Effect of air temperature and velocity on the drying characteristics and product quality of Clinacanthus nutans in heat pump dryer

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Abstract. Fresh Clinacanthus nutans (C. nutans) leaves were dried using a heat pump dryer where the effects of drying temperature (40, 50, and 60°C) and air velocity (2.5, 3.0, and 3.5 m/s) on the drying characteristics and product quality were investigated. Data showed that higher air temperature and velocity resulted in a shorter drying duration. At higher air temperature and velocity, more heat was supplied to the C. nutans leaves, which increased the drying force for moisture evaporation and subsequently led to faster drying rate. The drying kinetics were best fitted with Midilli et al. model ($R^2 = 0.9556$). The quality analysis revealed that vitexin and orietin contents were preserved at varied extent depending on the drying temperature and duration. The highest preservation of vitamin C and total colour change was achieved at drying conditions of 50 °C (3.5 ms⁻¹) with 90.7 % and 94.6 % maintained, respectively. This was because the pigment colours and vitamin C were easily degraded if the products were exposed to excessive heat (high temperature) and prolonged drying process (time taken). Overall, heat pump dryer presented a short drying duration without compromising the product quality for the drying of C. nutans. Heat pump dryer can be used to extend the shelf life of C. nutans and increase the commercialization potential and wide use of C. nutans.

1. Introduction

Recently, consumers have started looking for natural products that could provide health benefits without side effects upon consumption. Also, researchers are actively exploring traditional herbs for their potential to cure or prevent diseases [1]. Sabah Snake Grass or locally known as Belalai gajah with scientific name, Clinacanthus nutans (C. nutans) is a native medicinal herb that can be found in tropical region, mainly in Malaysia, Thailand, and Indonesia [2]. Currently, this plant has garnered much attention due to its high medicinal values. C. nutans has been used in medicinal and converted to herb products such as cream, lotions, capsule, tablet, herbal tea, concentrated extract and secondary metabolites products [3]. This plant reportedly useful in many applications for the control of skin rashes, insect and snake bites, diabetes mellitus, fever, diuretics, herpes simplex virus (HSV), and varicella-zoster virus (VZV) [4]. For example, in Thailand, this plant has been scientifically proven useful for the treatment of insect and snake bites, skin rashes, virus-related diseases such herpes simplex (HSV) and varicella-zoster lesions [5]. Another report stated that C. nutans possesses...
antihepatitis, antiherpes, and anti-inflammatory properties that could be potentially used to prevent and cure cancer [7]. These unique properties have drawn the public interest to consume its leaves been as herbal tea [7]. Studied reported by Yong et al. [8] has shown that the chloroform extracts on C. nutans leaves showed anti-proliferative effect on cancer cell lines of human erythroleukemia. However, the cytotoxicity test of C. nutans against cancer cells is still limited and lack of scientific evidence [7].

The versatility of C. nutans could be attributed to its leaves which are rich in bioactive constituents when it is being extracted using specific organic solvents. Useful phytochemical substances of C. nutans are stigmasterol, β-sitosterol, lupeol, betulin, six known C-glycosyl flavones, vitexin, isovitexin, schaftoside, isomollupentin, 7-O-β-glucopyranoside, orientin, isoorientin, two glycosylglycerolipids, a mixture of nine cerebrosides and a monoacylmonogalactosylglycerol, and five sulfur-containing glucosides [9]. C. nutans can be consumed fresh but it is easily perishable due to its high moisture content (about 75%) that promotes the growth of microbial. Hence, it could not be stored in its fresh form for a long period of time [10]. To lengthen the shelf life of a product, the moisture level in the food must be reduced to a certain level to inhibit the growth of the microorganism [11]. Drying process is a common technique used to preserve the quality of foods and fruits during storage period by removing the moisture content in the products. This helps to prolong the shelf life of food products in post-harvest processing stage. A good quality of drying process does not only remove moisture but also be able maintain the nutrition values and biological product’s quality, such as changes in appearance and alterations in aroma [12].

