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The Effect of Operating Conditions on Drying Characteristics and Quality of Ginger (Zingiber Officinale Roscoe) Using Combination of Solar Energy-Molecular Sieve Drying System

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Abstract. Ginger (*Zingiber officinale* Roscoe) is an agricultural product that can be used as beverages and snacks, and especially for traditional medicines. One of the important stages in the processing of ginger is drying. The drying process intended to reduce the water content of 85-90% to 8-10%, making it safe from the influence of fungi or insecticide. During the drying takes place, the main ingredient contained in ginger is homologous ketone phenolic known as gingerol are chemically unstable at high temperatures, for the drying technology is an important factor in maintaining the active ingredient (gingerol) which is in ginger. The combination of solar energy and molecular sieve dryer that are used in the research is capable of operating 24 hours. The purpose of this research is to study the effect of operating conditions (in this case the air velocity) toward the drying characteristics and the quality of dried ginger using the combination of solar energy and molecular sieve dryer. Drying system consist of three main parts which is: desiccator, solar collector, and the drying chamber. To record data changes in the mass of the sample, a load cell mounted in the drying chamber, and then connected to the automated data recording system using a USB data cable. All data of temperature and RH inside the dryer box and the change of samples mass recorded during the drying process takes place and the result is stored in the form of Microsoft Excel. The results obtained, shows that the air velocity is influencing the moisture content and ginger drying rate, where the moisture content equilibrium of ginger for the air velocity of 1.3 m/s was obtained on drying time of 360 minutes and moisture content of 2.8%, at 1.0 m/s was obtained on drying time of 300 minutes and moisture content of 1.4%, at 0, 8 m/s was obtained at 420 minutes drying time and the moisture content is 2.0%. The drying characteristics shows that there are two drying periods, which is: the increasing drying rate, and the falling drying rate, while the constant drying rate is not visible. The result of ginger quality shows that there are no significant changes in the organoleptic analysis, the ash content is about 7.52-7.94% and the oil content is 0.79-0.83%.

1. Introduction

Fresh ginger (Zingiber officinale roscoe) root is usually consumed as spice in the tropical countries and dried ginger is used as medicinal plant internationally. Dried ginger is produced from the mature rhizome. As the rhizome matures, the flavor and the aroma become much stronger. Dried ginger can be used directly as a spice or medicine. Ginger possesses a stimulant, aromatic and carminative properties when taken internally and when chewed it acts as a sialagogue. Quality demand for export as medicinal herbs, require the ginger to be properly cut into pieces, well dried and stored properly [1].

The product quality is determined from the distinctive aroma of ginger, spiciness (pungency) and also the purity of organic ingredients it contains. Therefore, post-harvest processing is a measure of success in maintaining the quality of ginger [2].

One of the post-harvest handling done today is by drying using direct sun. This drying model certainly cannot guarantee the uniformity of quality because the changes in weather, the high temperature at midday, and the material is dried in the open, so the cleanliness of the product is not guaranteed [3].


(a)


(b)

Figure 1. (a) Fresh Ginger (b) Dried Ginger

The main advantage of the combination of solar energy and molecular sieves dryer is the ability to produce good quality of dried ginger and uniformity. This is due to the drying takes place using a drying medium (air) which has a relatively uniform moisture. The uniformity in humidity of the drying media is achieved by passing atmospheric air into the molecular sieve, while in the sweltering afternoon the solar energy is also used to regenerate the saturated molecular sieves [4]. This dryer is a compact device and easy to operate. Moreover, the material is dried inside the box so the cleanliness of the product is guaranteed. This research aimed to study the effect of operating conditions,which is the dryer medium velocity towards the drying kinetics, drying characteristics and quality of dried ginger using the combination of solar energy and molecular sieve dryer.

2. Method

2.1. Sample Preparation

Ginger Rhizome was obtained from Pancur Batu regency of Sumatera Utara province of Indonesia. Ginger is firstly cleaned from dirt that attached to the rhizome, then washed with water and then drained. Before drying, the fresh gingers were peeled using cutter, then the ginger was cut into thin slices of 1 mm thick, then weighed 500 grams for one batch, then placed on a tray with holes, then put in a dryer box. The dry weight of ginger samples was analysed using an oven at 110^{o}C for 24 hours. The desiccant used is a molecular sieve.

2.2. Experimental Apparatus

The preliminary study consists of 3 parts, i.e. (i) to design the drying system including the solar collector, molecular sieve, and drying chamber; (ii) to investigate the drying characteristics related to moisture content and drying rate ; (iii) to examine the quality of dried ginger. To avoid or to reduce the intermittent effects, some researchers proposed solar dryer integrated with a thermal energy storage material to store excess heat in the daytime and uses it in the night time [5].

