Drying Kinetics of Aquilaria Subintegra Leaves

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***Abstract*— Technology on drying systems becoming more advanced for the preparation of quality-dehydrated food product continuously optimize the power level above a target value. Typical drying curves occurs in high drying rate which leads to quality damage based on the texture and color. To overcome the issues, the vacuum far infrared system is being proposed that is being assumed to get the optimum in terms of product quality, energy usage and drying time. The aim of this work was to investigate the vacuum far infrared drying towards Aquilaria Subintegra leaves. Leaves is subjected with different drying temperature (40, 50 and 60°C), to investigate the effect towards the drying kinetics, color and the quality of the leaves. The shortest time taken to achieve constant read of moisture content is 60°C, followed by 50°C and 40°C. Drying temperature also affecting the moisture ratio which the higher the temperature, the reduced the drying time to bring moisture ratio to constant. The drying rate which the higher the temperature, the higher the drying rate. It is found that Page mathematical model fitted best for the sample. The color changes determine that the longer the drying time, L* decreases, a* and b* increases. The browning effect occurs faster for higher drying temperature. As drying time increases, the color degraded significantly as well as the texture become crumpled and drier. The effect is faster as the higher drying temperature. However, the total color difference, chroma and hue angles values were similar at the end of processing for all temperatures.**

Keywords— Drying kinetics, Aquilaria Subintegra, Vacuum drying, modelling, Drying effieciency.

I. INTRODUCTION

Agarwood is very fast-growing forest tree based from Aquilaria genus in the plant family of Thymelaeceae. It can be present primarily Bangladesh, India, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, and Thailand [1]. Grown over 15-40 m tall and 0.6-2.5 m in diameter and blooming white flowers, Agarwood is a large evergreen tree [2]. Being adaptive towards various habitats, Aquilaria sp. have the capability to live in rocky, sandy or calcareous, well-drained slopes and ridges and land near swamps areas. From early ages, this resinous wood has been transported worldwide and been called with various name that includes oodh, agarwood, aloeswood, eaglewood, gaharu and kalamabak, depending on the regions. Due to its beneficial properties for drugs, incense and fragrances, there have been high demand throughout Europe, Middle East and Asia. First grade Agarwood are labelled as the most expensive natural raw materials in the world which can reach up to US$30, 000 per kg. Agarwood is currently being used by the premium brand such as Dior, Juicy Couture, Yves St. Laurent and other for their product [3].

Thus, preservation is required to increase shelf life of the product based on agarwood, which increasing the demand to study of the optimum preservation, such as drying specifically. Drying process of food is to remove moisture from the product to which it can help commercialize it while preserving the food from any microbial contamination. To improve the drying process, the study of drying kinetic have been widely operated both globally and locally. The complex phenomenon of food drying kinetics involves simple representations to predict the drying behavior that eventually improving the drying parameters. It is vital to identify moisture diffusivities and mass transfer coefficients for the various systems since complex mathematical models and correlations require data on specific mass transfer parameters that may lead to better understanding of drying operations [3].

Years ago drying have been acknowledge for its function in preserving food and the method is through solar drying. Some disadvantages of solar drying are it involves climate and it is very tedious to maintain the desired product characteristics since it involves nature that we cannot control. Through time, more technologies have been developed and one of the method is through convective drying and conventional method that can provide a more controlled environment. However, the consumption of long hours to dry the product and extreme heat lead to deteriorating of nutrient value, density and water absorbance capability of dried product besides worsening the taste and color [4].

Far infrared drying has some winning point over convective drying due to its high heat transfer efficiency, faster drying rate and also low energy cost [5]. Drying agricultural product using far-infrared radiation speed up drying rate and at the same time improves the quality of the product. It is recommended to dry food product under low temperature to preserve it since most foods are sensitive towards heat in nature [6]. Thus, having the capability to dry under low temperature, it is favoring toward usage of far infrared drying compared to other drying method.

