9919 and SSE and RMSE were lower i.e.,0.0247 and 0.0320 respectively than other models. And for unblanched leaves dried at 55°C, the value of R^2 obtained for Midilli model was higher i.e., 0.9971 and SSE and RMSE was lower i.e.,0.0078 and 0.0180 respectively. Again, Midilli model had higher R^2 i.e.,0.9958 and SSE and RMSE were lower i.e.,0.0118 and 0.0237 respectively for blanched leaves dried at 55°C. At 60°C, the value of R^2 obtained for Verma model was higher i.e., 0.9881 and SSE and RMSE were lower i.e.,0.0303 and 0.038 respectively. Similarly, for blanched one, the value of R^2 obtained for Midilli model was higher i.e.,0.9893. and SSE and RMSE were lower i.e.,0.0246 and 0.0369 respectively.

Drying curve equations were given below for each best model.

$\text{MR (50°C Unblanched)} = 1.001 \exp(-1.2418t^{0.7258}) + (-0.1226)\, t$

$\text{MR (55°C Unblanched)} = 1.004 \exp(-1.6669t^{0.7899}) + (-0.106)\, t$

$\text{MR (60 Unblanched)} = 1 \times \exp(-3.6941t) + (1-1) \times \exp\{-(-7.4132)t\}$

$\text{MR (50°C Blanched)} = 1.0048 \exp(-3.8097t^{1.1679}) + 0.0158t$

$\text{MR (55°C Blanched)} = 1.0027 \exp(-4.6236t^{1.2799}) + 0.0034t$

$\text{MR (60°C Blanched)} = 0.9975 \exp(-5.4215t^{1.2799}) + 0 \times t$

Lamharrar *et al*., (2017), Filho *et al*., (2018), Kusuma *et al*., (2023), Taheri-Garavand & Meda, (2018) and Zambra *et al*., (2021) also found the Midilli model as the suitable model to define stinging nettle leaves in solar dryers, parsley leaves, clove leaves, savory leaves and *Kageneckia oblonga* leaves respectively. Besides from leaves, Mugodo & Workneh, (2021), Siqueira *et al*., (2012) and Taheri-garavand *et al*., (2011) found Midilli model to describe the drying behavior of mango slice in hot air dryers, jatropa seed and tomato in convective dryer respectively. In Kamwere *et al*., (2015), Verma model predicted thin layer drying of stinging nettle in solar dryer. Also, this model was found to be the most suitable for describing the drying curve of cocoa beans in convective indirect solar dryer (O.O. *et al*., 2017) and pineapple (Reddy *et al*., 2017).

Effective moisture diffusivity and activation energy

De describes the ability of leaves to disperse their moisture and depend on drying conditions (time and power), variations in drying samples, and chemical-physical properties (leaf tissue characteristics, leaf thickness, leaf size, and leaf aging rate (Kusuma et al., 2023). Turgor pressure, a force created by stored water against plant cell walls, maintains cell shape, supports structures, and drives cell expansion and growth. Turgor pressure in plant cells impacted diffusivity by increasing water content, facilitating faster diffusion, and facilitating cell expansion. Temperature could increase turgor pressure by promoting water uptake, while too high temperature could cause water loss through transpiration. Water transport potential, a combination of osmotic, pressure, and gravitational potentials, influenced water movement within and between cells. Higher temperatures increased diffusivity, enhancing water diffusion within plant tissues.

The result showed that the effective moisture diffusivity increased with increase in drying temperature for dried stinging nettle ranging between 1.2802×10^{-12} m^2/s at 50°C, $1.6191\times10^{-12} m^2/s$ at 55°C and $2.5267\times10^{-12} m^2/s$ at 60°C. Similarly, for blanched dried stinging nettle leaves, it ranged between $2.0273\times10^{-12} m^2/s$ at 50°C, $2.8529\times10^{-12} m^2/s$ at 55°C and $3.1258\times10^{-12} m^2/s$ at 60°C. The higher temperature caused an increase of effective moisture diffusivity because of higher mass transfer. It increased vapor pressure within the stinging nettle leaves which accelerated the moisture diffusion process. The values of D_{eff} obtained from recent studies range generally between 10^{-8} and 10^{-12} m^2/s for dried food products (Zogzas et al., 1996). Jin Park et al., (2002) found D_{eff} as 0.47 to 2.94×10^{-12} m^2/s for mint leaves dry at 30-50°C. Yap,

(2021) found D_{eff} as 2.09×10^{-12} m^2/s to 2.18×10^{-12} m^2/s in papaya leaves.

