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Drying Performance of *Piper Nigrum* in a Swirling Fluidized Bed Dryer: An Experimental Study

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ABSTRACT

Sun drying is widely used in drying agricultural products such as piper nigrum because of its ability to dry a high volume in one batch. However, this conventional method of drying has many disadvantages, especially on the hygienic issue. This study investigates the drying performance of piper nigrum by using conventional sun drying and a new dryer called Swirling Fluidized Bed Dryer. Swirling fluidized bed dryer is operated using two inclination angles of air distributors, namely 45°, 67° and one perforated plate distributor. The drying performance is accessed in terms of drying time and moisture content reduction at three different operating temperatures. The results show that the drying time of piper nigrum using a swirling fluidized bed dryer is reduced as compared to conventional sun drying. Besides, the drying performance between different distributors in swirling fluidized bed shows that the moisture content reduction of piper nigrum using 45° angle of air distributor shows the most reduction compared to 67° angle distributor and followed by the perforated distributor. In conclusion, results show that the drying of piper nigrum in a swirling fluidized bed operated with 45° inclination angle of the distributor at high operating temperature gives the best performance.

1. Introduction

Black pepper is the most significant used spice in the world and known as the “king of spices” or “black gold” by traders hundreds of years ago [1]. Scientifically known as *Piper nigrum L.*, black pepper is mainly used as a flavouring and seasoning agent. Besides, active ingredients from black pepper have multi applications in medicines, insecticides, and perfume [2]. Black pepper is collected from unripe green berries of the pepper plants and has a pungent smell. The drying process is required to preserve the quality and taste of the black pepper. During the drying process, the colour transformation occurs from green to black as a result of enzymatic browning [3].

Drying is the method of thermally extracting water content to yield a reliable product. In many agricultural fields and food industries, drying is a significant operation. The most efficient and economical way to preserve the quality of the product is through drying [4]. Most food products

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experience the drying process to boost shelf-life, lower packaging costs, cut back transportation load, improve appearance, encapsulate original taste, and maintain organic process value [5,8]. The minimum moisture content that should be removed from black pepper is 12% to prevent the growth of moulds during storage [6]. By removing the moisture, it prevents the mould from growing and spoil the food [7]. There are two stages in the drying process. The first step occurs at the material surface, where the drying rate is constant, and the water vaporization to the surrounding is the same. The second stage starts when the drying rate is beginning to decrease. Due to the quality of the material to be dried, the condition for the second stage was determined [9]. Many products such as vegetables, fruits, grains, fish, meat, wood, and other agricultural products can be preserved by drying directly under the sun [10]. The objective of drying is to reduce moisture content in agricultural products. The dry field is easy to use but difficult to monitor the environmental factors such as animals and dirt from the surrounding [11]. The typical agricultural product preservation approach, such as grains, fruits, and vegetables, is by open sun drying, and this technique applies in most developing countries, such as tropical countries. However, sun drying has disadvantages such as non-uniform sunlight during the day and problems when it comes to rainy seasons that causing significant losses to dried goods in quantity and quality [9,12]. There are few known limitations of sun drying as damage to the crops by animals, birds, and rodents, decreasing in quality due to direct exposure to solar radiation, dew or rain, contamination by dirt, dust, and debris. Besides the environmental causes, this technique is time-consuming as crops must be covered against animals by night and bad weather [10].

The new method that was introduced to preserve the piper nigrum is drying using a swirling fluidized bed dryer (SFBD). The most effective approach was swirling fluidized bed drying, and the fluidization system is generally suspended in hot air or stream [13]. Swirling fluidized bed dryer is used for drying different products because the drying rate is very high due to the excellent gas-solid contact, relatively low cost and high thermal effectiveness [14,15]. The mechanism in a swirling fluidized bed dryer for the drying process is hot air flows through the bed of the distributor at a relatively high velocity to resist the force of gravity of the material [16]. When the air velocity is higher than the force of gravity and bed resistance, the product is suspended [17]. When this happens, fluidization, a physical process that converts solid particles into a fluidized state by suspension in a liquid or gas, is called this condition [18,19]. A heavy piper nigrum will sink, and partially dried piper nigrum will float [5]. A fluidized bed dryer offers advantages such as smooth operation and transportation of solid at high heat and mass transfer rates, optimized material mixing in bed and the possibility to use other sources of energy, including heating coils [20,21]. Swirling fluidized bed dryer is widely used because of its high heat transfer coefficients and uniform temperature [22,23]. It is commonly used in many commercial applications such as chemical production, drying, coating, roasting [24]. The drying temperature and speed of air usually affect the drying rate considerably. The SFBD can reduce the moisture content of Piper nigrum more rapidly than a conventional fluidized bed dryer (FBD) [25]. With the significant advantages offers by the swirling fluidized bed dryer, this study aims to compare the performance of the drying piper nigrum using conventional sun drying and swirling fluidized bed drying. In this study, drying using a swirling fluidized bed dryer is introduced with different distributor configurations, namely, perforated, 45°, and 67° distributor, to increase the drying rate of piper nigrum.