There is more scientific information of drying kinetics toward Subintegra leaves using conventional oven rather than VFIR drying. Thus, it has been proposed for a study of the effect on Subintegra leaves using VFIR drying compared to conventional oven. VFIR vacuum drying have higher drying rate, efficient energy usage, and uniform temperature distribution which can gives better quality of Subintegra leaves. Subintegra leaves own numerous advantages as example in pharmaceutical industry for its functionality in cancer treatment or any other illness that might cause uneasiness such as diarrhea, asthma and colics [7]. Also, there is still too little information in leaves drying mechanism that is in need to be studied more. Other than that, there is a need to find the optimum moisture content based on the study kinetic drying while preserving the nutrient composed inside the Subintegra leaves.

Recent study has discovered the significant of Subintegra leaves in pharmaceutical benefits. The leaves have the beneficial properties in being analgesic, anti-arthritic, anti-inflammatory, anticancer, antioxidant, antibacterial, lipid-lowering, laxative, acetylcholinesterase (AChE) inhibitory and hepatoprotective. Thus, making it one of demanded herbal drinks that requires more study in preserving it [7].

The drying kinetics is described as the combination macroscopic and microscopic mechanism of mass and heat transfer during drying. It is basically affected by drying conditions, type of dryer and characteristics of materials to be dried. As the microwave drying is time-consuming and it is complicated measurement of temperature and moisture, the drying kinetics are vital for better equipment design, process efficiency and product quality. [8]

The product should follow the quality standards where demand for dried food market value might be limited by quality loss [9]. The loss of quality is due to product collapse that it diminishes the porosity, destroy flavor retention, moisture distribution, rehydration capacity, that results in product hardening [9]. Rehydration is the basic aspect in drying process where it has the possibility to reproduce the optimum dried product resembles the fresh one.

The objectives are to investigate the drying kinetics and drying condition of the Subintegra leaves and also to study the impact of Vacumm Far Infrared (VFIR) drying towards Subintegra leaves toward the appearance, chemical composition and moisture content.

II. METHODOLOGY

A. *Materials*

The sample of Subintegra leaves is obtained freshly from a habitat in Jalan Kebun, Shah Alam. The chosen plant is ensured to be free from any disease and already mature. The leaves are also pick approximately same size with one another. The sample is washed and the water droplet is removed to avoid any error disrupting the data during drying the leaves. The sample is then stored under low temperature to avoid wilting of leaves until the experiment start. The initial moisture content of samples is recorded before initiating the experiment and during the intervals until the experiment stops.

B. *Drying*

24 sample with equal size is chosen for experiment and was washed and dried. The samples was organized to take picture for initial and final appearance comparison under the same lighting condition as it may changes the appearance. The VFIR was run before the actual experiment at temperature of 40°C and 0.5 bar vacuum pressure condition. The samples was arranged evenly at the center part of the tray to ensure that the drying process are at the same rate and dried. The sample was weighed to determine the moisture content at each time interval of 5 minutes. The drying process of samples was run until equilibrium state achieved. The weight of samples is taken thrice to get the most accurate data for every time interval. The experiment was repeated for 50°C and 60°C inside vacuum pressure of 0.5 bars.

C. *Color evaluation*

Chromameter (CR-400 Series, Konica Minolta Sensing Inc.) is used to measure the initial and final color of the each sample and recorded. It is first being calibrated with color reference (L = 89.6, a = 0.3148 and b = 0.3214). The color value sample is being expressed as L* (lightness), a* (redness/greenness) and b* (yellowness/blueness) value.

III. RESULTS AND DISCUSSION

A. *Changes in moisture content*

The drying process of Aquilaria Subintegra leaves is being analyzed through observing the weight changes on the leaves before and after the drying process using vacuum far-infrared (VFIR). The weight changes indicates the removal of moisture content due to heating and drying process. Through the data of moisture content, it is possible to obtain the efficiency of the whole process and as an indication of the effectiveness of the drying process. The samples is run with 3 different temperature of 40, 50, 60°C as tabulated in the data. The moisture content of the samples is calculated using dry and wet basis. Based on the moisture content, the moisture ratio and drying rate is being determined. The graphs is based on data obtained throughout the experiments. Figure 1 until figure 3 shows the results of VFIR's temperature that affect the moisture content, moisture ratio and drying rate of Aquilaria Subintegra leaves through the drying process at different drying time.