The natural logarithm of D_{eff} as a function of the reciprocal of absolute temperature was plotted for unblanched and blanched samples. It can be concluded that, 65.2 kJ/mol for unblanched and 38.9 kJ/mol for blanched, average energy is required to initiate the process of the mechanism i.e., triggering the moisture diffusivity during drying. The activation energy was higher in unblanched one which is also reported on Gupta et al., (2014). The blanching reduced the amount of energy required for mass diffusion to be initiated from a food material during the drying process (Fatimat Okeleye et al., 2021). According to Yao et al., (2012), the values of activation energy lie from 12.7 to 110 kJ/mol for most of food material. Dai et al., (2015) reported this value as 31.4 kJ/mol for apricot samples treated by continuous dehumidification.

Rehydration Ratio

Figure 4 shows rehydration ratio of dried leaves and blanched dried leaves at different temperatures. The RR of stinging nettle leaves were varied from 3.08±0.09 to 4.26±0.01 and 3.40±0.15 to 4.52±0.07 dried at 50-60°C for unblanched and blanched product, respectively. RR of unblanched samples dried at 55°C and 60°C were not significantly differ with each other. It might be due to cell wall damaged at 55°C for unblanched sample and it could not restore water at further temperature. However, in blanched sample, there was significantly different RR ($P\leq0.05$) in selected drying temperatures. Drying at 55°C resulted in the highest rehydration ratio i.e,.4.5 for blanched samples. The higher rehydration capacity obtained indicated that cellular structure damages were minimum in drying process and the extent of restoration are higher (Laurence et al., 2019). RR of unblanched and blanched samples were not significantly different ($p\geq0.05$) with each other. When the drying process is conducted in a way that preserves the cell structure of unblanched sample, it might rehydrate at a similar rate.

Effect of drying and blanching on chlorophyll of leaves

The total chlorophyll, chlorophyll a and chlorophyll b in fresh (undried) stinging nettle leaves were calculated as 2.03, 1.66 and 0.37 mg/g in dry weight basis respectively. The chlorophyll in fresh leaves was found similar to Case et al., (2022). The Chlorophyll a to b ratio in fresh leaves was found to be 4.48 which was nearly similar to Hojnik et al., (2007). Total chlorophyll, chlorophyll a and chlorophyll b decreased by 57, 54 and 70% when dried at 55°C respectively. Drying and blanching cause lower ($P\leq0.05$) chlorophyll a as chlorophyll a content was affected by both blanching and drying. Chlorophyll b in samples dried without and with blanching were not significantly different ($P\geq0.05$) because chlorophyll b content was affected by only drying method as reported by Chakravartula et al., (2021). Chaves et al., (2023) found degradation of 45.4% chlorophyll a (dried at 50°C) and 68% chlorophyll b (dried at 40-70°C) in purple basil leaves. The blanched samples had a more vibrant green color due to the disruption and trapped air that occurred during the blanching process. This prevented the air from clouding the colors, making the green color look darker and more vivid. In addition, when blanched leaves are submerged in water to cool, the chloroplasts enlarge and sometimes even burst, spreading the green pigment throughout the cell and giving the leaves' surface a deeper shade of green. Chlorophyll broke down into pyro-pheophytin and pheophytin during drying. The color of chlorophyll a is blue-green, while that of chlorophyll b is yellow green. Because chlorophyll a is less stable than chlorophyll b, it degrades more quickly at higher temperatures, resulting in a dull yellow-green color instead of the normal green color (Wickramasinghe et al., 2020).