Drying of herbal plant could be done by either natural or artificial methods. Currently, natural drying such as open sun drying method is the standard practice by most of the Malaysian herbal producers. Unfortunately, the traditional open sun drying method has inherent limitations where the products are susceptible to several issues: fungal attacks due to inadequate drying, insects, birds and rodents encroachment, unexpected down pour of rain and other weathering effects [13]. In addition, the product quality in terms of visual, textural attributes and the content of health promoting ingredients is not always guaranteed [14]. Hence, artificial drying such as heat pump drying, vacuum drying, freeze drying, and hot air drying are proposed by researchers for drying herbs or vegetables products [15]. Previous studied on C. nutans has been reported using a drying method from solar drying [16], spray drying [17], oven drying [18] and vacuum drying [19]. These drying methods have been known as helping to reduce the drying process duration as compared to the conventional method. In addition, these methods have been stabilizing the efficiency of food preservation [20]. Unfortunately, it has the adverse effects on the quality of dried products in terms of colour changes, total phenolic content, antioxidant and flavonoid compounds [18].

Among the different drying methods, heat pump dryer has been known as one of the effective drying process that provides higher drying rate and ensures the product quality (more hygienic since it uses heat and operated in a closed chamber as compared to natural method) [21][22]. Heat pump dryer reportedly has been successfully used to dry various kinds of fruit and herbs products. Among the applications of heat pump in the drying of fruits are (not limited to) pear, papaya, mango [12], banana, kiwi [23] and herbs products such as Jew’s mallow, spearmint, parsley [24]. Drying of fruits and vegetables using a heat pump dryer is to observe an improvement in terms of quality of dried products, including microbial safety, colour and vitamin C retention [25]. Considering that C. nutans is vulnerable to thermal degradation, heat pump dryer presents a good drying method to reduce the moisture level in the leaves while maintaining the quality of the leaves.

Hence, this work aimed to investigate the drying characteristics of C. nutans leaves under the effects of operating temperature and air velocity using a heat pump dryer. The changes in product quality in terms of flavonoid compound (vitexin and orientin), vitamin C and total colour changes were evaluated too.

2. Materials and methods

2.1. Sample preparation

Fresh C. nutans leaves were obtained from the supplier TKC Herbal Nursery Sdn. Bhd. in Jalan Pantai, Jelebu, Seremban, Negeri Sembilan, Malaysia. The leaves were separated from plant stems and
rinsed with tap water. The leaves were then cut into an average size of 1.0 cm x 1.0 cm to get the uniform sample size. The leaves were kept in a fridge at 4 °C to preserve their freshness and also to slow down the physiological and chemical changes before commencing the drying experiment (Karaaslan and Tuncer 2008). Figure 1 (a) and (b) shows the fresh C. nutans and cut C. nutans leaves, respectively.

![Figure 1. (a) C. nutans leaves and (b) Fresh Cut C. nutans leaves](image)

2.2. Equipment
A heat pump dryer (iLab LT1000; The University of Nottingham, Selangor, Malaysia) was used in the drying experiment. The overall dimension of the dryer was 2.3 m (length) × 1.0 m (width) × 2.1 m (height). In general, the heat pump dryer was constructed with a heat pump system (evaporator, condenser, compressor, heat exchanger, and drying chamber) [26]. Figure 2 shows the heat pump dryer with two drying chambers.

![Figure 2. Heat pump dryer](image)

2.3. Drying protocol of heat pump dryer
A wash net was used to place the C. nutans leaves in the middle of the drying chamber of heat pump dryer. The air temperature and air velocity of each experiment were varied where the range of drying temperature was 40-60 °C and air velocity varied between 2.5-3.5 m/s (air was supplied in the direction perpendicular to the wash net). The air velocity were determined using anemometer (Model 471 B Digital Thermo Anemometer, Dwyer, U.S.A.). The mass removal of the C. nutans was measured at 2-minute intervals for the first hour of drying and 5-minute intervals for subsequent hour using an analytical balance (BP 6100 Sartorius, Cole-Parmer, United States). Drying was terminated when no further change in mass readings was obtained towards the end of drying, i.e. until the equilibrium moisture content (Xeq) was achieved [12]. All the data were recorded and repeated triplicate for each experiment.
2.4. Moisture content