Based on figure 1 which shows the moisture content of A. Subintegra leaves that is affected by different drying temperature in VFIR. At 40oC, the leaves shows no significant constant moisture content until 120 minutes. The moisture removal is slowly increasing as time increases. The drying process is slower due to low drying temperature as it took longer time to have a constant moisture content. There is random fluctuation considering the temperature is low thus the drying mechanism may be disrupted by other factor such as damage in cell structure and leaves size. It is stated that larger leaves drying time is longer than the smaller one [10]. Thus, the moisture removal is easier on the young leaves rather than the mature and big sized leaves. At 50oC, the removal of moisture is rapid and the moisture content comes to constant starting at approximately 30 minutes of drying time. It is noticed that the moisture removal already achieved more than 40 %. There is a bit fluctuation of moisture content at drying time of 10 minutes until 30 minutes and also at 115 minutes may be due to the lower weight of leaves used as the samples. It is assumed that the leaves sample have minor damage in the cell structure making it harder to remove the moisture inside the leaves as stated by [11] where the rehydration process of the leaves affected by the degree of damage to cell structure. At 60oC, the removal of moisture content is very rapid and comes to constant at 15 minutes until 120 minutes. For 5 minutes, the moisture removal for 60oC is already high up to 60 %.

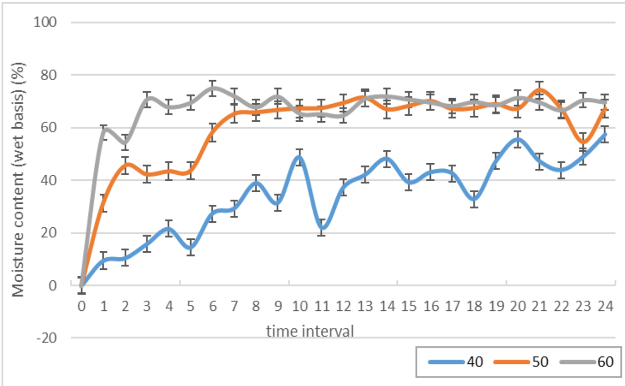

Fig 1: The moisture content of A. Subintegra leaves affected by different temperature.

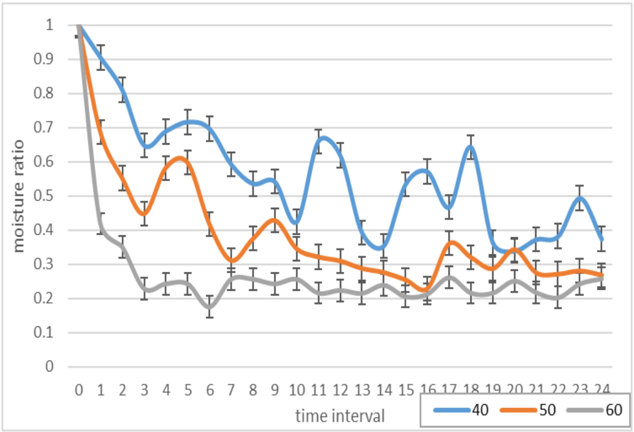

Fig 1: The moisture ratio of A. Subintegra leaves affected by different temperature.