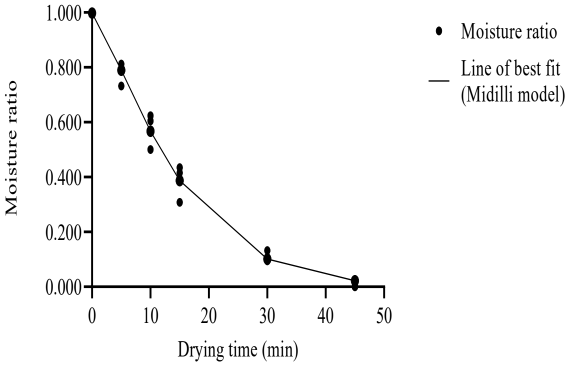

Figure 1 Measured and predicted moisture ratio variation with drying time of blanched stinging nettle during cabinet drying at 60°C

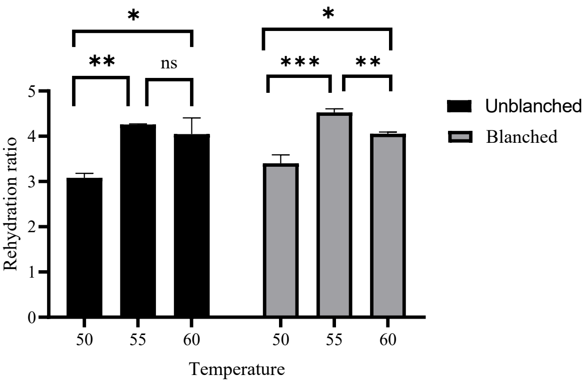

Figure 4 Rehydration ratio

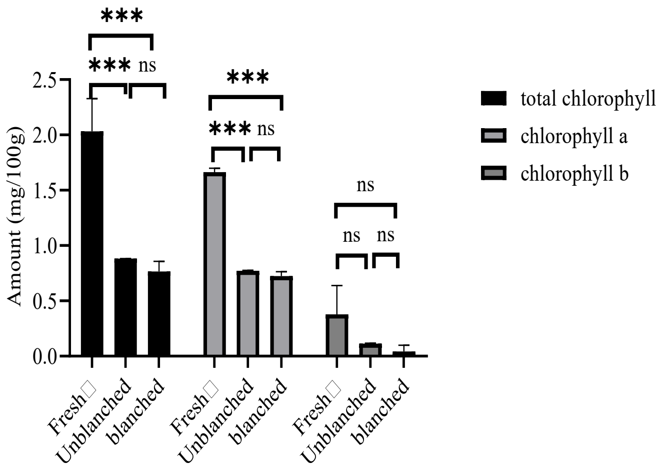

Figure 5 shows chlorophyll at 55°C

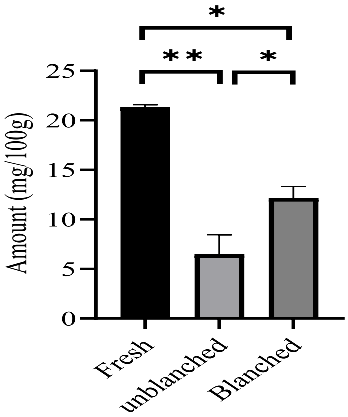

Figure 6 shows β-carotene content at 55°C

(ns indicate significantly not different and *, **, *** indicate significantly different)

Effect of drying and blanching on β-carotene of leaves

The β-carotene was found to be 21.3, 6.4 and 12.1 mg/g in fresh, dried and blanched dried stinging nettle. The β-carotene content of samples dried without and with pretreatment significantly differ (P≤0.05) with each other. β-carotene decreased by 69 and 43% when dried and dried with blanching was done. The degradation of β-carotene can occur during drying, but blanching has been found to help preserve its content (Wang et al., 2011). Cheptoo, (2019) reported that the thermal processing causes isomerization of all the naturally predominant trans-β-carotene to cis form due to presence of conjugated double bond hence higher β-carotene content in blanched samples. Kullamethee et al., (2020) reported β-carotene was decreased by 59.9% in pumpkin when dried at 65°C. Also in tomato paste, β-carotene decreased more that 50% (Kosmala & Ulańska, 2022). Uartea et al., (2005) reported that in the temperature range of 50-60°C, 55-42% of the β-carotene content could be retained. Also, he mentioned blanching led to the loss of 50–60% of β-carotene. These reports showed that more than 45% β-carotene can be loss during drying.