Moisture content ($X$) in dry basis (d.b) was calculated based on the mass of bone dry. Dry solid mass and $X$ was obtained by placing the dried $C. nutans$ leaves inside the laboratory oven (MMM Group Ecocell, Planegg, German) for at least 24 hours at 105°C and weighed [27]. Equation (Eq. 1) was used to determine the $X$ with reference to the bone dry mass of the $C. nutans$ as according to AOAC [28].

$$X = \frac{(W_i - W_{bd})}{W_{bd}}$$  \hspace{1cm} (1)

where $W_i$ (g) refers to the initial mass and $W_{bd}$ (g) refers to the mass of bone dry $C. nutans$ leaves [29].

2.5. Drying kinetic

The drying kinetics was interpreted using the drying curve and drying rate curve. The drying curve was obtained from the variation of moisture ratio $MR$ as a function of time $t$ whereas the drying rate curve was attained from the variation of drying rate ($dX/dt$) with $MR$ [30]. The following equation, Eq. (2) was used to obtain the moisture ratio where $X_0$ and $X_{eq}$ are the initial moisture content and equilibrium moisture content, respectively.

$$MR = \frac{X-X_{eq}}{X_0-X_{eq}}$$  \hspace{1cm} (2)

Four models (table 1) commonly used for modelling of drying curves were chosen to fit the experimental data. Analysis with non-linear regression was performed using Microsoft Excel spreadsheet (Microsoft Office 2010, USA) using the SOLVER tool by minimizing the residual sum of squares. The values of the coefficient of determination ($R^2$), reduced chi-square ($X^2$), and root mean square error (RMSE) were compared to evaluate the fitness for all the models. A good fit to the data can be concluded in the presence of large values of $R^2$ and low values of $X^2$ and RMSE [30]. Eqs. (3) and (4) outline the calculations of $X^2$ and RMSE [31].

Table 1. Mathematical models applied to the drying curves.

| Model no. | Model name | Equation | Reference |
|-----------|------------|----------|-----------|
| 1.        | Page       | $MR = \exp (-kt^n)$ | Page [32] |
| 2.        | Handerson and Pabis | $MR = a\exp (-kt)$ | Handerson and Pabis [33] |
| 3.        | Two term exponential | $MR = a\exp (-kt) + (1-a)\exp(-kat)$ | Sharaf-Eldeen et al. [34] |
| 4.        | Midilli et al. | $MR = a\exp (-kt^n) + bt$ | Midilli et al. [35] |

$$X^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N-z}$$  \hspace{1cm} (3)

$$\text{RMSE} = \left[ \frac{1}{N} \sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2 \right]^{1/2}$$  \hspace{1cm} (4)

2.6. Product quality

2.6.1. Flavonoid retention (Orientin and Vitexin)

The $C. nutans$ leaves were extracted using the reflux method, which was usually used to determine bio-active compounds from herbal products [36]. The dried product was ground into fine powder form before commencing extraction. $C. nutans$ leaves powder was mixed with 70% methanol in a round bottom flask with a cooling condenser and boiled for 60 minutes. By using a vacuum pump, the
supernatant was filtered and then evaporated to obtain the crude extract. The extract was kept in a tight-glass bottle and stored inside a fridge for further analysis.

The presence of vitexin and orientin were determined using a Waters HPLC system (Milford, MA, USA) consists of Waters e2695, photodiode array model Waters 2998. A C18 reversed-phase Xbridge column (5 μm, 4.6 × 150 mm) was used for separation at 35°C. The mobile phase A contained 0.1% phosphoric acid in distilled water whereas the mobile phase B contained acetonitrile. Separation was achieved at the flow rate of 0.8 ml/min. The developed gradient program was as follows: 0 min – 5%B, 15.0 min – 35% B, 17.0 min – 5% B, 18.0 min – 5% B, and 12.0 min – 20% B. The injection volume was 20 µl and the data were integrated at the wavelength of 335 nm by Empower 3 software (Waters). Nylon filters (0.45 μm) were used to filter all samples before injection.