In order to design the drying system, it should be noted that the integrated system of solar energy and molecular sieve is applying dried air for the drying process. The very low humid dried air was produced by conducting the air from atmosphere through a molecular sieve. The solar energy will be converted to heat energy in the solar collector. The heat will be applied to remove water vapor from the humid air. Most of the dried hot air produced will be used to draw the moisture from the molecular sieve, while less dried hot air will be applied as the drying medium at the same time. The desiccant is then heated using direct solar energy in order to release the moist of the molecular sieves.

A prototype solar dryer has been fabricated and used in experiments. The integrated solar dryer for the day time drying is shown in Figure 1(a) and for the night time drying is shown in Figure 1(b). It consists of three main components: drying chamber; solar collector, and desiccant. The drying chamber is a room with dimension of 50 cm x 50 cm x 50 cm. The solar collector is a flat plate type with dimension of 2 m x 0.5 m x 0.1 m. The collector was black-painted and made of 1 mm galvanized steel sheet. Two plain window glasses separated by a 2 cm air gap were used as transparent covers to prevent the heat loss from the top. The solar collector was oriented Northward with a tilt angle of 60^{O}. The dried gingers rhizome were spread in a drying tray made of perforated aluminum sheet with an area of 49 cm x 49 x 3 cm. the desiccant was placed in an open container made of steel with dimension of 30 cm x 30 cm x 5 cm.

The solar dryer was operated in two drying modes, daytime and night time. In the daytime, the gingers rhizome is dried inside the drying chamber by using hot air resulted by the solar collector. In the night time, the desiccant is placed inside the drying chamber along with gingers rhizome and the drying chamber was isolated from the ambient air. Thus, the drying process will be continued, even though temperature is relatively low, with low RH, because part of the moisture in ambient air is absorb by molecular sieves before contacting the ginger. The meaning of continuous term here is that during sunshine hours and off-sunshine hours the drying process is uninterrupted. In all experiments, temperatures, mass of the gingers rhizome, relative humidity and air velocity, were recorded. To measure the humidity inside the drying chamber, 2 USB Temperature Humidity Data Logger were used. The accuracies of temperature and relative humidity were 70.5 ^{O}C and 73% RH, respectively. The mass of the gingers rhizome was measured using a load cell weight system data logger with an accuracy of 0.001 kg. The desiccant mass was measured using an analytic balance (Mettler Toledo, USA) with capacity of 500 g and accuracy of 0.01 g. The scheme of the solar dryer and data measurement systems are shown in Figure. 1.

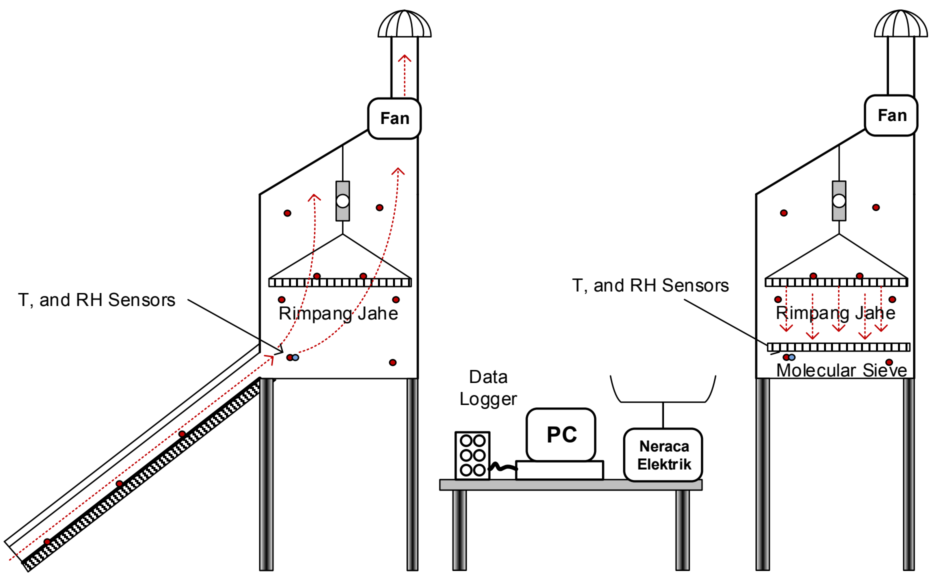

Figure 2. Schematic of The Solar Dryer and Measurement Systems

3. Results and Discussions

The effect of operating conditions on the drying kinetics, characteristics, and quality of ginger is studied by experimenting various air velocity. This causes the air velocity flowing into the drying box increased as well.

