International Journal of Postharvest Technology and Innovation

ISSN online: 1744-7569 - ISSN print: 1744-7550
https://www.inderscience.com/ijpti

Effect of storage conditions and temperature on dried lemon myrtle leaves quality

Ainaa Abdul Kahar, Ong Sze Pheng, Nicholas J. Watson, Law Chung Lim

DOI: 10.1504/IJPTI.2022.10050970

Article History:

Received:	30 April 2020
Last revised:	09 February 2022
Accepted:	21 February 2022
Published online:	03 October 2022

Effect of storage conditions and temperature on dried lemon myrtle leaves quality

Ainaa Abdul Kahar, Ong Sze Pheng, Nicholas J. Watson and Law Chung Lim*

Department of Chemical and Environmental Engineering,
Faculty of Science and Engineering,
University of Nottingham Malaysia,
Jalan Broga, 43500 Semenyih,
Selangor, Malaysia
Email: kebx6aak@nottingham.edu.my
Email: sze-pheng.ong@nottingham.edu.my
Email: Nicholas.Watson@nottingham.ac.uk
Email: chung-lim.law@nottingham.edu.my
*Corresponding author

Abstract: The impact of various packing conditions and storage temperatures on the colour and biochemical content of lemon myrtle leaves (LML), dehydrated using different drying processes is presented in this research. LML were dried and stored using a heat pump dryer, an oven and a vacuum dryer. The dried LML was subjected to quantitative tests on radical scavenging activity, total phenolic content and ferric reducing antioxidant power on a monthly basis for six months after drying was performed. Normal and vacuum packaging were used to package the dried LML, and each pack was stored at either ambient temperature of 25°C (RT) or chilled at 4°C. As a comparison to non-vacuum packed LML, vacuum packing resulted in greater colour and biochemical content preservation. For the heat pump dried sample, this technique paired with storage at a cold temperature (4°C) resulted in greater retention of its green colour, total phenolic content, radical scavenging activity and ferric reducing antioxidant power percentages (49%, 72%, and 56%, respectively). The vacuum dried sample, on the other hand, had the lowest colour and biochemical content retention in vacuum packing, and the similar pattern was seen in the oven dried and heat pump dried samples.

Keywords: oven drying; heat pump drying; vacuum drying; biochemical content; storage; vacuum packaging; lemon myrtle leaves; LML.

Reference to this paper should be made as follows: Kahar, A.A., Pheng, O.S., Watson, N.J. and Lim, L.C. (2022) 'Effect of storage conditions and temperature on dried lemon myrtle leaves quality', *Int. J. Postharvest Technology and Innovation*, Vol. 8, No. 4, pp.292–312.

Biographical notes: Ainaa Abdul Kahar is a research scholar under the guidance of Prof. Ir. Dr. Law Chung Lim. Her main interests focus on drying of agricultural products for maximum biochemical retention. She is a PhD graduate from the Department of Chemical and Environmental Engineering, Faculty of Science and Engineering, University of Nottingham Malaysia.

Ong Sze Pheng is an Associate Professor of Chemical Engineering. She works at the University of Nottingham Malaysia and her research areas are mainly in industry drying, food microstructure, processing of phytochemicals and edible antioxidants, product development, process optimisation and simulation.

Nicholas J. Watson is an Assistant Professor in Department of Chemical Engineering, University of Nottingham, UK. His research is focused on optimisation of industrial processes using non-invasive sensor technology.

Law Chung Lim is a Professor of Chemical and Process Engineering. He works at the University of Nottingham Malaysia and his research interests include product dehydration and preservation, advanced drying technology, fluidised bed technology, food quality and safety, dimensionless analysis and scale up, diffusion and application of drones in agriculture and chemical industry.

1 Introduction

Lemon myrtle, also known as *Backhousia citriodora*, is a native Australian rainforest tree. After its first release in Malaysian fields in 2009, this tea-tree-like plant has become successfully established (Sandrang et al., 2013). This plant has a distinct fragrance and flavour that is reminiscent of a combination of lemon, lemongrass, and lime (Sultanbawa, 2016). Citral is found in abundance in lemon myrtle (90% to 98%) (Sandrang et al., 2013). Lemon Myrtle is also widely utilised as a dried herb flavouring ingredient in herbal tea and permitted as a food category in European Union (Sultanbawa, 2016). lemon myrtle leaves (LML) has two possible uses in Malaysia: the fresh leaves can be used for essential oil extraction and dehydrated LML obtained by drying of the LML leaves. Many useful products for cosmeceutical and nutraceutical applications may be produced from these semi-finished materials. Lemon Myrtle is therefore seen as a Malaysia's potential crop due to its wide applicability in the local industry (Sandrang et al., 2013). Malaysia now contains 10 acres of Lemon Myrtle. The leaves are either freshly processed for essential oil production or dried and exported for nutraceutical and pharmaceutical goods to countries such as the United States and Germany (AgriFutures Australia, 2017). Some of the dried leaves are also used for functional products development LML add values to the functionality of indigenous agricultural products.

Foods are dried for a variety of reasons, including preservation, extending the shelf life of a product, making transportation easier, and adding value to the product. The transport of the drying medium into the process, whether via convection, conduction, radiation, or volumetrically, distinguishes drying processes. Generally, conventional hot air dryers are used for food drying, particularly on a larger scale (Achariyaviriya et al., 2000; Oliveira et al., 2015). Wu et al. (2013) reported that the antioxidant components in *Angelica sinensis* leaves are greatly impacted by drying temperature. As the temperature rose, biochemical activities dropped. As a result, heat-sensitive crops should be dried at a low temperature to retain quality (in terms of bioactive component retention) and limit the risk of microbial contamination associated with prolonged drying times (Hossain et al., 2013). Low temperature drying methods such as heat pump dryers (HPDs) have the potential to function more effectively at lower temperatures than traditional dryers such

as hot air dryers since their drying temperature is considerably lower than the standard drying technique. Moreover, unlike traditional air dryers, in a closed cycle, it may absorb and reuse the heat from circulating air, and the water vapour's latent energy is recovered throughout the process of drying (Brushlyanova et al., 2013). HPDs are used to preserve a variety of heat-sensitive products, including lemongrass (Fadhel, 2014); mint leaves (Ceylan and Gürel, 2016) and *Moringa oleifera* (Potisate et al., 2015). Due to the possibility of controlling drying conditions (Strømmen et al., 2002), HPDs are used to maintain bioactive substances that are heat sensitive and volatile (citral in the case of LML), allowing the leaves to retain the majority of their phytochemical qualities after drying. Vacuum drying is another option for protecting heat-sensitive materials. Heat-sensitive materials may be dried in a vacuum environment, allowing for moisture evaporation at lower drying temperatures. Furthermore, since the lack of air in the drying chamber during dehydration reduces oxidation processes, vacuum drying may protect the drying material from degradation due to oxidation. Alibas (2007) and Therdthai and Zhou (2009) applied vacuum drying and compared its performance with convective drying in dehydrating nettle leaves and mint (*Mentha cordifolia* Opiz ex Fresen) leaves. Both reported that vacuum drying could preserve the colour better than convective drying. Better colour retention is a good indication of high biochemical content retention. Argyropoulos and Müller (2014) reported that when dried at 30°C and 25 mbar, vacuum drying yielded the least amount of essential oil recovery of lemon balm (*Melissa officinalis* L.), specifically the amount of neral and geranial.

LML includes bioactive components, which are easily destroyed during processing, particularly drying. As a result, it's critical to use the right drying procedure in order to protect and keep the bioactive ingredient's activity once it's dried or processed, or else the functionality would be lost. This, in turn, has an impact on the product's quality. To retain the quality of LML and their volatiles in this research, the leaves were dehydrated using a heat pump, a vacuum pump- and oven-drying. The effects of the three drying techniques on the bioactive component retention were examined.

Water migration, oxidation, and degradation of active chemicals or volatile compounds might occur during storage, jeopardising the dried product's quality. As a result, vacuum packing may be used to protect and maintain the quality of dehydrated items. The goal of vacuum packing is to exclude oxygen from the container, preventing oxidation and bacteria or fungal development, and so extending the shelf life of the dried food. Vacuum packing may also aid in the reduction of volatile component losses (Joubert et al., 2010). Whereas, another report by Araújo et al. (2017) stated that, all nutritional constituents in hot air dried kale reduced after 5 months of storage, but lower drying temperatures (40°C) resulted in increased chlorophyll content, total phenolic content (TPC), vitamin C retention and total antioxidant capacity (i.e. 48, 38, 62, and 92%, respectively). Furthermore, it was discovered that vacuum packing made no significant impact in terms of vitamin C, TPC, or TAC retention, independent of the hot air drying temperature.