Figure 2 indicated the effect of moisture ratio towards the A. Subintegra leaves with different drying temperature in VFIR. The ratio starts at 1 which it depicted to moisture ratio at time t being equal to the initial moisture. At 40oC, the moisture ratio decrease slowly with time. The moisture ratio is almost come to a constant at less than 0.4 starting approximately at 65 minutes and comes to constant after that until the 120 minutes. However there is fluctuation along 50 until 65 minutes and 75 until 95 minutes. There is fluctuation in the graph that is assumed to be due to uneven heat supply which causes different rate of moisture removal. At 50oC, the moisture ratio is decreases rapidly compared to 40oC and already reaching 0.4 within 15 minutes. It is also proven by [12] that drying time will be lesser with higher// drying temperature. He stated that there is increasing acceleration of water migration and heat transfer between air and red ginseng. It is also been proven by [13] for red pepper, [14] for oak boxthorn and [15] for red ginseng. The moisture ratio decreases slowly afterwards until it reaches 0.3 starting within 35 minutes. The reading shows a constant data until 120 minutes but have few fluctuation on 40 to 45 minutes and 80 until 100 minutes. Meanwhile at 60oC, the moisture ratio is very rapid that it reaches almost 0.2 within 15 minutes. The heat transfer of Subintegra leaves is increasing as temperature increases. The moisture comes to constant afterwards until 120 minutes. Increasing temperature will affect the drying rate by increasing the holding capacity of moisture towards the air and accelerating the diffusion rate of moisture through leaves subtances [12- 14].

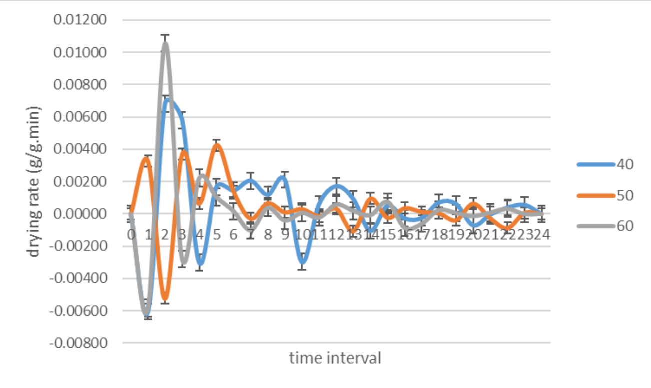

Fig 3: The drying rate changes of A. Subintegra leaves affected by different temperature.

Figure 3 shows the drying rate of Subintegra leaves affected by different drying temperature. The results shows mostly at the falling rate period at as fast as 10 minutes drying time. Initially the drying rate increased with temperature which happens because there is more heat provided to the leaves that causes drying of leaves and thus, the rate of drying also increases such that being approved by [18]. However as the moisture content is slowly decreasing, the drying rate also decreases since the moisture is no longer available to be remove afterwards which is then the drying rates will falls and comes to a constant. At 40oC, the drying rate is maintained to be around 0.007 to -0.006 g/g.min until 120 minutes. The highest drying rate is at 10 minute where the drying rate is 0.0068 g/g.min. The drying rate is as expected where the lowest temperature might shows almost constant drying rate as [19] for dried mentha arvensis leaves. There might be some errors due to uneven heat transfer on the dried leaves which causes fluctuation of data. The falling rate starts at 10 minutes and comes to almost constant at 70 minutes afterwards. However for 50oC, the drying rate curve does not as expected where it should be higher than 40oC. As it come out as being at -0.005 g/g.min at 10 minutes that might be due to uneven mass transfer from the Subintegra leaves that it affected the drying rate data. It comes to almost constant rate at 35 minutes which is faster than 40oC. At 60oC, the falling rates starts at 10 minutes where the highest drying rate occurs at 0.0106 g/g.min. It is then comes to a constant starting at 30 minutes and afterward.

B. Mathematical Modelling and Statistical Analysis of Drying Curves.

The experimental drying kinetic data at each temperature was fitted to the three different models. The models is being determined by moisture ratio (MR) as the dependent variable against the drying time. Using non-linear regression in MS excel, the model is fitted to the experimental moisture ratio. The model constants, coefficient of determination ($R2$), reduced sum square error (SSE), root mean square error (RMSE), and reduced Chi-square ($\chi2$) are tabulated in Table 1. The models is fitted with R2 ranging to 0.9 to 1 and reasonably low value of SSE, RMSE, and $\chi2$. The best model fitted is being determined based on the highest value of R2 and lowest value of SSE, RMSE, and $\chi2$ [20]. Therefore, it is determined that the best fitted model is Page model with R2 of 0.9442 and lowest SSE, RMSE, and $\chi2$.