3.1. Effect of Drying Air Velocity on Drying Kinetics

Drying kinetics curves of ginger rhizome are the result of plotting the changes in the normalized moisture content (X*) during the drying time (t). The Normalized moisture content is the moisture content at one time divided with the highest moisture content at one time. The curve for moisture content versus time and the curve of the drying kinetics of ginger at air velocity of 0.8. 1,1 and 1,3 m/s is presented in Figure 2. drying kinetics curve is in the form of an exponential curve, it explained the early stages of drying where removal of unbound water occurs, followed by removal of the bound water from the material. Figure 2 shows that at a higher velocity of dryer air, drying time becomes shorter, meaning that the higher the velocity of air, the removal of water from the material is faster. From this curve also shows that the equilibrium of moisture content of ginger for air velocity of 1.3 m / s was obtained on drying time of 360 minutes, at 1.0 m / s was obtained on drying time of 300 minutes, at 0, 8 m / s was obtained at 420 minutes drying time. The final moisture content of the dried ginger rhizome is about 1.4-2.8%. The final moisture content value of dried ginger rhizome meets the commercial market demand which is around 10-12%.

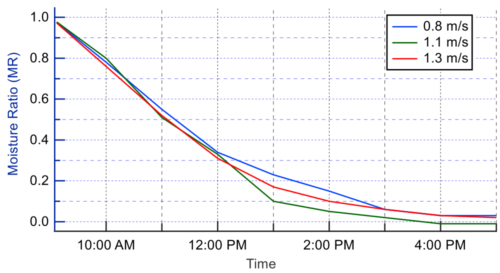

Figure 3. Moisture Ratio (X*) vs Drying Time (t) on Different Air Velocity

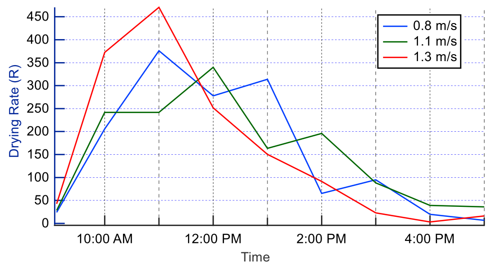

Figure 4. Drying Rate (R) vs Drying Time (t) on Different Air Velocity

3.2. Effect of Drying Air Velocity on Drying Characteristics of Ginger

Krischer curve or curve that is not relying on the time is the drying rate curve vs. Moisture content [6]. Usually this curve is obtained from the combination of the drying curve and the curve of drying content. These curves are used as the basis for the drying characteristic curve. This curve can be explained drying mechanism better by describing the rate changes in the moisture content of the sample (dx / dt) towards the moisture content of the material (X). Regarding the product quality, this study examined the product of dried ginger encountered with the physical appearance and chemical composition before and after the drying process applying the designed integrated solar drying –molecular sieve system. This study determined the drying rate on the base of formula proposed by Lopez et al [7], i.e.

$$\frac{dx}{dt}=-k(X-X_e) \quad (1)$$

where:
X = moisture content (dry basis, g/g)
Xe = equilibrium moisture content (dry basis, g/g)
k = a constant
t = drying time (min)

If the above equation is integrated with the state of initial limit at t = 0, and X = 0, then the drying rate equation obtained :

$$\frac{X-Xe}{X_0-Xe}=e^{-kt} \quad (2)$$

The mathematical model may be used for various drying processes. Van Meel [8] was the first to propose a normalized drying characteristic curve, which was then developed by Keey [9]. The drying characteristics curve are defined as drying rate vs. Normalized moisture content as shown in figure 5. The drying characteristics curve is a parabolic curve over the range of air velocity variation. In describing the characteristic curve for normalized drying, the moisture content has to be in normalized graph.

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$$(X)^* = X - Xe/ X_{cr} - X_e \text{ vs Drying Rate } (dx/dt) \quad (3)$$

Drying characteristic curve is defined as the drying rate curve vs normalized moisture content as shown in Figure 5. The drying characteristic curve is in the form of a parabolic curve over a range of varied velocity. Figure 5. also indicates that the air velocity of 0.8 m/s has three drying period, the air velocity of 1.1 m / s has three drying period, while the air velocity of 1.3 m / s are found only two drying period , Keech et al. [10] reported that there were two period found in a drying process, namely the constant drying rate period (constant rate drying period) and the decreases drying rate period (falling drying rate period) that goes fast and slow. Yet according to Chen in the journal reported by Polat [12] in addition to a second period which should have been reported above there is also another very important period, that period is the increasing drying rate period, because half of the drying process occurs in this period.