2.6.2. Vitamin C Content.
Vitamin C content was determined based on the AOAC [37], 16th Ed. 967.21 (STP/Chem/A) (ascorbic acid) method by a certified chemist.

2.6.3. Colorimetric parameters.
A chroma meter CR-400/410 (Minolta Co., Osaka, Japan) with the reflectance mode with D65 illuminant and 2° observer angle was used to measure the surface colour of the sample. The value of L*, a*, and b* are usually refer as brightness, redness, and yellowness, respectively. Such characterization was in accordance with the International Commission on Illuminant (Commission International l’Eclairage, CIE). Three readings were obtained from three different points of the samples and averaged. Differences in L*, a*, and b* were used to indicate the change in the colour parameters. Eq. (5) was used to determine the total colour change [38].

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\Delta E^* = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2}
\] (5)

3. Results and discussions
3.1. Drying characteristics
3.1.1. Effect of air temperature
The variation of the moisture ratio with drying time at different drying temperature for the C. nutans is demonstrated in Figure 3 (a – c). It can be seen that the increase of air temperature resulted in shorter drying duration, as reflected with the steeper decline of MR with time. The time taken to reduce the moisture content from initial moisture content to Xeq were 90, 210, and 300 minutes corresponding with the drying temperature 60 °C, 50 °C, and 40 °C, respectively, at air velocity of 2.5 m/s. At air velocity of 3.0 m/s and 3.5 m/s, the shortest and longest drying time were reported at 54 and 60 minutes (60 °C) and 160 and 210 minutes (40 °C), respectively. The observed trends of drying curves were supported with the similar findings reported by numerous researchers, where the drying time was much shorter when the drying air temperature was increased [39][12]. At elevated drying air temperature, more heat were transferred to the samples and accelerated the diffusion of moisture from inside the materials to the surface. This strengthened the drying force for moisture evaporation and subsequently led to complete drying [40]. As expected, the drying air temperature had a more significant effect on the drying curves of C. nutans as compared to air velocity.
3.1.2. Effect of air velocity.

Air velocity also influences the drying kinetic of *C. nutans*. The elevation of air velocity reduced the drying time as shown in Figure 4 (a-c). The steeper decline of MR curves indicated a shorter drying duration. It was postulated that the air turbulence from recirculating fan inside the dryer led to rapid water migration and moisture removal from sample surfaces. Higher air velocity enhanced the moisture loss through evaporation in samples and led to a higher drying rates and cut down the drying duration [41]. The findings aligned well with the similar observation trends reported by Promvonge et al. [42].
Figure 4. Moisture ratio Vs drying time at different air velocity in a heat pump dryer.

3.1.3. Effect of temperature and air velocity on drying mechanism.

Figure 5 display the drying rate curves of C. nutans leaves dried at varied temperature and air velocity, respectively. The drying rate curves in the figures can be characterized by initial, constant, and falling rate period, as normally found in other drying study [16]. The initial warming-up period was due to the heating of sample. At this period, the mass loss was due to the evaporation of moisture initially present on the sample surface. As the drying process progressed with time, the drying rate reduced due to the diminishing free moisture on the sample surface [39].