2. Methodology

The piper nigrum was obtained from a pepper farm located at Pusa, Sarawak. It was freshly picked and come with spikes that have raw green colour pepper attached. Raw piper nigrum was stored in a refrigerator to maintain its quality and taken out at least 1 hour before the experiment. The raw pepper has been removed manually from the spikes and left to rest at room temperature.

This study involves two experiments, which are conventional sun drying and swirling fluidized bed drying. The result of both dryings was varied using the drying parameter. Moisture content and moisture ratio are the critical parameters used to measure the drying effect. It is necessary to calculate the loss in moisture content reduction to achieve the research outcome. Drying curves obtained under controlled conditions provided significant details regarding the mechanisms for water transport and were used to determine the effective diffusion coefficient. The moisture content (M) at any time of drying (%), was calculated according to Eq. (1). In contrast, W_i is the initial weight of the piper nigrum before drying, and W_d is the weight of piper nigrum after drying:

$$M = \frac{W_i - W_d}{W_i} \times 100\% \tag{1}$$

The reduction in moisture ratio with drying time was used to analyze the experimental drying data. The moisture ratio (MR) is the moisture left in the sample at the first moisture content recorded [26]. It was calculated using Eq. (2), whereas M is the weight of the piper nigrum for each drying hour and day, M_e is the minimum weight of the Piper nigrum that should be reduced, and M_o is the initial weight of the piper nigrum before drying process:

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{2}$$

The equilibrium moisture content (M_e) was measured until no further weight change in each experiment [27].

The conventional sun drying was conducted in an open space under sunlight without any shades of buildings or trees. The initial weight of 1000 grams of piper nigrum was weighed and dried on the rattan tray, as shown in Figure 1. The temperature of the piper nigrum and the surrounding air were recorded using the temperature data logger, as shown in the experimental setup in Figure 1. The piper nigrum was exposed to the sunlight from 9.00 am until 6.00 pm. The weight before and after drying of piper nigrum was measured and recorded each day until the piper nigrum were thoroughly dried.

Fig. 1. The conventional sun drying set up with the data logger

The experiment using a swirling fluidized bed dryer was varied by using three different inclination angles distributors: perforated, 45°, 67° inclination angle distributor, and three different temperatures, room temperature, medium and high temperature. A 1000 gram of raw piper nigrum was weighed and inserted into the bed of the swirling fluidized bed dryer, in which the experimental setup is shown in Figure 2.