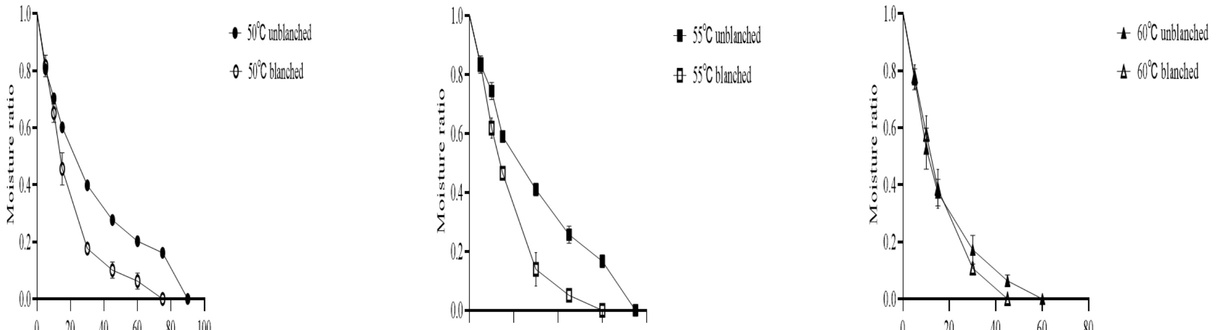

Figure 2 shows the drying curve (moisture ratio vs time) of stinging nettle leaves during thin layer drying operation

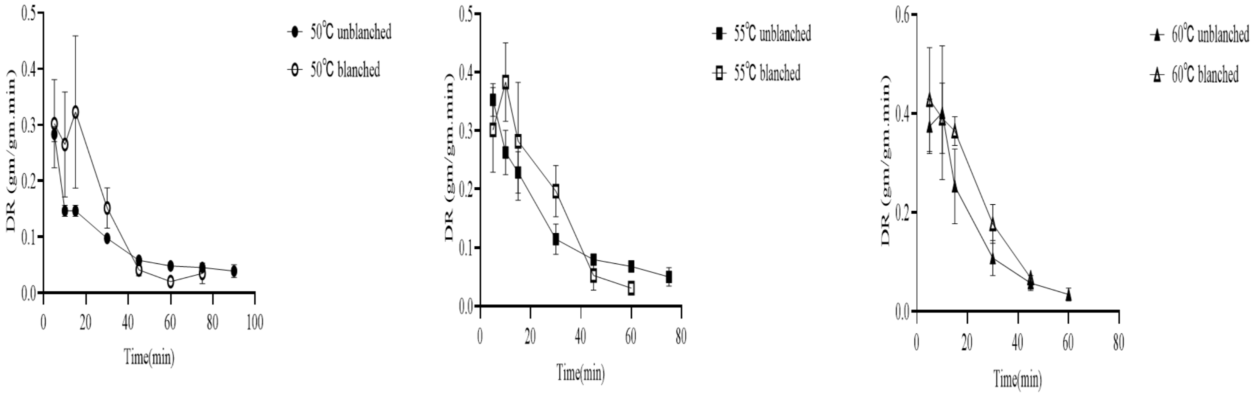

Figure 3 Drying rate curve showing drying rate as a function of time

Table 1 Empirical constant and error function value of selected models at selected temperature