For this work, a constant drying rate was found to be at 0.017 g/g.min, 0.030 g/g.min, and 0.073 g/g.min at temperature 40 °C, 50 °C, and 60 °C, respectively at velocity 2.5 m/s. Meanwhile, the constant drying rate at velocity 3.0 m/s was 0.022 g/g.min, 0.037 g/g.min, and 0.085 g/g.min corresponding for the same temperature range (40-60 °C). At air velocity of 3.5 m/s, the constant drying rate were found to be 0.03 g/g.min, 0.02 g/g.min, and 0.083 g/g.min at temperature 40 °C, 50 °C, and 60 °C, respectively. During the constant drying rate period, on the C. nutans leaves surface, the movement of moisture from the interior to the sample surface and the loss of moisture from the sample surface to the air through evaporation are equivalent. Towards the end of the constant drying rate, the moisture from inside the sample has to be transported to the surface by capillary action or diffusion. This is known as a transition point or critical moisture content ($X_{cr}$) where the constant drying rate period ended [43].
As drying process continued, the remaining internal moisture movement within the materials has to be diffused through molecular diffusion and this phase was known as falling drying rate. Dry spots started appearing on the material surface due to the reduction of moisture on the surface through evaporation [43]. At this phase, the drying rate declined sharply within a short duration until approaching the $X_{eq}$ which the moisture on the surface of materials is entirely evaporated. Surprisingly, the constant drying rate period at temperature 40 °C and 50 °C (air velocity 3.5 m/s) was shorter than the rest. Such a short constant rate has also been observed in the study conducted by Velic et al. [44] for the drying of apple using a convection tray dryer. Though, the reasons contributed to this observation was unclear and it was suspected that the quality of the *C. nutans* samples could be the main factor.

As expected, the highest drying rate curves were observed at the highest temperature (60 °C) and air velocity (3.5 m/s) for each period of drying rate. An increment of temperature and air velocity resulted in increase moisture removal rate due to the increase in driving force (moisture gradient) between the inner and the leaves surface. Subsequent, a shortened drying time was attained due to the higher drying rate [26]. Similar findings also has been reported by Singh et al. [45] of drying Amaranth leaves under Greenhouse Type Solar Dryer.

![Figure 5](image)

**Figure 5.** Drying rate Vs moisture ratio at different temperature in a heat pump dryer.
3.2. Validation of drying models

Table 2 shows that the four drying models were fitted to the experimental data by performing non-linear regression analysis. The experiment fitting was conducted on the shortest drying time to validate the drying models. The fitting between the experimental drying data and the four predicted curves was shown in Figure 6. As shown in Figure 6, Midilli et al. [35] has the highest $R^2$ (0.9556). The other models were either over- or under-predict at high or low moisture content.

For the current study, given by its highest $R^2$, lowest RMSE values, and close match between the predicted and experimental data, the Midilli et al. [35] model was selected as the most applicable model for characterizing the drying kinetics of the C. nutans leaves for single layer drying process. The appropriateness of the models was additionally confirmed by the close match between the experimental and predicted data for the C. nutans at different drying temperatures and air velocity (3.5 m/s), as shown in Figure 7. The Midilli et al. [35] model has been reported to well-describe the drying kinetics of single layer foods and agricultural products such as the blackberry leaves [46], savory leaves [47], and Vernonia amygdalina leaves [48].

Table 2. Constant and statistical parameters obtained for different models at different temperatures and air velocity of 3.5 m/s.

| Models                      | Constant(best-fit values) | $R^2$ | $X^2$ | RMSE |
|-----------------------------|---------------------------|-------|-------|------|
| **T = 60°C**                |                           |       |       |      |
| Page                        | $k=1.84E-06$, $n=4.307$   | 0.8337| 0.652 | 0.012|
| Henderson and Pabis         | $k=0.0499$, $a=1.0791$    | 0.9036| 0.089 | 0.0016|
| Two term exponential Midilli et al. | $k=0.0140$, $a=0.9659$, $b=-0.0015$, $n=1.3252$ | 0.9556| 0.008 | 0.0002|
| **T = 50°C**                |                           |       |       |      |
| Page                        | $k=8.48E-02$, $n=0.8413$  | 0.7352| 0.013 | 0.0002|
| Henderson and Pabis         | $k=0.0615$, $a=0.9869$    | 0.6773| 0.001 | 0.0015|
| Two term exponential Midilli et al. | $k=0.0511$, $a=0.9999$, $b=-0.0006$, $n=0.7618$ | 0.7357| 0.003 | 0.0003|
| **T = 40°C**                |                           |       |       |      |
| Page                        | $k=5.23E-02$, $n=0.8441$  | 0.7240| 0.028 | 0.0003|
| Henderson and Pabis         | $k=0.0364$, $a=1.0025$    | 0.6455| 0.0001| 0.0006|
| Two term exponential Midilli et al. | $k=0.0299$, $a=0.9411$, $b=-7.315E-05$, $n=0.8672$ | 0.7153| 0.038 | 0.0004|
|                            |                           |       |       |      |
3.3. Flavonoid (Orientin and Vitexin) content after drying