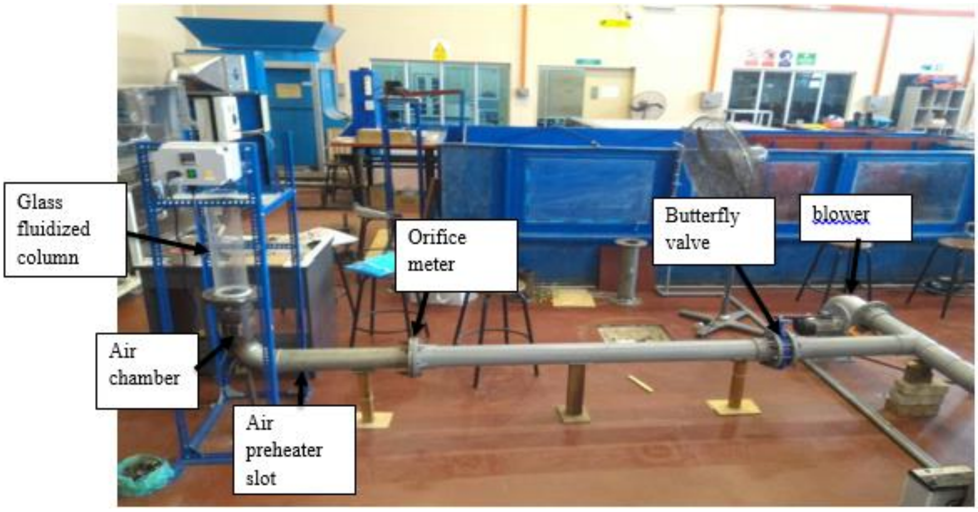

Fig. 2. The swirling fluidized bed dryer setup

The swirling fluidized bed drying system consists of a glass drying chamber, an inter-changeable distributor slot, and a blower. The size of the glass drying chamber used for the study is 108 mm internal diameter and 310 mm length, which is made of silica glass sheets of thickness 5 mm. The air distributor system consists steel plate that has the same diameter as the glass column's flange was mounted at the bottom. The metal plate is connected to the air plenum's flange and act as a distributor holder where interchangeability of distributor plate was allowed to be performed. Fluidization air was supplied by a medium pressure blower (BAK Type MD14) with a maximum flow rate capacity of 0.275 m^3/s. An orifice meter was installed 13*D* downstream of the plenum chamber along a 3" diameter PVC pipeline to measure the airflow rate by the mean pressure difference. In this study, the experiment was performed with three different operating temperatures of air, namely, room-temperature, medium-temperature and high-temperature. The temperature recorded was about 27 to 34 degrees Celsius for room-temperature experiments when the air heater is turned off. For medium-temperature experiments, the temperature of air recorded by the data logger ranged from 34 to 50 degrees Celsius. For high-temperature experiments, the temperature of air recorded by the data logger ranged from 47 to 59 degrees Celsius. The experimental apparatus was instrumented with HUATO HE804 temperature data logger with temperature accuracy of ±1℃±5‰ as shown in Figure 3. This was achieved by probing four thermocouple probes, equally spaced at 90° around the circumference of the bed at four different axial locations just above the distributor. Figure 4 shows the position of the thermocouple at the fluidized bed dryer.

Fig. 3. The HUATO HE804 temperature data logger for temperature recording

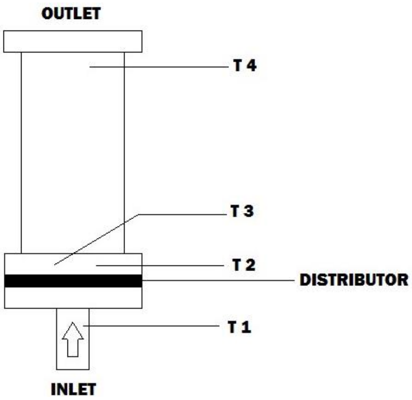

Fig. 4. Schematic diagram of the position of the thermocouple at fluidized bed dryer

The 1000 g piper nigrum was poured into the swirling fluidized bed dryer from the top fluidized bed inlet. The piper nigrum was weighed with an electronic weighing scale before pouring into the swirling fluidized bed dryer to calculate its original moisture content. The blower was turned on, and the speed of the blower was set to the maximum flow rate for all drying experiments. Depending on the experiments, for example, for experiments at room temperature, the electric heater was turned off so that the drying air is operated at room temperature. After the piper nigrum was dried, it was weighed again to calculate the moisture ratio and to calculate moisture content loss reduction.

The experiments were repeated with three different types of distributors, namely perforated plate, 67° and 45° inclined distributors, as shown in Figure 5. Due to the large perforation area of the distributors compared to the size of the piper nigrum used in the experiments, 100 μm-size mesh screen was fixed on top of the distributors to prevent the piper nigrum passing through the distributors. The perforated distributor consisted of 97 holes, each 4mm diameter and was arranged evenly spaced concentric rectangular having 11% opening. The distributor geometry then was modified to introduce a novel swirling distributor by making a circular edge opening consists of 8 air slots with 6.5mm diameter and 29mm long circular edged openings extended to the peripheral of the distributor with 45° and 67° inclination angle air intake. The opening ratio for the swirling distributors is 13%.