In Figure 5, it is shown that the changes in the rate of drying towards the moisture content ginger rhizome that dried using a combination of solar energy dryers and molecular sieves. Both curves keep to the drying theory, which is divided into increasing drying rate periods, falling rate drying period and the constant drying rate period is not visible. This study is similar to what Polat [11] and Chen and Douglas [12]. Chen states that the ascending drying period is a very important event because of approaching almost half than the overall drying.

In Figure 5 it is also shown that the increasing drying rate period increases abruptly to the top of the curve (maximum drying rate). At the maximum drying period the constant drying rate period should happen because at this stage, the surface of the material will always be wet, so the drying rate becomes constant. But the constant drying rate does not appear on all three air velocities. The highpoint of the drying curve is the maximum drying rate, that depends on the operational state of drying (this case is air velocity). The higher the air speed then the highpoint of the curved obtained higher and brief.

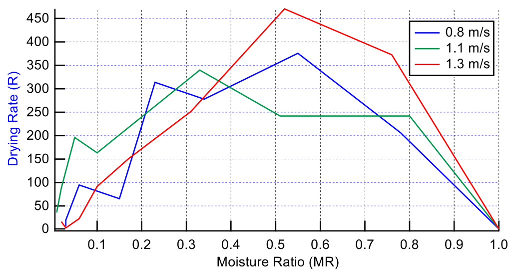

Figure 5. Drying Characteristics Curve of Dried Ginger

3.3. Effect of Air Velocity on Quality of Dried Ginger

Table 1. Quality Test Result on Varied Air Velocity

Air Velocity	Unknown Objects	Existence of Fungi	Odour/ Aroma	Taste	Shape/ Texture	Colour	Ash Content %	Moisture Content %	Oil Content %
0,8 m/s	None	None	Normal/ Typical	Normal/ Typical	Normal/ Solid	Normal/ Typical	7.68	2.80	0.80
1,1 m/s	None	None	Normal/ Typical	Normal/ Typical	Normal/ Solid	Normal/ Typical	7.94	1.40	0.83
1,3 m/s	None	None	Normal/ Typical	Normal/ Typical	Normal/ Solid	Normal/ Typical	7.52	2.00	0.79

From the analysis of quality test for ginger rhizome before and after the drying using combination of solar dryers and molecular sieves with a variation of air velocity as shown in table 1 above which is done by Baristand (Badan Riset dan Standarisasi Sumatera Utara), there are no differences in the results between ginger that is dried at air velocity of 0.8, 1.1 and 1.3 m / s, with the dried ginger that is dried without the help of a fan in the case organoleptic analysis. The dried ginger rhizome using a combination dryer with the variation of 0.8 m/s, 1.1 m/s, 1.3 m/s has a moisture content respectively %, %, % and oil content respectively 0.80%, 0.83%, 0.79%. All the results of the analysis shown for organoleptic are in accordance with SNI standards for dried ginger rhizome where there are no significant changes in between the ginger that is dried with fan and not using fan.

Table 2. Indonesian National Standard (SNI 01-3393-1994) for Dried Ginger

Characteristics	Quality Req.	Methods
Odor/Aroma	Typical	Organoleptic
Moisture Content, % (weight/weight), max	12,0	SP-SMP-7-1975 (ISO R 939-1969 (E))
Oil Content, ar (ml/100g), min	1,5	SP-SMP-37-1975
Ash Content, % (weight/weight), max	8,0	SP-SMP-35-1975 (ISO R 929-1969 (E))
Existence of Insects and molds	None	Organoleptic
Unknown Objects, % (weight/weight), max	2,0	SP-SMP-32-1975 (ISO R 937-1969 (E))

4. Conclusions

The combination of solar energy and molecular sieve dryer have proven to be capable of drying ginger rhizome until the moisture content is 1.4%. The operating conditions, which is the air velocity affect the drying kinetic and drying characteristics of ginger, but does not giving a significant impact in the quality of dried ginger. Effect of air velocity is very evident in the removal of moisture content. In various velocity of air, the drying characteristic consist of an increasing drying rate and falling rate drying periods, while the constant drying rate is not visible because it is very short which is visible only in the form of peak point. At the air velocity of 1.3 m/s, 1.1 m/s, and 0.8 m/s, moisture content is reduced respectively to 2.0%, 1.4%, and 2.8% with the drying time of 360 minutes, 300 minutes, and 420 minutes.

Base on this results, it is indicated that the combination of solar energy and molecular sieve dryer proved capable of drying heat sensitive product like ginger because the drying process conducted at low temperature and relatively low RH. Also, the solar drying system may be developed for pilot scale because the contribution of energy from solar is very high**.**

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