Storage conditions also affect other quality parameters of dried products including colour, essential oil and biochemical properties (Chong and Lim, 2012). For instance, Baritaux et al. (1992) reported that after 7-months of storage, there was a significance decrease in methylchavicol and eugenol content with reduction of essential oil yield up to 66% in hot air dried basil (*Ocimum basilicum L.*). Arabhosseini et al. (2007) studied the

long-term storage effect on the colour of tarragon leaves dried at different drying conditions. It was reported that colour parameters did change during the storage period and were thought to be impacted by moisture content, where greater moisture levels may result in higher colour changes during storage. Korus (2011) reported the effect of storage temperature [cold temperatures (8ºC–10ºC) and ambient (18ºC–20°C)] on the content of biochemicals in *Brassicca oleracea* L. var. acephala leaves dried by using convective drying and freeze drying. After 12 months of storage, antioxidant retention was shown to be higher in dried leaves kept at a colder temperature. Thus, proper selection of conditions of storage contributes to the quality preservation of dried food products.

LML are usually dried by hot air drying, which involves blowing hot air into the drying chamber at a temperature of 40ºC and the moisture content is reduced over a longer period of time (Sandrang et al., 2014). The quality of dried leaves, notably their colour qualities, tends to deteriorate with time, increasing the danger of biochemical content degradation and volatile component loss (Buchaillot et al., 2009; Saifullah et al., 2019). All items, whether bio-origin or non-bio-origin, may be dried. The choice of drying process is critical since the bioactive components may be damaged if the wrong drying method is used. As a result, the purpose of this research is to see how different drying processes affect the quality of LML. To retain the quality of LML and maximise the preservation of biological compounds in the dried leaves, it is essential to select the most effective drying procedure and conditions of storage. Therefore, the aims of this study are;

1 to analyse the effect of storage temperature (room temperature and chilled) on quality of dehydrated LML (subjected to oven-, heat pump- and vacuum drying) throughout six month storage

2 to analyse the effect of packaging condition (with and without vacuum packed) on quality of dried LML during storage.

2 Materials and methods

2.1 Sample

Freshly harvested LML (variety: Linpinwood B.) were collected at Malaysian Agricultural Research and Development Institute Research Station in Selangor, Malaysia and utilised for the drying experiment the same day. Before being collected, the LML were guaranteed to be 3 months old. Before drying, the leaves were removed from the stalks.

2.2 Drying of LML

A total of five hundred g of LML samples (90 mm x 30 mm x 1 mm) were dehydrated using three methods:

1 oven

2 heat pump

3 vacuum drying.

In the dryer, samples were put on a tray (W: 26.5cm x L: 45.5cm x H: 10cm). The drying experiment was repeated three times. The samples were weighed every fifteen minutes for the first three hours, every thirty minutes for the following three hours, and every two hours after that until a consistent weight was established using a digital scale (Mettler Toledo, Switzerland). For further investigation, the dried materials were kept in airtight plastic containers in a dark at room temperature (25°C).

2.2.1 Heat pump drying

The fabricated dryer was designed and built by i-Lab Sdn. Bhd (Selangor, Malaysia). The HPD removes the moisture from a sample by blowing heated air (45°C) through the drying chamber. The heat is then transferred to the refrigerant when the moist air travels through the evaporator coils in the system. As a consequence, the temperature of the drying air is reduced. The air is cooled to the dew point, and additional cooling causes water to condense. As a consequence, dehumidified air is produced. The dehumidified cold air is then brought into contact with the heat pump system's condenser. The cooled air near the condenser absorbs the heat from the condenser, raising its temperature. The relative humidity of the drying air is further reduced by raising the temperature of the dehumidified air. The drying chamber is then charged with dehumidified drying air (at 45°C). The closed loop system continues its cycle until the sample moisture is at equilibrium.

2.2.2 Oven drying

OD (Memmert, Germany) was performed at 50°C. As suggested by Buchaillot et al. (2009), the optimal temperature of drying for maximum citral retention in LML is 50°C. The temperature selection is also based on a previous study carried out by Buchaillot et al. (2009), who reported that the optimised temperature for oven-drying is 50°C for retention of biochemical content.

2.2.3 Vacuum drying

A vacuum oven (Model V200; Memmert, Germany) was used to dry the samples at a temperature of 50°C and vacuum pressure of fifty mbar. The vacuum oven's pressure and temperature range from 5 to 1100 mbar and 20°C to 200°C, respectively. The vacuum oven has a working output of 1200 W and drying chamber's dimension is 550 x 600 x 400 mm. The vacuum oven has a digital pressure display that shows the vacuum pressure in mbar.

2.3 Conditions of storage

After the LML leaves were dried using the three drying processes, the dried samples were cooled before being packaged to minimise condensation. Each drying procedure (OD, VD, and HPD) yielded 2 g of dried samples, which were wrapped in bags composed of polyethylene with a 0.04 mm thickness. Normal packaging and vacuum packaging were used to pack dried LML leaves in two distinct ways. The bags were vacuum packed using a vacuum sealer (Model: DZ-400/2ES; Fullwell, Malaysia) for 10 seconds at 1 mbar.

Both packing conditions were stored at two distinct temperatures: cooled (at a temperature of 4°C–6°C) and ambient temperature (25°C).

2.4 Determination of quality parameters

Moisture content, colour parameters and TPC were recorded from the samples in this work. The data were further analysed and also subjected to statistical analysis.

2.4.1 Moisture content

Using the oven drying technique, the moisture content of the dried samples was determined (Model: UF750, Memmert, Germany). The dried samples were dried until they attained a consistent weight in a 105°C oven (AOAC, 1990). For dried materials, the weight is considered as the bone dry weight. The moisture content of the drying samples was then determined at various drying periods.

2.4.2 Colour assessment

A colorimeter was used to determine the colour of the dried samples (HunterLab ColorFlex EZ). The colour values (L*, a*, and b*) are used to evaluate colour. The negative or positive a* value indicates the sample's greenness or redness; the value of L*, which ranges from 0 (darkness) to 100 (lightness) and the b* value indicates the sample's colour, which ranges from blue (negative b* value) to yellow (positive b* value), respectively.

To evaluate the colour changes using different types of drying, the saturation index or chroma, hue angle and browning index were calculated by using equation (1) to equation (4) (Oliveira et al., 2015).

$$Chroma = \sqrt{a^{*2} + b^{*2}} \tag{1}$$

$$Hue\ angle = \tan^{-1}\frac{b^*}{a^*} \tag{2}$$

$$Browning\ index = \frac{100(X - 0.31)}{0.17} \tag{3}$$

where

$$X = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*} \tag{4}$$

2.4.3 Biochemical analysis

2.4.3.1 Materials

Folin-Ciolcalteau phenol reagent, ascorbic acid, gallic acid, sodium carbonate (Na2CO3), 2,4,6-tripyridyl-s-triazine (TPTZ), iron (III) chloride hexydrate (FeCl3.6H2O), sodium acetate trilydrate, 1-1-diphenyl-2-picrylhydrazyl (DPPH), methanol, acetic acid, pentane and hydrochloric acid were procured from Sigma-Aldrich (Missouri, USA). Ultrapure water was obtained from a Milli-Q water purification system (Pall C, IL, USA).

2.4.3.2 Extraction for biochemical assays

The dehydrated sample was extracted by heating one gram of dried LML in a water bath at 55°C for 10 minutes with 10 mL deionised. The solution was centrifuged for ten minutes at 10,000 rpm (Model: Centrifuge 5810 R, Eppendorf, Germany). The supernatant was filtered using Whatmann No. 1 filter paper and kept at –20°C for subsequent analysis.

2.4.3.3 Total phenolic content

The TPC was measured using the Folin–Ciocalteu technique described in Abd Razak et al. (2017), with certain modifications. For 3 to 8 minutes, 5 mL Folin–Ciocalteau reagent was allowed to react with 1 mL extract before being reacted for two hours at room temperature with 4 mL 7.5% (w/v) sodium carbonate. The mixture's absorbance was measured using a spectrophotometer (Model: Cary 50 UV-Vis, Varian, USA) at 765 nm, and represented as mg of Gallic Acid Equivalent (GAE)/g sample.