(a) (b) (c)

Fig. 5. The photograph of the different inclination angle distributor, (a) perforated distributor, (b) 45° distributor, (c) 67° distributor

3. Results

3.1 Conventional Sun Drying Experiment

The conventional sun drying experiment took place on a sunny day, and the investigation begins 9.00 am to 6.00 pm for three days. A raw piper nigrum without the stem was weighed at 1000 g and then were spread in a thin layer under the sunlight. After 9 hours of drying, the weight of the piper nigrum was measured. During the experiment, four thermocouples were placed on the rattan tray to record the temperature of the piper nigrum and the surrounding air. Figure 6(a) shows the experimental setup for conventional sun drying of piper nigrum with the location of the thermocouple. Initially, the physical colour of piper nigrum consists of black and green colour berries. After three days of drying, the visual inspection of the piper nigrum shows that the outer layer of the piper nigrum is turning to a blackish grey colour as shown in Figure 6(b). The outer layer of piper nigrum also found to shrink and was covered with some surrounding debris.

(a) (b)

Fig. 6. The visualization of piper nigrum (a) before drying and (b) after conventional sun drying

Table 1 shows the results of the conventional drying of piper nigrum and Figure 7 show the graph of the conventional sun drying of piper nigrum.

Table 1
Conventional sun drying

Drying time (day)	Weight before (g)	Weight after(g)	Weight loss (%)	Moisture ratio
0	1000	1000	0	1
1	1000	674	32.6	0.6295
2	674	483	51.7	0.4125
3	483	329	67.1	0.2375

Table 1 shows the weight reduction of piper nigrum for conventional drying. It can be seen from the data that the piper nigrum took three days to dry until the final weight reached 329 g from the initial weight of 1000 g. The weight is significantly reduced by 32.6 % on the first day of drying, followed by 19.1% on the second day and 15.4% weight reduction on the third day. After three days of drying, the percentage of total weight loss from 1000 g is 67.1%. The moisture ratio of the conventional sun drying is proportionally decreased as the day of the drying time increase, as shown in Figure 7. The moisture ratio for the first day is 0.6290, followed by 0.4125 for a second day and 0.2375 for the third day of the conventional sun drying experiment.

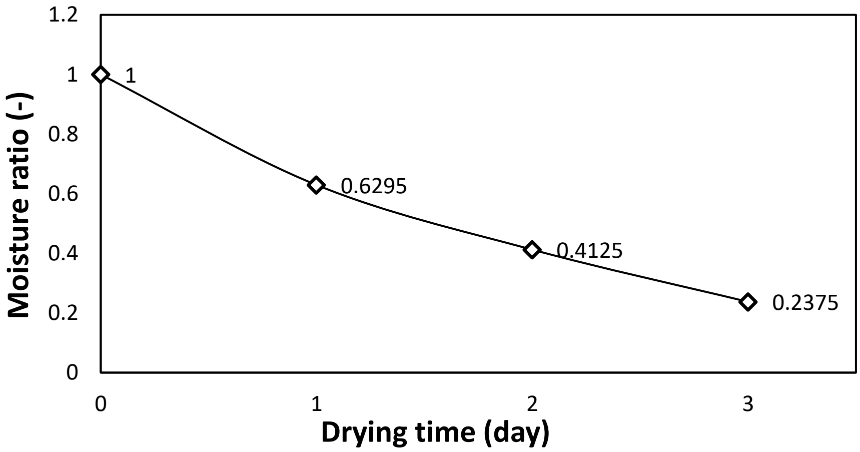

Fig. 7. Graph of the moisture ratio of conventional sun drying vs time taken for drying

Figure 8 shows the average temperature over the dying time-recorded by the thermocouples on the drying tray. Thermocouples T1, T2 & T3 were immersed inside the piper nigrum on the rattan tray. Meanwhile, thermocouple T4 is located in a position where it recorded the temperature of the surrounding air. From the graph, it can be seen that the temperature of the surrounding air T4 is in the range of 28°C to 37°C. Meanwhile, the recorded temperature of the piper nigrum (T1, T2, T3) is from 28°C to 56°C. The maximum temperature recorded by the thermocouples T1, T2, and T3 at 55-56°C is due to the intense heat that accumulated and trapped inside the spread layer piper nigrum although the surrounding temperature is in the range of 28°C to 37°C.