Model	T (°C)	Pre-treatment	Constants	R^2	RMSE	SSE
Newton	50	Unblanched	k=1.9197	0.9909	0.0327	0.0289
	55		k=2.4096	0.9919	0.0305	0.0223
	60		k=3.7207	0.9877	0.0390	0.0320
	50	Blanched	k=3.0044	0.9898	0.0389	0.0357
	55		k=3.2316	0.9896	0.0483	0.0490
	60		k=3.7563	0.9838	0.0534	0.0515
Page	50	Unblanched	k=1.8471 n=0.9362	0.9918	0.0304	0.0250
	55		k=7.4454 n=1	0.9340	0.1284	0.3954
	60		k=3.9265 n=1.0384	0.9877	0.3799	0.3130
	50	Blanched	k=3.5374 n=1.1384	0.9916	0.0329	0.0260
	55		k=4.7000 n=1.2920	0.9957	0.0238	0.0119
	60		k=5.5044 n=1.2683	0.9893	0.0370	0.0246
Two-term	50	Unblanched	a=b=0.4866 k_0=k_1=1.8510	0.9917	0.0303	0.0249
	55		a=b=0.4934 k_0=k_1=2.3658	0.9922	0.0299	0.0215
	60		a=b=0.5060 k_0=k_1=3.7786	0.9876	0.0387	0.0315
	50	Blanched	a=0.0000 b=1.0287 k_0=0.8482 k_1=3.1165	0.9896	0.0366	0.0321
	55		a=b=0.5231 k_0=k_1=3.4142	0.9878	0.0435	0.0398
	60		a=1.0346 b=0 k_0=3.9133 k_1=0	0.9818	0.0509	0.0467
Logarithmic	50	Unblanched	k=1.5873 a=1.0210 c=-0.0618	0.9930	0.0274	0.0202
	55		k=2.1221 a=1.0187 c=-0.0427	0.9930	0.0279	0.0187
	60		k=3.6789 a=1.0200 c=-0.0149	0.9877	0.0387	0.0311
	50	Blanched	k=3.0013 a=1.0396 c=-0.0149	0.9898	0.0361	0.0313
	55		k=2.8626 a=1.1122 c=-0.0819	0.9912	0.0344	0.0248
	60		k=3.0495 a=1.1430 c=-0.1275	0.9880	0.0389	0.0272
Henderson and Pabis	50	Unblanched	k=1.8510 a=0.9732	0.9917	0.0303	0.0249
	55		k=2.3659 a=0.9867	0.9922	0.0299	0.0215
	60		k=3.7786 a=1.0120	0.9876	0.0387	0.0315

	50	Blanched	k=3.1165 a=1.0287	0.9896	0.0366	0.0322
	55		k=3.4142 a=1.0462	0.9878	0.0435	0.0398
	60		k=3.9134 a=1.0346	0.9818	0.0510	0.0467
Midilli	50	Unblanched	k=1.2418 n=0.7258 a=1.0019 b=-0.1226	0.9989	0.0108	0.0031
	55		k=1.6669 n=0.7899 a=1.0049 b=-0.1060	0.9971	0.0180	0.0078
	60		k=3.9164 n=1.0295 a=1.0074 b=0	0.9877	0.0384	0.0311
	50	Blanched	k=3.8097 n=1.1679 a=1.0048 b=0.0158	0.9919	0.0320	0.0247
	55		k=4.6236 n=1.2799 a=1.002 b=-0.0034	0.9958	0.0237	0.0118
	60		k=5.5215 n=1.2728 a=0.9975 b=0	0.9893	0.0369	0.0246
Verma	50	Unblanched	k=182.76 a=0.0567 g=1.7765	0.9936	0.0273	0.0201
	55		k=2.3545 a=1 g=-6.0127	0.9952	0.0249	0.0149
	60		k=3.6941 a=1 g=-7.4132	0.9881	0.0380	0.0303
	50	Blanched	k=2.2268 a=5.7030 g=2.0904	0.9897	0.0369	0.0326
	55		k=2.2085 a=1.6932 g=1.2242	0.9916	0.0350	0.0258
	60		k=2.4718 a=1.6314 g=1.1583	0.9883	0.0388	0.0271

Table 2 Effective moisture diffusivity and activation energy

	Temperature (°C)	D_{eff}		E_a	
		Slope of curve	Diffusivity(m^2/s)	Slope of curve	Energy (KJ/mol)
Unblanched	50	-0.0312	$1.2309\times10^{-12}m^2/s$	7849	65.2
	55	-0.03946	1.6191×10^{-12} m^2/s		
	60	-0.06158	$2.5267\times10^{-12}m^2/s$		
Blanched	50	-0.04941	$2.0273\times10^{-12}m^2/s$	4678	38.8
	55	-0.06953	$2.8529\times10^{-12}m^2/s$		
	60	-0.07618	$3.1258\times10^{-12}m^2/s$		

CONCLUSION

It can be concluded that drying of stinging nettle leaves can be accomplished at 50-60°C with relatively short time (60-90 min) and high values of rehydration ratios are obtained at 55°C. Both Midilli and Verma models can be employed to predict the drying time and/or final moisture content of the dried product. Pretreatment retained better quality attributes (β-carotene) than untreated samples during drying.

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