2.4.3.4 Radical scavenging activity

The extract's radical scavenging activity was measured using the technique published by Thaipong et al. (2006), with certain modifications. A total of 0.15 mL extract was treated for 30 minutes in the dark with 2.85 mL of DPPH working solution. The following equation, equation (5) was used to calculate the scavenging activity:

$$DPPH\ radical\ scavenging\ activity\ (\%) = \frac{A_{blank} - A_{sample}}{A_{blank}} \times 100 \quad (5)$$

where

A_{blank} = Blank sample's absorbance

A_{sample} = Sample's absorbance.

2.4.3.5 Ferric reducing antioxidant potential

The assay was completed according to the method described in Benzie and Strain, (1996), with some alterations. A mixture of 25 mL acetate buffer, 2.5 mL TPTZ (2,4,6-tripyridyl-s-triazine) solution, and $FeCl_3.6H_2O$ solution were used to make the working solution for this test. Before the ferric reducing antioxidant potential (FRAP) assay, the working solution was warmed to 37°C. Then, in the dark, extract (0.15 mL) was mixed with FRAP solution (2.85 mL). After 30 minutes, the absorbance of the mixture was measured at 593 nm using a spectrophotometer. The value of FRAP is represented as mg ascorbic acid equivalent (AAE)/g sample.

Table 1 Moisture content after drying (at month 0) until month six of storage for fresh, oven-, heat pump- and vacuum-dried LML

Samples	*Storage condition*	*Month of storage*						
		0	*1*	*2*	*3*	*4*	*5*	*6*
Fresh	Before drying	63.27 ± 4.66						
OD	After drying	11.10 ± 0.09^{b}						
HPD		10.31 ± 0.11^{a}						
VD		9.88 ± 0.19^{b}						
OD	NRT		11.31 ± 0.4^{a}	11.53 ± 0.19^{a}	11.3 ± 0.32^{a}	9.97 ± 0.41^{a}	10.37 ± 0.18^{a}	9.96 ± 0.28^{a}
	VRT		10.97 ± 0.21^{a}	11.17 ± 0.11^{a}	10.81 ± 0.22^{ab}	9.87 ± 0.11^{a}	9.66 ± 0.38^{a}	9.28 ± 0.17^{a}
	NCH		10.73 ± 0.46^{a}	11.62 ± 0.32^{a}	11.65 ± 0.14^{a}	10.81 ± 1.21^{a}	9.89 ± 0.89^{a}	9.24 ± 0.65^{a}
	VCH		10.22 ± 0.11^{ab}	11.13 ± 0.61^{a}	11.05 ± 0.12^{a}	10.16 ± 0.53^{a}	10.64 ± 0.53^{a}	9.08 ± 0.59^{a}
HPD	NRT		12.13 ± 0.52^{a}	12.05 ± 0.16^{a}	12.19 ± 0.23^{a}	9.42 ± 0.07^{a}	10.16 ± 0.78^{a}	10.17 ± 0.13^{a}
	VRT		11.17 ± 0.31^{a}	11.09 ± 0.16^{a}	11.02 ± 0.27^{a}	9.38 ± 0.6^{a}	9.63 ± 0.2^{ab}	9.65 ± 1.09^{a}
	NCH		11.76 ± 0.46^{a}	11.25 ± 0.24^{a}	11.82 ± 0.62^{a}	10.65 ± 0.15^{b}	10.78 ± 0.57^{a}	9.31 ± 0.85^{a}
	VCH		10.83 ± 0.26^{ab}	11.14 ± 0.48^{a}	11.36 ± 0.18^{a}	10.42 ± 0.45^{ab}	9.82 ± 0.86^{a}	8.63 ± 0.38^{ab}
VD	NRT		9.62 ± 0.02^{a}	10.38 ± 0.07^{a}	10.19 ± 0.21^{a}	8.95 ± 0.09^{a}	8.75 ± 0.47^{a}	8.99 ± 0.31^{a}
	VRT		9.48 ± 0.08^{a}	10.16 ± 0.52^{a}	9.63 ± 0.5^{a}	9.1 ± 0.35^{a}	8.69 ± 0.05^{a}	8.53 ± 0.23^{a}
	NCH		9.42 ± 0.16^{a}	10.58 ± 0.14^{a}	10.82 ± 0.26^{a}	9.43 ± 0.71^{a}	10.67 ± 0.97^{a}	9.00 ± 0.04^{a}
	VCH		9.23 ± 0.35^{a}	10.06 ± 0.31^{a}	9.97 ± 0.3^{a}	9.99 ± 0.03^{a}	10.06 ± 1.24^{a}	7.93 ± 0.02^{a}

Notes: OD, oven drying, HPD, heat pump drying, VD, vacuum drying, NRT, stored at room temperature in normal packaging, NCH, stored at chilled condition in normal packaging, VRT, stored at room temperature in vacuum packaging, VCH, stored at chilled condition in vacuum packaging. Values are means of three (3) replications ± standard deviation. Values with the same letter are not substantially different ($p > 0.05$).

2.5 Statistical analysis

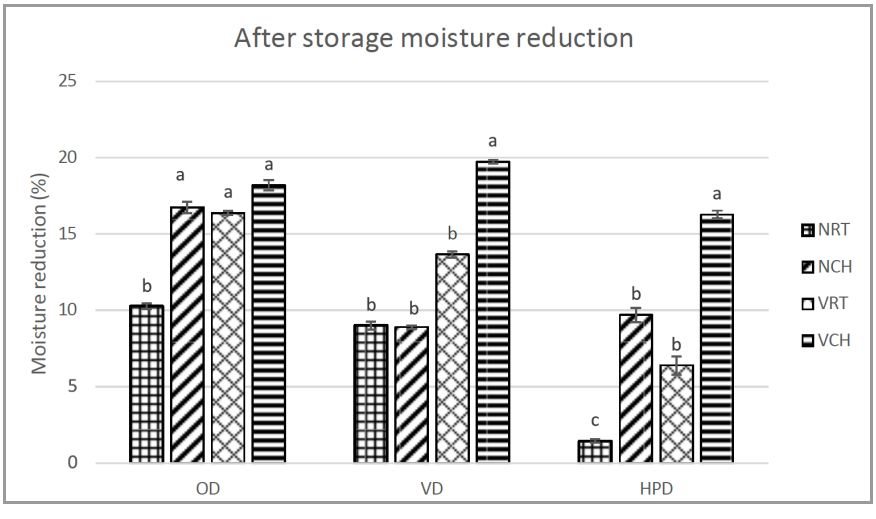
The data was analysed using a two-way ANOVA and Tukey's honest significance difference (HSD) test at $p < 0.05\%$ using SAS software (Version 9.4, S.A.S. Institute Inc. Cary, North Carolina, USA). All data are expressed as mean ± standard deviation.

3 Results and discussion

3.1 Moisture profile and final moisture content of dehydrated LML after six months of storage

Table 1 displays the final content of moisture in dried LML after each of the three respective drying techniques. Table 1 also displays the moisture fluctuation profile from the first month of storage to the sixth month of storage. Before storage, the moisture level of the dried sample varied from 9.88 to 11.10%, whereas the moisture content of the fresh sample was 63.27 to 4.66%. Depending on the temperature of the storage environment and the packing quality, the stored samples revealed variable degrees of moisture loss during storage. The three different dehydrated samples that were kept in vacuum packing under cold conditions (VCH) showed the greatest drop ($p < 0.05$) in moisture content after six months of storage. Regardless of the conditions of storage, the drying processes had a significant ($p < 0.05$) impact on the changes in sample moisture content during storage. The storage humidity values in the various kinds of storage bags used in this investigation could be linked to observed fluctuations in the sample's moisture content. The similar finding was observed by Norawanis et al. (2018), who found a decrease in moisture content in *Orthosiphon stamineus* dried leaf samples after 8 weeks of storage in plastic bags and glass containers.

Figure 1 Reduction of moisture after six months of storage in various conditions of storage of storage for HP, OD, and VD



Note: The standard deviation is indicated by vertical bars, and values with the same letter are not substantially different ($p > 0.05$).

After six months of storage, moisture levels in vacuum-, oven- and heat pump dried LML had decreased. Figure 1 also shows the moisture reduction variation for various packing and storage temperatures. As indicated in Figure 1, VD samples had the maximum moisture decrease of 19.9% after six months of storage, compared to HPD samples, which had a moisture reduction of 16.29%. This finding indicates that after six months of storage, temperature and packing have a substantial impact on the moisture level of dried LML. This is similar to finding by Ji and Pi (2012) that reported the impact of a two-month storage duration on the content of moisture of sun- and oven-dried okra kept in a dry and dark environment, over a fire. Moisture loss was seen in the sample held at 30°C and 60% relative humidity.