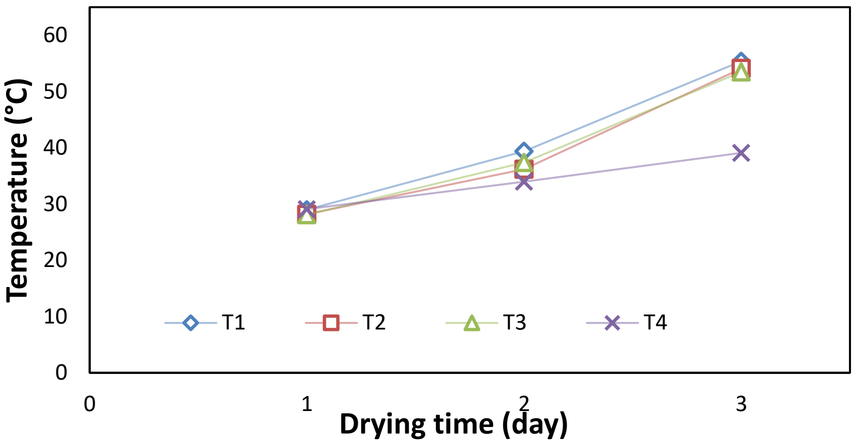

Fig. 8. The temperature of the conventional sun drying vs time taken for drying

3.2 Swirling Fluidized Bed Drying Experiment

The drying experiments in a swirling fluidized bed dryer were performed with three different operating temperatures of air, namely, room temperature, medium temperature (40°C) and high temperature (50°C). The experiments are repeated with three different distributors, namely perforated plate, 67° and 45° inclined distributors. 1000 g of piper nigrum, the same weight as the experiment conducted by using conventional drying, was investigated in the swirling fluidized bed dryer. Figure 9 shows the condition of the piper nigrum in a bed of swirling fluidized bed dryer before drying before the experiment.

Fig. 9. The condition of piper nigrum in a bed before drying experiment

3.2.1 The Swirling fluidized bed drying experiment using perforated distributor

The drying process by using a swirling fluidized bed dryer was initiated by using a perforated plate distributor at room temperature. The experiments were then repeated by changing the fluidizing air supply from room temperature to heated air supply of two elevated temperatures at 40°C and 50°C. A perforated distributor has 97 holes through the distributor and is different from the 67° and 45°

inclined angle distributors. The perforated distributor was chosen to be investigated in this study. It acts as a baseline for the conventional-type distributor used currently in the fluidised bed dryer market. The perforated distributor will not create a spiral air pattern as compared to the inclined type distributor. Figure 10 shows the flow pattern of piper nigrum using a perforated distributor during the drying process in a fluidized bed dryer.

Fig. 10. The swirling pattern of piper nigrum using a perforated distributor

Table 2 to Table 4 show the weight reduction (every three hours), percentage of the weight loss, and the moisture content of piper nigrum by using a swirling fluidized bed dryer with a perforated distributor at three different temperatures. The moisture ratio of the drying in a swirling fluidized bed operated with a perforated plate at three different operating temperatures is proportionally decreased as the drying time increase as shown in Figure 11. From the data collected, it can be concluded that the high operating temperature is the recommended temperature to dry the piper nigrum using a swirling fluidized bed dryer with the perforated distributor because it shows the most moisture reduction after 9 hours drying process. The final moisture ratio of the piper nigrum is 0.315 for the high-temperature experiments (60.5% weight loss), 0.438 for the medium temperature experiments (49.5% weight loss), and 0.713 for the room temperature experiments (25.3% weight loss).

Table 2
The swirling fluidized bed drying using perforated distributor at room temperature

Drying time (hr)	Weight before (g)	Weight after(g)	Weight loss (%)	Moisture ratio
0	1000	1000	0	1
3	1000	891	10.9	0.8761
6	891	807	19.35	0.7801
9	807	747	25.3	0.7125

Table 3
Swirling fluidized bed drying using perforated distributor at medium temperature

Drying time (hr)	Weight before (g)	Weight after(g)	Weight loss (%)	Moisture ratio
0	1000	1000	0	1
3	1000	778	22.2	0.7477
6	778	629	37.1	0.5784
9	629	506	49.45	0.4381

Table 4
Swirling fluidized bed drying using perforated distributor at high temperature

Drying time (day)	Weight before (g)	Weight after(g)	Weight loss (%)	Moisture ratio
0	1000	1000	0	1
3	1000	638	36.5	0.585
6	635	468	53.25	0.395
9	468	395	60.5	0.315