Table 1: The data comparison between different Mathematical Modelling

Temp (°C)	Mathematical modelling	R^2	SSE	RMSE	X^2
40	Page	0.9442	0.0022	0.0469	0.0024
	Two-term	0.9436	0.0025	0.0501	0.0030
	Modified Henderson and Pabis	0.9124	0.0025	0.0501	0.0101
50	Page	0.9442	0.0021	0.0462	0.0023
	Two-term	0.9436	0.0030	0.0551	0.0036
	Modified Henderson and Pabis	0.9124	0.0030	0.0551	0.0121
60	Page	0.9442	0.0021	0.0457	0.0023
	Two-term	0.9436	0.0025	0.0502	0.0030
	Modified Henderson and Pabis	0.9124	0.0025	0.0502	0.0101

C. COLOR MEASUREMENT

The changes color of Subintegra leaves after being dried is evaluated as an indicator effectiveness in drying process and the quality of the dried product. This review the effect of VFIR drying through different drying temperature. The physical appearance of the dried leaves as shown in figure 4 where the after effect of drying at 40oC through different drying time. The first few interval does not cause significant changes however, as drying time increases, the color differs more significantly. The color changes to more brownish lighter and brownish color and it is crumpled and easily crushed. The effect is faster as the higher drying temperature. It is also being observed by sampling okara being dried using different temperature that shown higher temperature attributes to faster color degradation [21].

Next, the total color difference (ΔE) indicated the magnitude of overall color difference based on the dried and fresh samples. As shown in figure 5, the total color difference at 40°C remains almost constant until 120 minutes. This shows that the color is well preserved since the changes is remain at constant. While the color difference at 50°C, color changes is more significant rather than at 60°C especially after 30 minutes drying time. It is assumed that the leaves used for 50°C is young leaves where young leaves is more sensitive thus tend to change color more than mature leaves.

Then, chroma as shown in figure 6 is a degree indicator of difference of a hue compared to grey color in a same lightness. More chroma values indicates that the intensity of color is higher to be observed by human. It is noted that the highest chroma value is at drying temperature of 60oC, followed by 40oC and 50oC. The chroma value is no significant with increasing in drying temperature. However, the longer the time, the more changes occurs in chroma value. The chroma value at 60oC increases starting at 55 minutes while other drying temperature, does not shows any increment. However, chroma at 50oC shows chroma is decreasing with time. This may be assumed due to color of leaves sample that affected the chroma value.

Fig 4: Example of color changes that occurs on A. Subintegra after drying at 40^{O}C within different drying time.

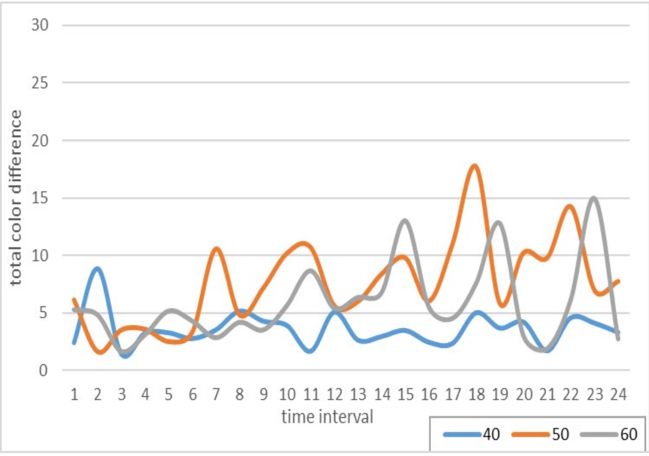

Fig 2: The total color difference affected by different drying temperature.