When comparing storage at chilled conditions and room temperature in Figure 1, it can be seen that samples kept at lower temperature condition absorbs more moisture from the surrounding, resulting in larger moisture decrease in the chilled condition samples. Figure 1 shows that HPD samples had a smaller moisture decrease ($p < 0.05$). These results might be owing to the HPD sample's cell structure being less altered. The original complete and regular form of parenchyma cell structures of the HPD sample is better preserved with less modification to the dried product's structure. The cell structure of LML exposed to OD and VD, on the other hand, was more damaged and altered, making the structure unable to hold moisture, and therefore the moisture was quickly evaporated from the dry LML. As a result, the moisture decrease in OD and VD samples is greater. In comparison to convective drying, Klungboonkrong et al. (2018) and Tummanichanont et al. (2017) found that HPD is a superior drying technique for keeping a regular and fuller form of the structure of parenchyma cells in *Orthosiphon aristatus* and *Andrographis paniculata*. However, more moisture loss was reported in the NCH and VCH samples, indicating decreased absorbed moisture from the storage environment. This result is consistent with Razak et al. (2018)'s findings, which reveal that *O. stamineus* powder held at 25°C had a greater moisture content than powder stored at 10°C after been kept in storage for four weeks. Due to the lower relative humidity at a temperature of 10°C, it is a better alternative to higher storage temperature as it produces a larger humidity gradient, making moisture removal easier. As a result, it can be concluded that keeping dried samples in a cold environment prevents the samples from absorbing moisture from the storage environment and instead reduces their moisture content. As a result, the sample is kept at a low moisture level. This is crucial for extending the sample's shelf life.

3.2 Impact of storage temperature and packing on dried LML quality

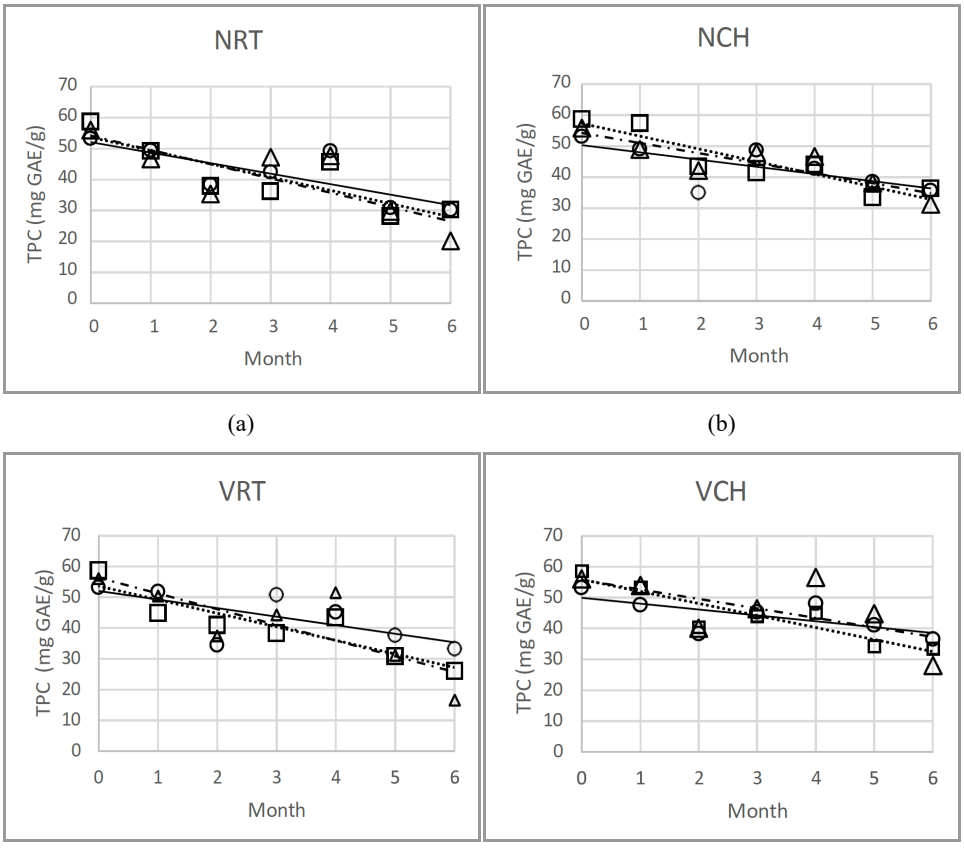
3.2.1 Impact on bioactive compound

3.2.1.1 Total phenolic content

Phenolic molecules account for 80% of the total antioxidant capacity in plant materials (Podsędek, 2007). Figure 2 shows the TPC of heat pump, oven and vacuum dehydrated LML throughout storage at 1-month intervals. Figure 2 also demonstrates how TPC content varies depending on conditions of storage. Figure 2 shows that throughout the six month storage period, the quantity of TPC in all conditions of storage decreases. Figure 2(a) demonstrates that VD samples had a larger TPC decrease than OD and VD samples. Figures 2(b), 2(c), and 2(d) all show the same pattern (d). In all conditions of storage, vacuum dried samples exhibit the most reduction of TPC value after six months. For

samples kept in NRT, VRT, NCH and VCH, the value of TPC loss ranged from 55.98 to 20.19, 16.54, 31.32 and 27.9 mg GAE/g sample, respectively. Meanwhile, as compared to other methods, TPC retention from HPD samples is the lowest. From a value of 53.2 mg GAE/g sample (initial value), the TPC were only decreased to 30.19, 35.8, 33.13, and 36.49 mg GAE/g sample under NRT, NCH, VRT, and VCH conditions of storage.

Figure 2 Value of TPC after drying and storage of one to six months of different dehydrated LML



(a) (b)

(c) (d)

Notes: O: HPD; : OD; Δ: VD

The HPD sample in vacuum packaging held at cold temperature (VCH) had retained the maximum TPC value after six months storage, whereas VD samples vacuum-packed and stored at ambient temperature had the lowest TPC retention (VRT). Samples held at lower temperatures, regardless of drying procedures, tend to preserve greater TPC values than those stored at room temperature. The findings show that the storage temperature had an impact on retention of TPC during storage. This is owing to the fact that a cold environment is not favourable to enzyme processes, which might lead to the breakdown of herbs' biochemical content. Mediani et al. (2014) examined dehydrated *Cosmos caudatus* by freeze- and air drying held at low (–20°C) and room temperature, finding that low temperature storage retained more TPC than room temperature storage. This is

due to the fact that higher temperatures (such as room temperature) might stimulate enzymatic processes, causing bioactive substances to degrade during storage. This is also similar to report by Phahom et al. (2017) that reported after 180 days of storage of dried *Thunbergia laurifolia*, the TPC values dropped while stored at higher temperatures.

Table 2 demonstrates the mean TPC values after six months of storage, as well as the substantial interconnection between storage types and conditions of storage on TPC value. Table 2 shows the types of dryers and the conditions of storage's interaction to highlight how these two major factors affect TPC retention after storage. As demonstrated in Table 2, HPD samples have the greatest TPC value whereas VD samples have the lowest, independent of conditions of storage of storage. Among the storage settings, samples stored in chilly temperatures (CH) retain TPC values better, independent of drying procedures. Table 2 further reveals that the drying process and storage condition have a significant interaction ($p < 0.05$) on TPC retention after storage for six months. The presence of remarkable interaction between the conditions of storage and types of drying suggests that the types of dryers employed have a significant impact on the amount of TPC in leaves preserved under various conditions.