The orientin and vitexin content of fresh and dried *C. nutans* leaves was tabulated in Table 3. The samples dried at velocity of 3.5 m/s was chosen for the analyse of flavonoid content which demonstrated the shortest drying time at those temperature (40 °C, 50 °C, and 60 °C). Overall, all the orientin and vitexin content increased after the drying process. This could be due to the extended drying duration (150 min for 40 °C) at lower temperature that reduced the chemical constituents in the products. Studied reported by Ng et al.[16] also that the vitexin content much higher in the product dried at highest drying rate and short drying time. In addition, the elevated temperature may lead to the decrease of enzymatic activity of polyphenol oxidase enzyme, resulting in lower degradation of flavonoid content [49]. Subsequently, the shorter drying period and higher temperature managed to retain the vitexin compounds in the dried *C. nutans* leaves.

On the other hand, the orientin content was found to be higher at the lowest temperature (40 °C). Such observation could be due to the reason that the orientin content was preserved better at lower drying temperature [16]. According to Davey et al. [50], heating may degrade L-ascorbic acid which...
affects cell wall integrity and cause leakage of some flavonoid compounds. Madrau et al. [51] stated that the stability of flavonoid content could be altered by factors due to the breakdown or migration by chemical reactions including oxygen, enzymes and light. A high drying heat tend to obtain a lower orientin content, which indicated that drying at lower temperature would be able to preserve the orientin content [16].

Interestingly, the vitexin and orientin content in dried product was higher than in fresh C. nutans which contradicted with the study conducted by Munirah et al. [18] where the flavonoid compounds decreased after drying process. On the other hand, Tasirin et al. [30] reported that the composition of essential oil of kaffir lime leaves was slightly higher in dried product than in fresh product. With the heat pump dryer, the vitexin and orientin content can be preserved even exposed to long period of heat (at 40 °C) or higher temperature (60 °C) without compromising the product quality. These findings have proved that heat pump dryer could preserve the flavonoid contents of C. nutans.

### Table 3. Flavonoid (orientin and vitexin) content between fresh and heat pump dried C. nutans at u=3.5 m/s.

| Type of C. nutans | Vitexin (%w/w) | Orientin (%w/w) |
|------------------|---------------|-----------------|
| Fresh            | 0.33          | 2.77            |
| Dried            |               |                 |
| Heat pump (40 °C)| 3.17          | 11.69           |
| Heat pump (50 °C)| 3.20          | 10.35           |
| Heat pump (60 °C)| 3.54          | 10.55           |

### 3.4 Vitamin C content after drying

Table 4 shows the vitamin C (ascorbic acid) content of fresh and dried C. nutans at different temperature and air velocity of 3.5 m/s (which performed the highest drying rate). According to Santos and Silva [52], temperature was the predominant factor in the drying process that had a significant impact on the vitamin C content. It was found that the vitamin C content was higher in the product dried at 50 °C. This could be due to the exposure of heat at 60 °C led to the loss of vitamin C. Meanwhile, exposing the samples in the long drying duration at 40 °C also led the loss of vitamin C [53]. The highest retention of vitamin C content was preserved at 50 °C at 90.7%. Such finding indicated that the vitamin C was susceptible to the heat and drying period. Higher degradation of vitamin C occurred in the sample dried at higher temperature (heat pump drying at 60 °C) albeit at a shorter drying duration [52]. On the other hand, prolonged heating at lower temperature (heat pump drying at 40 °C) still degraded the vitamin C too. Khraisheh et al. [54] showed that the vitamin C content decreased with the increase in processing time.