Hue angles is the attribute that is associated with differences in absorbance at different wavelength. Lower hue angle values indicated higher yellow character in the analyzer. The hue angle ranging from 40 to 80^{o} indicated that it orange to red color is observed. As expected the hue angle at drying temperature of 40^{o}C does not change rapidly with time. It maintained at the range 60 to 40^{o} until 120 minutes drying time. This also shown on the dried leaves at 60^{o}C where the changes almost remain constant at 50^{o} hue angle. Meanwhile, 50^{o}C shows a significant changes especially at 90 minutes and 100 minutes. This color changes also being noted on the color parameter L, a and b which affected hue angle as well.

The data also demonstrated the influence of drying temperature on the color of Aquilaria Subintegra leaves. It is observed the longer the drying time, L* decreases, a* and b* increases. The browning effect occurs faster for higher drying temperature. However, 40^{o}C can well preserved the color as it does not give significant color changing throughout 120 minutes in total. Meanwhile as drying time increases, the color degraded significantly as well as the texture become crumpled and drier. The effect is faster as the higher drying temperature. However, the total color difference, chroma and hue angles values were similar at the end of processing for all temperatures.

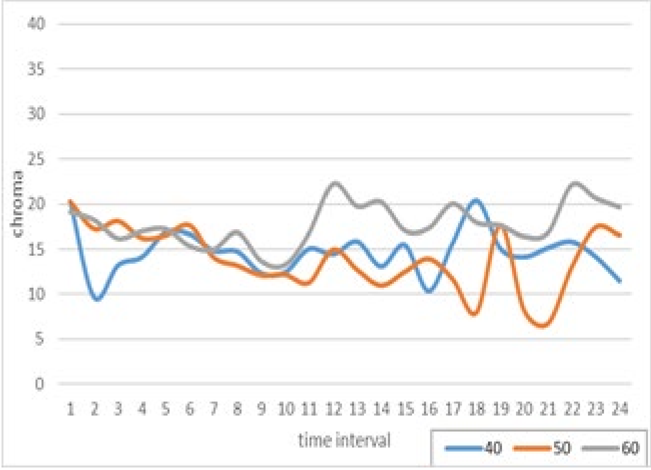

Fig 3: The chroma affected by different drying temperature.

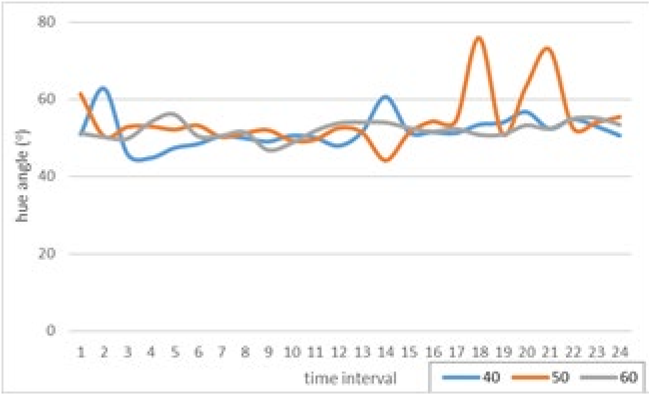

Fig 4: The hue angle affected by different drying temperature.

IV. Conclusion

The aim of this experiment is to investigate the drying kinetics and to study the impact of vacuum far infrared drying towards Aquilaria Subintegra leaves from the appearance, chemical composition and moisture content. The experiment were taken with drying temperature of 40, 50 and 60^{o}C in a vacuum far infrared drying.

The higher the temperature, the shorter time taken to achieve constant moisture content. Drying temperature also affecting the moisture ratio which the higher the temperature, the reduced the drying time to bring moisture ratio to constant. This also applied to drying rate which the higher the temperature, the higher the drying rate. Drying temperature significantly affecting the moisture content, moisture ratio and drying rate. The best fitted mathematical modelling is Page comparing with Two-Term and Modified Henderson and Pabis.

Acknowledgment

Huge gratitude to my supervisor and Universiti Teknologi Mara.

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