Table 2 After six months storage effects of drying methods, conditions of storage and its interaction on TPC, DPPH and FRAP (antioxidant activities) of dehydrated LML

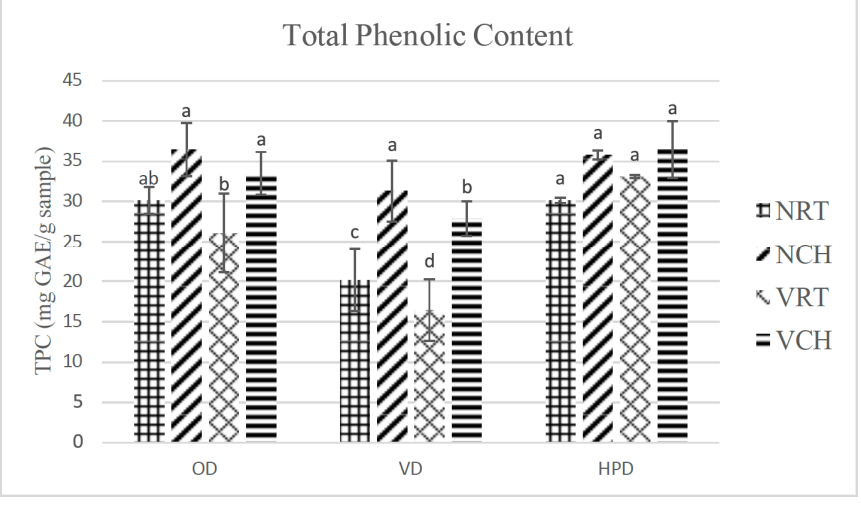
Factors		*TPC (mg GAE/g sample)*	*DPPH (% scavenging)*	*FRAP (mg AAE/g sample)*
Types of dryers	OD	31.54[a]	63.98[a]	43.85[a]
	VD	24.17[b]	49.61[b]	31.81[b]
	HPD	33.90[a]	66.29[a]	46.87[a]
Conditions of storage	NRT	27.09[b]	56.38[b]	38.06[b]
	NCH	34.53[a]	64.94[a]	45.45[a]
	VRT	25.23[b]	53.62[b]	35.35[b]
	VCH	32.63[a]	64.90[a]	44.52[a]
Types of dryers, D		**	**	**
Storage condition, S		**	**	**
D*S		*	ns	ns

Notes: ns: Not significant. **Significant at 1% probability level, *significant at 5% probability level. According to Tukey's HSD, the means in each column with distinct letters within each component show a significant difference at the $p < 0.05$% level (Mean ± S.E, n = 3).

Figure 3 depicts the effect of drying technique on TPC retention in various conditions of storage of LML exposed to heat pump-, vacuum- and oven drying after six months. In contrast to VD, which has a large range from 16.45 to 31.32, the TPC content at six months storage of all samples held at various conditions is in a modest range for HPD sample from 30.19 to 36.49 mg GAE/g sample. Figure 3 further shows that leaves preserved in various settings had no significant differences in TPC amongst HPD samples. In all conditions of storage, however, there is a considerable difference in final TPC between VD and OD samples. When OD and VD samples are held in VRT, their TPC is much smaller than when they are stored in other conditions of storage. The substantial difference ($p < 0.05$) between the VD and OD samples indicates that conditions of storage of storage have an influence on the dried samples' final TPC values.

The lower TPC retention in VRT for VD and OD samples is most likely owing to sample damage caused by vacuum packing. Vacuum packing might cause LML cells to burst, causing damage to the leaves. Injuries may induce changes of polyphenols' chemical structure in vacuum-packed samples, resulting in reduced TPC values. When dried leaves are maintained at a cold temperature and in a vacuum-packed state (VCH) for HPD samples, however, increased TPC retention is seen. The preservation of the cell structure, which is greater for HPD samples, influences the variety of TPC decrease from various dehydration processes. Generally, heat pump dried LML may provide more homogenous final TPC after six months of storage in all settings. Because it delivers relatively high TPC values after 180 days, vacuum packing with reduced storage temperature (VCH) is the most effective technique for preserving TPC in storage of heat pump dried LML.

Figure 3 TPC retention after six months in various storage settings as a result of different drying techniques



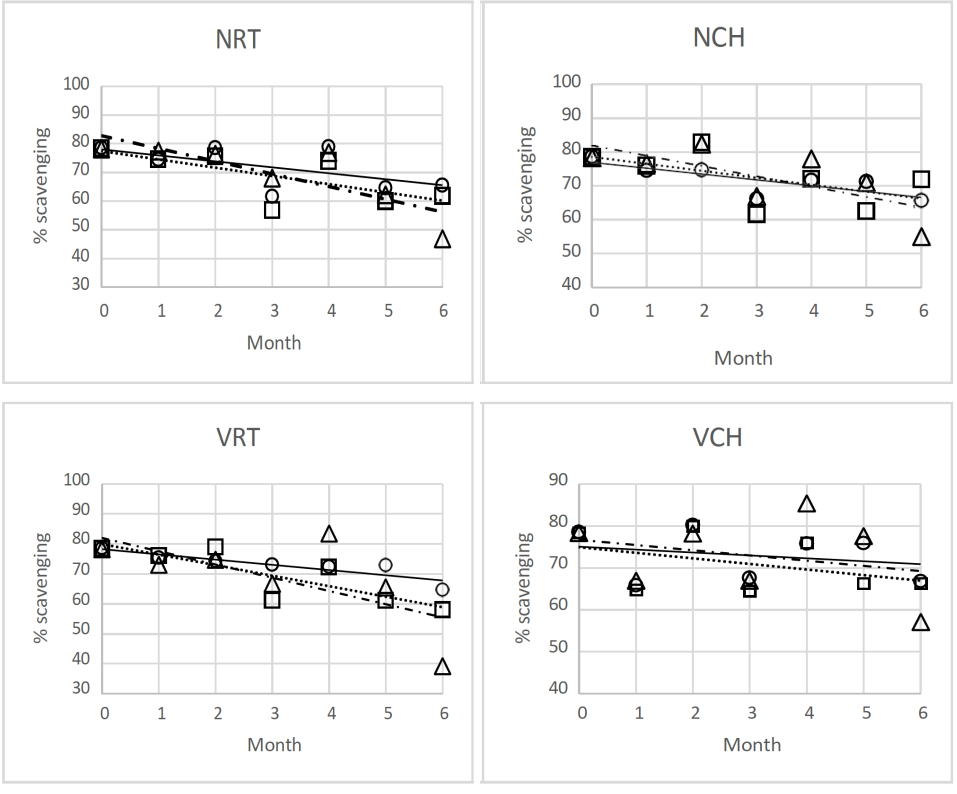
Note: The standard deviation is indicated by vertical bars, and values with the same letter are not substantially different ($p > 0.05$).

3.1.1.2 Radical scavenging activity

The radical scavenging test is the most common method for assessing phytochemical activity. It's a quick and easy test that uses the rate of reaction between a stable free radical called 1,1- diphenyl-2-pycrylhydrazyl (DPPH) and antioxidants. Figure 4 displays the DPPH Radical scavenging activity (%) values for samples after drying and one to six months storage for different dehydrated LML. Under all four kinds of conditions of storage of storage, all DPPH readings decrease over the course of six months. Using the DPPH readings after drying (month 0) as a benchmark, the smallest decrease is shown in the HPD sample which is in the range of 15%–17%, followed by OD, which is in the range of 16%–26% and VD sample, which is in the range of 27%–50%, independent of conditions of storage. The drying activities that create the cell wall's fragility and give efficient extraction owing to the ease and deliverance of metabolites responsible for this bioactivity may impact the variance of the DPPH reduction (Mediani et al., 2014). HPD

samples had the least decline in DPPH value because this process is better at preserving the cell leaves' structure.

Figure 4 Value of DPPH Radical scavenging activity (%) after drying and storage of one to six months of different dehydrated LML