### Table 4. Comparison of vitamin C content between fresh and heat pump dried C. nutans at air velocity of 3.5 m/s.

| Type of C. nutans | Vitamin C content (mg/100 g) |
|------------------|-------------------------------|
| Fresh            | 6.12                          |
| Dried            |                               |
| Heat pump (40 °C)| 4.90                          |
| Heat pump (50 °C)| 5.55                          |
| Heat pump (60 °C)| 4.90                          |
3.5. Colour changes of C. nutans after drying

Colour is a necessary product quality determination that consumers will consider before purchasing the food since it represents the first visual response [12]. The colour parameters used to compare the fresh and dried C. nutans subjected to three different drying temperature were shown in Table 5. Ng et al. [16] claimed that higher $L^*$ values were preferable for drying of leaves product as it indicated the preservation of leaves brightness. Current study showed that the heat pump drying at 50 °C demonstrated the lowest total colour change ($\Delta E$), which was 5.42 and the highest value of $L^*$ parameter (34.91) was the closest to the fresh C. nutans (35.09). Exposure at high temperature (60 °C) led to increase total colour change and $L^*$ values albeit a short period of drying time were observed during elevated temperature. The prolonged drying duration (40 °C) also led to the highest total colour change and low $L^*$ values, even though the samples have been exposed to lower temperature. Similar findings also have been reported by numerous researches when exposure at high drying temperature and prolonged drying time could lead to more colour changes [12]. This phenomenon could be due to the oxidative effect that turned the sample to more yellowish. The effect of the oxidative effect were discoloration, reduction in the nutritional value and solubility, the presence of off-flavour, and textural changes [12]. Hence, the operating condition that maintained the colour of the C. nutans will at the same time help to retain the nutritious compounds too [53]. In general, longer drying time and exposure to excessive heat will result in greater pigment losses.

Table 5. Colour parameters of fresh and dried C. nutans by Heat pump dryer at different temperature and air velocity (3.5 m/s).

| Leaves     | Temperature (°C) | $L^*$     | $a^*$       | $b^*$       | $\Delta E^*$ |
|------------|------------------|-----------|-------------|-------------|--------------|
| C. nutans  | Fresh            | $^{a}35.09\pm0.47$ | $^{a}-14.27\pm0.97$ | $^{a}17.09\pm1.98$ |              |
|            | 40 °C            | $^{a}28.92\pm1.23$ | $^{a}-8.44\pm0.11$ | $^{a}19.13\pm0.53$ | 8.69         |
|            | 50 °C            | $^{a}34.91\pm0.31$ | $^{a}-10.01\pm0.61$ | $^{a}20.56\pm1.08$ | 5.42         |
|            | 60 °C            | $^{a}30.74\pm1.11$ | $^{a}-9.56\pm1.11$ | $^{a}19.64\pm1.74$ | 6.80         |

*Mean values ± standard deviation (n=3 replication) within the same sample.

4. Conclusion

The heat pump dryer was able to dry the C. nutans leaves in a much shorter time when the highest drying air temperature (60 °C) and velocity (3.5 m/s) without compromising the quality of the dried product in terms of flavonoid content, vitamin C, and total color changes. The drying duration was reduced from 300 minutes to 54 minutes when the air temperature (from 40 °C to 60 °C) and air velocity (from 2.5 m/s to 3.5 m/s) were increased. This implies that the increment in temperature and air velocity were governed by the drying force for moisture evaporation and led to faster drying rate. The Midilli et al. model demonstrated the best fit to the experimental data compared to the other existing models. In terms of vitexin and orientin content, the highest preservation was found at temperature 60 °C and 40 °C, respectively. From the aspects of vitamin C content and total colour change, heat pump drying at 50 °C (3.5 m/s) noticeably reported the highest retention rate, with only 9.3% and 5.4% loss of vitamin C and total colour change, respectively. This revealed that heat pump dryer could be used to dry the C. nutans leaves without compromising the product quality.

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