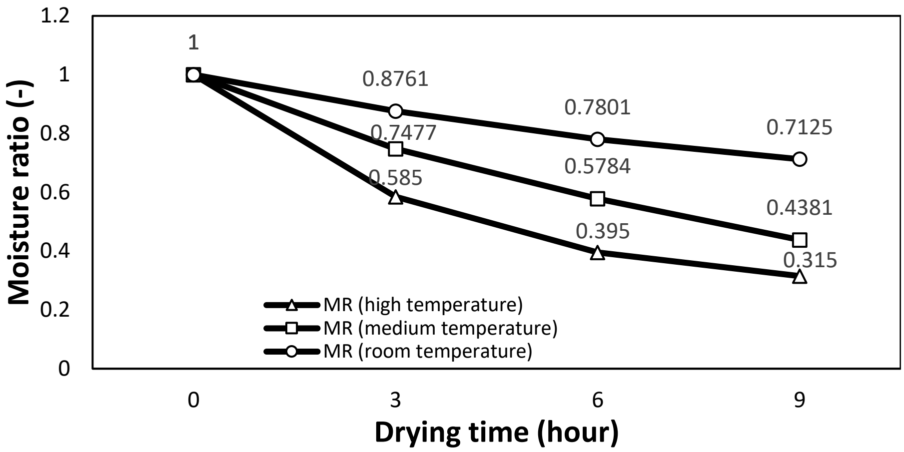

Fig. 11. The graph of the drying at three different temperature using perforated distributor

Figure 12 shows the graph of the airflow temperature inside the swirling fluidized bed dryer vs drying time. From the graph, the temperature variation and fluctuation is recorded more apparent between the thermocouples. It comes to understand that during the drying process in a perforated plate distributor, the bubble formations and bubble eruption through the perforated holes have caused the temperature fluctuations.

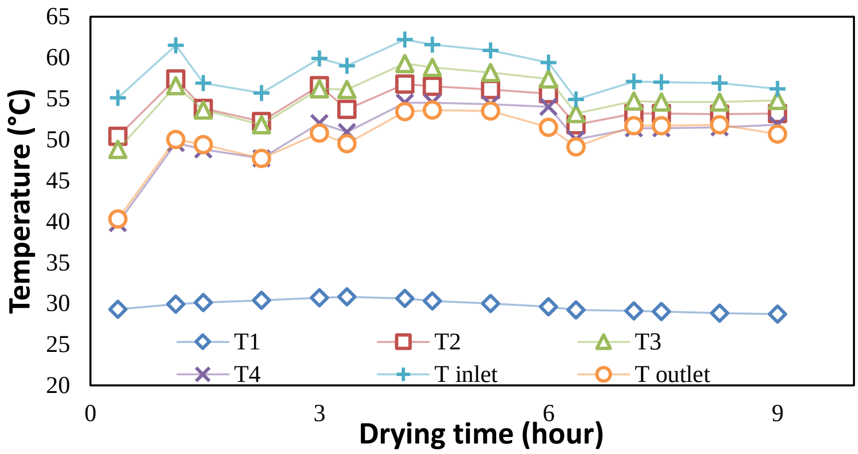

Fig. 12. The temperature vs drying time taken at high temperature using perforated distributor

3.2.2 The swirling fluidized bed drying experiment using 45° inclination angle distributor

While the experiments with perforated plate distributor were conducted to give an overview of the drying by using conventional distributor of fluidized bed dryer, the experiments using 45° angle distributor were undertaken to investigate the effect of inclination angle on drying in a swirling fluidized bed dryer. Three operating temperature experiments were conducted – room temperature, medium operating temperature and high operating temperature to investigate the effect of operating temperature on drying of piper nigrum in a swirling fluidized bed. Contradict to perforated plate, the 45° angle distributor will create the swirling air pattern in a fluidized bed. Figure 13 below shows the swirling pattern of the piper nigrum during the drying process using a 45° angle distributor.

Fig. 13. The swirling pattern of the piper nigrum during the drying process using a 45° angle distributor

Table 5 to Table 7 show the result for the weight reduction (every three hours), percentage of the weight loss, and the moisture content of piper nigrum using a swirling fluidized bed dryer with a 45° angle distributor at three different temperatures. The moisture ratio at three different operating temperatures is proportionally decreased as the drying time increases, as shown in Figure 14. The data collected shows that the high operating temperature is the recommended temperature to dry the piper nigrum using a swirling fluidized bed dryer with 45° angle distributor because it shows the most moisture reduction after 9 hours drying process. The final moisture ratio of the piper nigrum is 0.215 for the high-temperature experiments (68.7% weight loss), 0.319 for the medium temperature experiments (59.9% weight loss), and 0.561 for the room temperature experiments (38.7% weight loss).