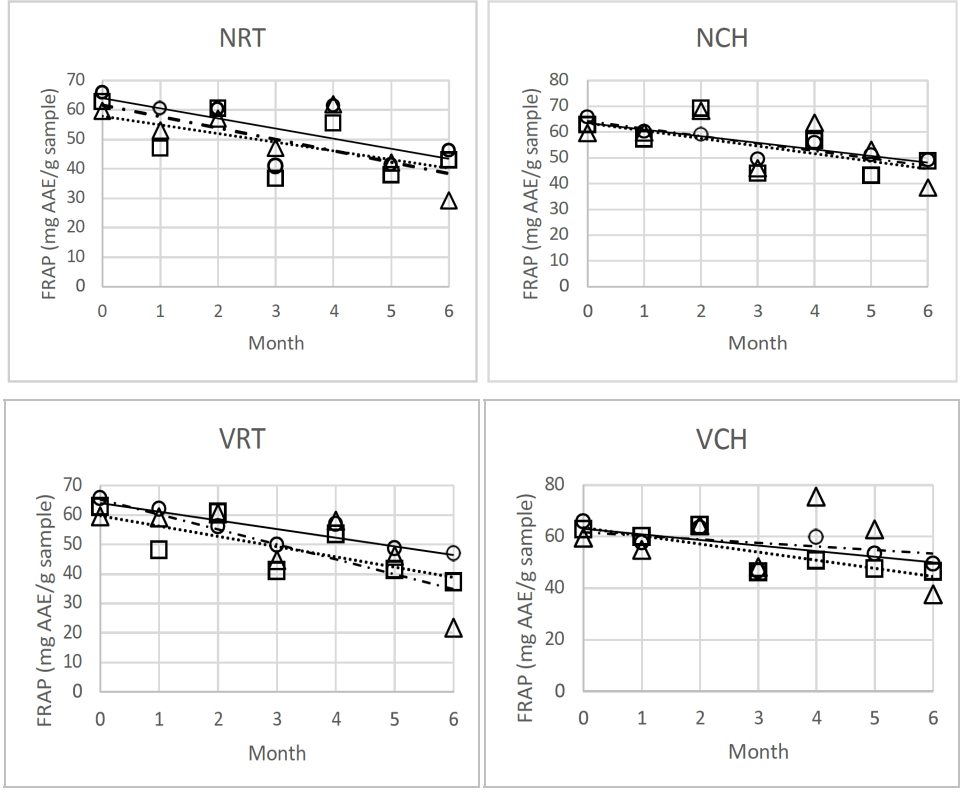
Notes: O: HPD; : OD; Δ: VD

Table 2 indicates no significant interaction ($p > 0.05$) between the conditions of storage and types of drying in the DPPH column. LML dried using HPD and OD exhibited considerably greater DPPH concentration than VD, regardless of conditions of storage of storage. Regardless of the drying procedures, LML preserved in NCH and VCH exhibited considerably greater DPPH than NRT and VRT. This might be caused by the effect of heat treatment, which occurs at higher temperatures and causes enzymatic denaturation through the Maillard reaction, lowering bioactive components (Mediani et al., 2014). However, when comparing non-vacuum (N) and vacuum (V) conditions of storage, it is discovered that vacuum packing is advantageous when the samples are kept chilled (VCH) rather than at ambient temperature (VRT). Among all drying processes and conditions of storage, HPD kept under VCH had the highest DPPH retention, whereas VD VRT samples had the largest DPPH loss.

3.1.1.3 Ferric reducing antioxidant potential

Unlike the DPPH process, FRAP is based on reaction of an electron transfer (Jemli et al., 2016). Figure 5 depicts the FRAP variation across a six month storage period for OD, HPD and VD samples under various conditions of storage, with one-month intervals. Throughout the storage period, the FRAP values for all drying procedures indicated a decrease. In contrast, the FRAP value of the fresh sample was 88.04 ± 0.15 mg AAE/g sample. Regardless of the drying procedures used, the dried LML showed retention values ranging from 25% to 56%.

Figure 5 Value of ferric reducing antioxidant power (FRAP) after drying and during storage of one to six months of different dehydrated LML



Notes: O: HPD; □: OD; Δ: VD

In general, VD caused the most FRAP loss of the four storage strategies, with VRT having the lowest retention. The difference in conditions of storage for HPD samples, on the other hand, is not significant. This is consistent with TPC's results. As a consequence of the findings, HPD samples are a drying approach that may provide a more stable quality throughout the storage period, and vacuum packing and chilling HPD samples is helpful in terms of preserving bioactive chemicals in storage.

FRAP value, like DPPH, indicates no significant ($p > 0.05$) interaction between the various drying processes and conditions of storage (Table 2). LML dried with HPD had a considerably larger amount of FRAP than LML dried with OD and VD, regardless of

conditions of storage of storage. Regardless of the drying procedure, leaves maintained in chilled condition (CH) exhibit much greater FRAP than leaves stored at room temperature (RT). This is in line with Korus (2011) that found that after 12 months of storage, dried kale leaves held at cold-store temperature retained more antioxidants. For all drying procedures in this investigation, materials treated to cool conditions of storage had the maximum FRAP retention. However, for HPD and OD samples, sample stability may be increased by using vacuum packing in conjunction with refrigerated storage to prevent FRAP value loss over time.

3.2.2 Colour assessment

Long-term storage after drying might result in colour, nutritional, and bioactive component loss (Phahom et al., 2017). For green-leaf goods, colour retention is frequently linked to quality factors (such as biochemical content). Table 3 shows the colour characteristics (L*, a*, b*) and colour change (Chroma, Hue angle, and Browning Index) for OD, HPD and VD samples after six months of storage under varied conditions of storage. Colour characteristics are modified in general for different drying procedures and under different packing conditions of storage. Different drying techniques and storage temperatures resulted in a significant variation ($p < 0.05$) in LML colour characteristics, as shown in Table 3.

Table 3 After six months storage effects of types of dryers, conditions of storage and its interaction on a* (greenness), L* (lightness), b* (yellowness), Chroma, hue angle and browning index (BI) values of dehydrated LML

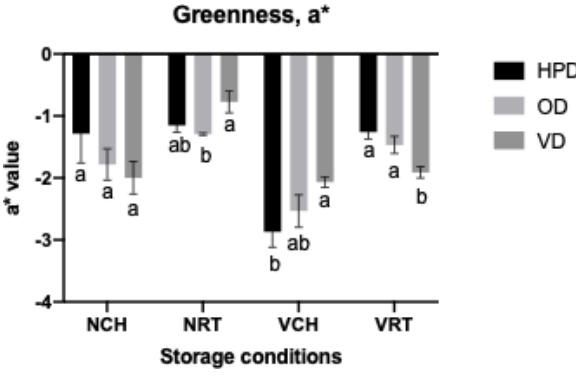
Factor		*a**	*L**	*b**	*Chroma*	*Hue angle*	*Browning index (BI)*
Types of dryers	OD	–1.69^{a}	48.21^{a}	26.42^{c}	26.66^{b}	178.53^{a}	78.99^{c}
	VD	–1.64^{a}	46.39^{b}	27.41^{a}	26.86^{ab}	178.49^{b}	88.06^{a}
	HPD	–1.77^{a}	47.67^{a}	26.85^{b}	27.12^{a}	178.53^{a}	76.91^{b}
Conditions of storage	NRT	–1.07^{a}	45.11^{b}	26.00^{b}	26.42^{b}	178.50^{c}	82.71^{a}
	NCH	–1.69^{b}	49.50^{a}	27.72^{a}	27.3^{a}	178.51^{b}	80.58^{c}
	VRT	–1.55^{b}	45.59^{b}	25.91^{b}	26.38^{b}	178.52^{b}	81.53^{b}
	VCH	–2.49^{c}	49.49^{a}	27.96^{a}	27.44^{a}	178.53^{a}	80.48^{c}
Types of dryers, D		ns	**	**	*	**	**
Storage condition, S		**	**	**	**	**	*
D*S		*	ns	ns	ns	ns	ns

Notes: ns: Not significant, *Significant at 5% probability level, **Significant at 1% probability level. According to Tukey's HSD, the means in each column with distinct letters within each component show a significant difference at the $p<0.05$% level. (Mean ± S.E, n = 3)

The a* value reflects the sample's greenness, which ranges from a negative (greenness) to a positive value (redness). In terms of drying procedures, the HPD sample has the greatest a* value, followed by OD and VD (Table 3). The VCH condition after six months storage, on the other hand, had the smallest a* values (more green), regardless of the drying technique. The lower the a* value, the more intense the sample's green colour.

Table 3 shows that the interaction between drying procedures and conditions of storage of storage has a statistically significant ($p < 0.05$) effect on the a* value after six months of storage. Significant interactions between conditions of storage and drying procedures suggest that conditions of storage have a significant impact on the a* values in dried LML kept in various settings. Figure 6 shows that all three kinds of drying processes had greater a* values when stored at room temperature (NRT). The greater the a* value, the less green the samples are and the closer they are to redness. The oxidation of chlorophyll in packaging with the existence of oxygen at higher storage temperatures may be the source of the difference in a* value under various conditions of storage. As a result, throughout storage period in NRT condition, two hydrogen atoms substitute the magnesium atom of the chlorophyll, changing the sample's colour to darker green (more positive a* value) from bright green (more negative a* value). This finding is also reported by Phahom et al. (2017), that found a substantial shift in the green colour of dried *Thunbergia laurifolia* from bright green to olive green at higher storage temperatures with non-vacuum packing.

Figure 6 Effect of conditions of storage on the value of a* (greenness) of oven-, vacuum- and heat pump dried LML



Note: Values with the same letter are not substantially different (Mean ± S.E; n = 3).

The L* value shows a sample's lightness level, and is beneficial for revealing the brownness and blackness of leaves after they have been dried (Arabhosseini et al., 2007). The higher the L* value, the lighter the sample's colour, and the lower the L* value, the darker the sample's colour. Table 3 shows the lightness value after a six month storage period. The conditions of storage of storage had no effect on the L* value for each dryer of each sample since there was no significant interaction ($p > 0.05$) between drying techniques and conditions of storage. Regardless of conditions of storage, LML dried by HPD and OD had a greater L* value than VD samples. This is due to the fact that VD takes longer. As a consequence, there is a considerable colour shift and the VD colour becomes darker. Furthermore, regardless of the drying process, refrigerated storage yielded a greater value of L* than storage at room temperature for both non-vacuum and vacuum packing. The darker sample that resulted after six months of storage at room temperature might be due to chlorophyll oxidation, which results in the loss of magnesium atoms, causing the colour to shift from brighter to darker.

The b* value represents a sample's yellowness or blueness. The lower the b* value, the more blue the sample is, and the higher the b* value indicate the more yellow it is. Table 3 reveals that the conditions of storage and drying process have no effect on the b* value. VD samples had a higher b* value regardless of conditions of storage of storage. Regardless of the drying process, storage at cold temperatures resulted in a greater b* value than storage at ambient temperature. A higher b* value suggests a yellowish colour, which results in a brighter sample colour. The effects of conditions of storage on L*, a* and b* are positive. The lower the temperature, the smaller the difference. This might be owing to the chilly state, which inhibits the enzymatic activity and hence preserves chlorophyll, which is responsible for the sample's colour. Chlorophyll in leaves may change colour due to oxidation, hydrolysis, and isomerisation. Similar result also reported by Mudau et al. (2018) that found out that the spinach leaves kept in modified air packaging had much lower a* values than samples stored in regular air packing. As a result, refrigerated storage is effective in reducing changes in colour, particularly the degree of greenness (a*) during storage.

The saturation of colour or chroma (C*) value allows for the qualitative measurement of the degree of reaction to a colour's hue by interpreting its intensity and depth (Rubinskien, 2006). After six months of storage samples for colour changes assessments of dried samples are shown in Table 3. The chroma value or colour intensity of the sample after storage is shown in Table 3 for each storage environment and drying process. In general, conditions of storage of storage have a big impact on chroma values. Samples stored in cold conditions, particularly under VCH conditions, had higher chroma values, indicating more intense (pure) colour. Regardless of drying processes, the hue angle value was higher at chilled storage temperature (CH) compared to higher temperature of storage. The colour angle, which is determined by the arctan value of b*/a*, was impacted by the value of a*. This finding is consistent with Phahom et al. (2017), who found that after 180 days of microwave HPD *Thunbergia laurifolia* leaves, the hue angle dropped and the storage temperature increased.

Browning index is a crucial measure for determining the degree of browning in a sample. BI stands for brown colour purity, and the determined value is displayed in Table 3. BI was lower in cold storage than storage in room temperature, with a greater value in non-vacuum packed storage than vacuum-packed storage, regardless of the dryer employed. This is in line with Alagoz et al. (2015) and Yao et al. (2020) findings. Both revealed non-proportional relationships between BI levels and brown colour development. When compared to room temperature storage, samples held at lower temperatures had lower BI values. The packing condition, on the other hand, had an impact on the BI of the samples. This finding agrees with Aroújo et al. (2017), who found that non-vacuum packing resulted in higher BI values due to the concurrent and recurrent reaction of Maillard that take place, that aided by the existence of air in non-vacuum packed dry kale.

Storage at low temperature results in low value of BI, greater greenness (lower a* value), hue angle, chroma, antioxidant activities and TPC values. These findings indicate how storage temperature affects the biochemical activity of dehydrated samples throughout the storage period. These findings suggest that change in colour has a proportional relationship with the remaining of bio-active components in dehydrated products, with greater colour difference indicating lesser bio-active contents' retention, implying substance breakdown. In microwave HPD of *Thurnbergia laurifolia*, Phahom et al. (2017) found that storage at cold temperatures resulted in higher TPC and FRAP

values. Finally, VCH is better for storing LML, particularly for HPD samples, since it produces low BI and high chroma value with a greener (lower a* value) and brighter (higher L* value) colour. As a result, this condition of storage helps to retained dehydrated LML colour while also increasing its shelf life.

4 Conclusions

The impact of storage temperature and packing on the quality characteristics of LML dehydrated using 3 drying processes (oven, heat pump and vacuum dryers) was investigated. The dried LML were stored for six months in four different ways: non-vacuum packed at room temperature (NRT), non-vacuum packed at chilled temperature (NCH), vacuum packed at room temperature (VRT), and vacuum packed at chilled temperature (VCH). After six months of storage, VD gave lower concentrations of all physicochemical parameters, while HPD provided higher values. Packing employing vacuum and cold storage (VCH) preserves dried samples better than room temperature storage, notably for HPD samples, in terms of bioactive component retention. TPC, FRAP, and DPPH values are slightly reduced in HPD samples kept at chilled environment in vacuum-packed (VCH), with losses of 31, 15, and 25%, respectively, compared to TPC, DPPH and FRAP losses of 50%, 37%, and 27% in VD samples stored in VCH conditions. This is due to the lower degree of Maillard reaction that happens in vacuum packed foods since oxygen is not present, preventing oxidation. As a result, the colour and nutritional properties are preserved throughout storage. HPD is a viable alternative for drying LML, according to this research. Furthermore, the packing condition chosen is critical in protecting the quality of herbal products, since quality factors may vary during storage. Storage in vacuum packed at cold storage (VCH) is the most ideal packing condition for improved preservation of colour and biochemical content of dried LML, particularly on maintaining the quality of HPD samples.

References

Abd Razak, D.L., Abd Rashid, N.Y., Jamaluddin, A., Sharifudin, S.A., Abd Kahar, A. and Long, K. (2017) 'Cosmeceutical potentials and bioactive compounds of rice bran fermented with single and mix culture of *Aspergillus oryzae* and *Rhizopus oryzae*', *Journal of the Saudi Society of Agricultural Sciences*, Vol. 16, No. 2, pp.127–134, doi: http://dx.doi.org/10.1016/j.jssas.2015.04.001.

Achariyaviriya, S., Soponronnarit, S. and Terdyothin, A. (2000) 'Mathematical model development and simulation of heat pump dryer', *Drying Technology*, Vol. 18, Nos. 1–2, pp.479–491, http://dx.doi.org/101080/07373930008917718.

Alagoz, S., Turkyilmaz, M., Tagi, S. and Ozkan, M. (2015) 'Effects of different sorbic acid and moisture levels on chemical and microbial qualities of sun-dried apricots during storage', *Food Chemistry*, Vol. 174, pp.356–364.

Alibas, I. (2007) 'Energy consumption and colour characteristic of nettle leaves during microwave, vacuum and convective drying', *Biosystems Engineering*, Vol. 96, No. 4, pp.495–502.

AOAC (1990) *Official Methods of Analysis of the Association of Official Analytical Chemists*, 11th ed., AOAC, Washington DC, USA.

Arabhosseini, A., Huisman, W., Boxtel, A.V. and Müller, J. (2007) 'Long-term effects of drying conditions on the essential oil and color of tarragon leaves during storage', *Journal of Food Engineering*, Vol. 79, pp.561–566, doi:10.1016/j.jfoodeng.2006.02.014.

Araújo, A.C., Oliveira, S.M., Ramos, I.N., Brandão, T.R.S., Monteiro, M.J. and Silva, C.L.M. (2017) 'Evaluation of drying and storage conditions on nutritional and sensory properties of dried Galega Kale (*Brassica oleracea* L. var. Acephala)', *Journal of Food Quality*, Vol. 2017, Article ID 9393482, 9pp., https://doi.org/10.1155/2017/9393482.

Argyropoulos, D. and Müller, J. (2014) 'Effect of convective-, vacuum- and freeze drying on sorption behaviour and bioactive compounds of lemon balm (*Melissa officinalis* L.)', *Journal of Applied Research on Medicinal and Aromatic Plants*, Vol. 1, pp.59–69.

Baritaux, O., Richard, H., Touche, J. and Derbesy, M. (1992) 'Effects of drying and storage of herbs and spices on the essential oil. Part I. Basil, *Ocimum basilicum* L.', *Flavour and Fragrance Journal*, Vol. 7, pp.267–271.