Table 5
Swirling fluidized bed drying using 45° angle distributor at room temperature

Drying time (hr)	Weight before (g)	Weight after(g)	Weight loss (%)	Moisture ratio
0	1000	1000	0	1
3	1000	790	21.05	0.7608
6	790	700	30.05	0.6585
9	700	614	38.65	0.5608

Table 6
Swirling fluidized bed drying using 45° angle distributor at medium temperature

Drying time (hr)	Weight before (g)	Weight after(g)	Weight loss (%)	Moisture ratio
0	1000	1000	0	1
3	1000	632	36.8	0.5818
6	632	480	52.05	0.4085
9	480	401	59.9	0.3193

Table 7
Swirling fluidized bed drying using 45° angle distributor at high temperature

Drying time (day)	Weight before (g)	Weight after(g)	Weight loss (%)	Moisture ratio
0	1000	1000	0	1
3	1000	564.5	43.55	0.505
6	564.5	379	62.1	0.295
9	379	313	68.7	0.215

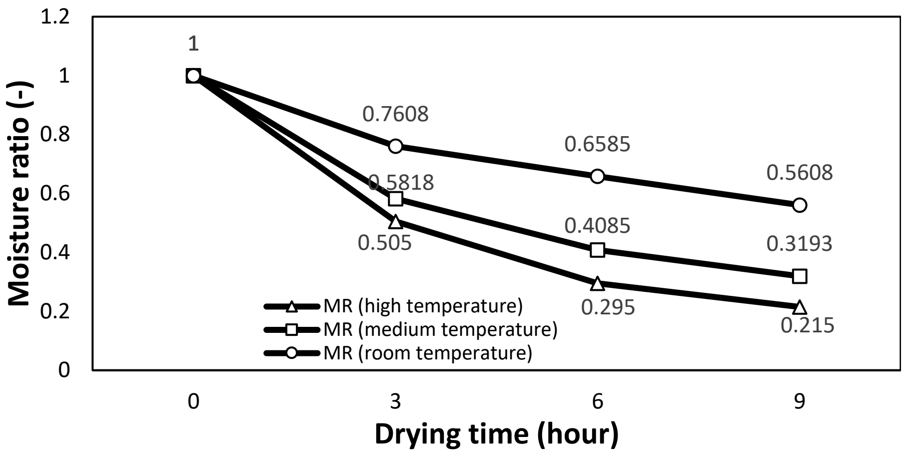

Fig. 14. The graph of the drying at three different temperatures using 45° angle distributor

Figure 15 shows the temperature variations over drying time for high-temperature experiments operated with 45° angle distributor. The temperature variation and fluctuation were recorded steadier between the thermocouples. It comes to understand that during the drying process by using 45° angle distributor, the swirling air flow has caused less temperature fluctuations than the experiments by using perforated plate distributor.

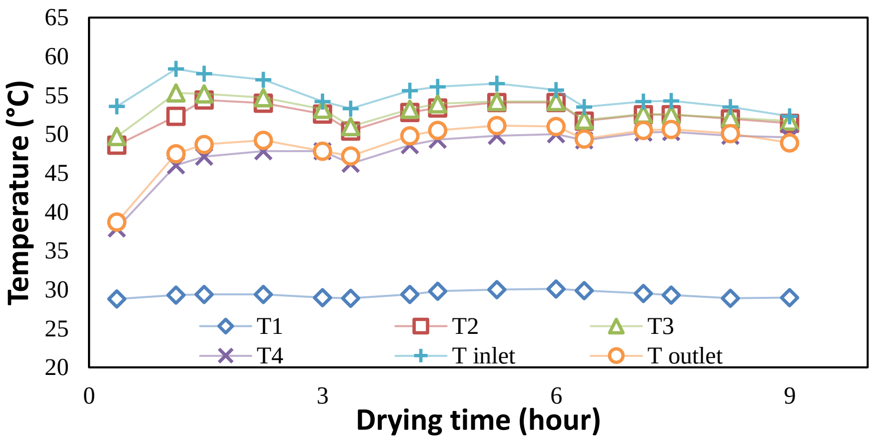

Fig. 15. The high temperature vs drying time at high temperature using 45° angle distributor