Benzie, I.F.F. and Strain, J.J. (1996) 'The ferric reducing ability of plasma (FRAP) as a measure of 'antioxidant power': the FRAP assay', *Analytical Biochemistry*, Vol. 239, No. 1, pp.70–76, doi: http://dx.doi.org/10.1006/abio.1996.0292.

Brushlyanova, B., Petrova, T., Penov, N., Karabadzhov, O. and Katsharova, S. (2013) 'Drying kinetics of different fruit pomaces in a heat pump dryer', *Bulgarian Journal of Agricultural Science*, Vol. 19, No. 4, pp.780–782.

Buchaillot, A., Caffin, N. and Bhandari, B. (2009) 'Drying of lemon myrtle (*Backhousia citriodora*) leaves: Retention of volatiles and color', *Drying Technology*, Vol. 27, No. 3, pp.445–450, Taylor & Francis.

Ceylan, İ. and Gürel, A.E. (2016) 'Solar-assisted fluidized bed dryer integrated with a heat pump for mint leaves', *Applied Thermal Engineering*, Vol. 106, pp.899–905, doi: http://dx.doi.org /10.1016/j.applthermaleng.2016.06.077.

Chong, K.L. and Lim, Y.Y. (2012) 'Effects of drying on the antioxidant properties of herbal tea from selected *Vitex* species', *Journal of Food Quality*, Vol. 35, pp.51–59.

Fadhel, M.I. (2014) 'Drying characteristics of lemongrass in solar assisted chemical heat pump dryer', *2nd International Conference on Food and Agricultural Sciences*, Vol. 77, pp.39–43, doi: 10.7763/IPCBEE.

Hossain, M.A., Gottschalk, K. and Hassan, M.S. (2013) 'Mathematical model for a heat pump dryer for aromatic plant', *Procedia Engineering*, Vol. 56, pp.510–520, DOI: 10.1016 /j.proeng.2013.03.154.

Jemli, M.E., Kamal, R., Marmouzi, I., Zerrouki, A., Cherrah, Y. and Alaoui, K. (2016) 'Radical-scavenging activity and ferric reducing ability of *Juniperus thurifera* (L.), *J. oxycedrus* (L.), *J. phoenicea* (L.) and *Tetraclinis articulata* (L.)', *Advanced Pharmacol Sci.*, p.6392656.

Ji, E. and Pi, A. (2012) 'Effect of drying methods and storage on the physicochemical properties of okra', *Journal of Food Processing and Technology*, Vol. 3, No. 177, pp.1000177–1000176.

Joubert, E., Manley, M., Maicu, C. and De Beer, D. (2010) 'Effect of pre-drying treatments and storage on color and phenolic composition on green Honeybush (*Cyclopia subternata*) herbal tea', *Journal of Agricultural and Food Chemistry*, Vol. 58, pp.338–344.

Klungboonkrong, V., Phoungchandang, S. and Lamsal, B. (2018) 'Drying of *Orthosiphon aristatus* leaves: Mathematical modelling, drying characteristics and quality aspects', *Chemical Engineering Communications*, Vol. 205, No. 9, pp.1239–1251, DOI: 10.1080/00986445 .2018.1443080.

Korus, A. (2011) 'Effect of preliminary processing, method of drying and storage temperature on the level of antioxidants in kale (*Brassica oleracea* L. var. acephala)', *LWT-Food Science and Technology*, Vol. 44, pp.1711–1716, doi:10.1016/j.lwt.2011.03.014.

Lemon Myrtle [online] https://www.agrifutures.com.au/farm-diversity/lemon-myrtle/ (accessed 15 November 2021).

Mediani, A., Abas, F., Tan, C.P. and Khatib, A. (2014) 'Effects of different drying methods and storage time on free radical scavenging activity and total phenolic content of *Cosmos caudatus*', *Antioxidants*, Vol. 3, No. 2, pp.358–370, Multidisciplinary Digital Publishing Institute.

Mudau, A.R., Soundy, P., Araya, H.T. and Mudau, F.N. (2018) 'Influence of modified atmosphere packaging on postharvest quality of baby spinach (*Spinacia oleracea* L.) leaves', *HortScience*, Vol. 53, No. 2, pp.224–230, doi:10.21273/hortsci12589-17.

Norawanis, A.R., Shaari, A.R. and Leng, L.Y. (2018) 'Effect of packaging materials on *Orthosiphon stamineus* dried-leaf quality during storage', *IOP Conference Series: Materials Science and Engineering*, Vol. 318, p.012010, doi:10.1088/1757-899x/318/1/012010.

Oliveira, S.M., Ramos, I.N., Brandão, T.R.S. and Silva, C.L.M. (2015) 'Effect of AirXDrying temperature on the quality and bioactive characteristics of dried Galega Kale (*Brassica oleracea* L. var. Acephala)', *Journal of food processing and preservation*, Vol. 39, No. 6, pp.2485–2496, Wiley Online Library.

Phahom, T., Kerr, W.L., Pegg, R.B. and Phoungchandang, S. (2017) 'Effect of packaging types and storage conditions on quality aspects of dried *Thunbergia laurifolia* leaves and degradation kinetics of bioactive compounds', *Journal of Food Science and Technology*, Vol. 54, No. 13, pp.4405–4415, DOI 10.1007/s13197- 017-2917-9.

Podsędek, A. (2007) 'Natural antioxidants and antioxidant capacity of Brassica vegetables: a review', *LWT*, Vol. 40, pp.1–11, doi:10.1016/j.lwt.2005.07.023.

Potisate, Y., Kerr, W.L. and Phoungchandang, S. (2015) 'Changes during storage of dried *Moringa oleifera* leaves prepared by heat pumpXassisted dehumidified air drying', *International Journal of Food Science & Technology*, Vol. 50, No. 5, pp.1224–1233, Wiley Online Library.

Razak, N.A., Hamid, N.A. and Shaari, A.R. (2018) 'Effect of storage temperature on moisture content of encapsulated *Orthosiphon stamineus* spray-dried powder', *AIP Conference Proceedings*, Vol. 2030, p.020194, https://doi.org.10.1063/1.5066835.

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

Sandrang, A.K., Idris, S. and Mahmood, Z. (2013) 'Lemon myrtle: new potential crop for Malaysia', *Buletin Teknologi MARDI*, Vol. 3, pp.41–45.

Sandrang, A.K., Khalid, K. and Bidin, I. (2014), 'Processing and marketing of lemon myrtle primary products', *Buletin Teknologi MARDI*, Vol. 5, pp.113–121.

Strømmen, I., Eikevik, T.M., Alves-filho, O., Syverud, K. and Jonassen, O. (2002) 'Low temperature drying with heat pumps new generations of high quality dried products', *13th International drying symposium*, pp.1–9.

Sultanbawa, Y. (2016) 'Lemon Myrtle (*Backhousia citriodora*) Oils', *Essential Oils in Food Preservation, Flavor and Safety*, Chapter 59, 1st ed., pp.517–521, Elsevier.

Thaipong, K., Boonprakob, U., Crosby, K., Cisneros-Zevallos, L. and Hawkins Byrne, D. (2006) 'Comparison of ABTS, DPPH, FRAP, and ORAC assays for estimating antioxidant activity from guava fruit extracts', *Journal of Food Composition and Analysis*, Vol. 19, No. 6, pp.669–675, doi: http://dx.doi.org/10.1016/j.jfca.2006.01.003.

Therdthai, N. and Zhou, W. (2009) 'Characterization of microwave. Vacuum drying and hot air drying of mint leaves (*Mentha cordifolia* ex Fresen)', *Journal of Food Engineering*, Vol. 91, pp.482–489.

Tummanichanont, C., Phoungchandang, S. and Srzednicki, G. (2017) 'Effects of pretreatment and drying methods on drying characteristics and quality attributes of *Andrographis paniculate*', *Journal of Food Processing and Preservation*, Vol. e13310, pp.1–11, https://doi.org/10.1111/jfpp.13310.

Wu, T., Shiau, S. and Chang, R. (2013) 'Effects of drying temperature and extraction solvent on the antioxidant, color and sensory properties of *Angelica sinensis* leaves', *Journal of Food Processing and Preservation*, Vol. 37, No. 4, pp.371–379, Wiley Online Library.

Yao, L., Fan, L. and Duan, Z. (2020) 'Effects of different packaging systems and storage temperatures on the physical and chemical quality of dried mango slices', *LWT-Food Science and Technology*, Vol. 121, p.108981, doi:10.1016/j.lwt.2019.108981.