3.2.3 The swirling fluidized bed drying experiment using 67° inclination angle distributor

The experiment by using 67° angle distributor was conducted to investigate the effect of inclination angle on drying in a swirling fluidized bed dryer. Same with perforated and 45° angle distributor, three operating temperature experiments were conducted – room temperature, medium operating temperature and high operating temperature to investigate the effect of operating temperature on drying of piper nigrum in a swirling fluidized bed. Contradict to perforated plate distributor, the 67° angle distributor will create the swirling air pattern in a fluidized bed. Figure 16 below shows the swirling pattern of the piper nigrum during the drying process using a 67° angle distributor.

Fig. 16. The swirling condition of the piper nigrum using a 67° angle distributor in fluidized bed dryer

Table 8 to Table 10 show the result for the weight reduction (every three hours), percentage of the weight loss, and the moisture content of piper nigrum using a swirling fluidized bed dryer with a 65° angle distributor at three different temperatures. The moisture ratio of the drying in a swirling fluidized bed operated with a perforated plate at three different operating temperatures is proportionally decreased as the drying time increase as shown in Figure 17. From the data collected, it can be concluded that the high operating temperature is the recommended temperature to dry the piper nigrum using a swirling fluidized bed dryer with the perforated distributor because it shows the most moisture reduction after 9 hours drying process. The final moisture ratio of the piper nigrum is 0.330 for the high-temperature experiments (59.0% weight loss), 0.418 for the medium temperature experiments (51.2% weight loss), and 0.645 for the room temperature experiments (31.2% weight loss).

Table 8
Swirling fluidized bed drying using 67° angle distributor at room temperature

Drying time (hr)	Weight before (g)	Weight after(g)	Weight loss (%)	Moisture ratio
0	1000	1000	0	1
3	1000	850	15	0.8295
6	850	787	21.3	0.7580
9	787	688	31.2	0.6455

Table 9
Swirling fluidized bed drying using 67° angle distributor at medium temperature

Drying time (hr)	Weight before (g)	Weight after(g)	Weight loss (%)	Moisture ratio
0	1000	1000	0	1
3	1000	803	19.75	0.7756
6	803	657	34.3	0.6102
9	657	488	51.2	0.4182

Table 10
Swirling fluidized bed drying using 67° angle distributor at high temperature

Drying time (day)	Weight before (g)	Weight after(g)	Weight loss (%)	Moisture ratio
0	1000	1000	0	1
3	1000	594	40.65	0.535
6	594	492	50.8	0.425
9	492	410	59	0.33

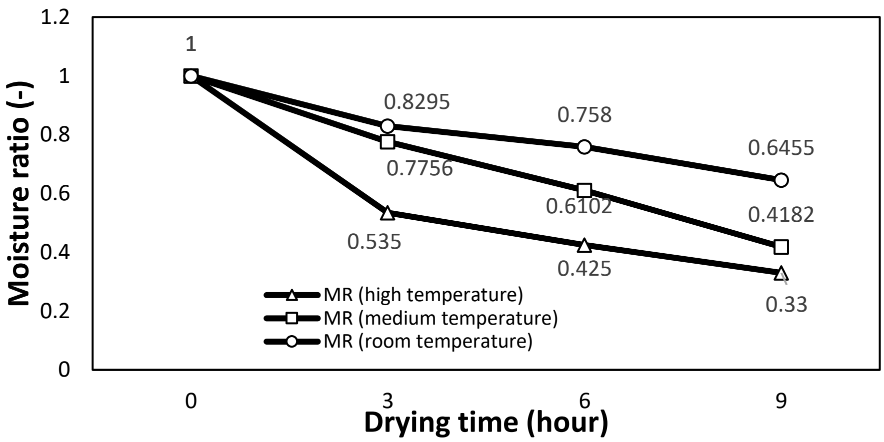

Fig. 17. The graph of the drying at three different temperatures using 67° angle distributor

Figure 18 shows the temperature variations over drying time for high-temperature experiments operated with 67° angle distributor. For the high-temperature experiments, temperature variation and fluctuation are recorded more stable between the thermocouples. It comes to understand that during the drying process by using 67° angle distributor, the swirling air flow has caused less temperature fluctuations than the experiments by using perforated plate distributor.

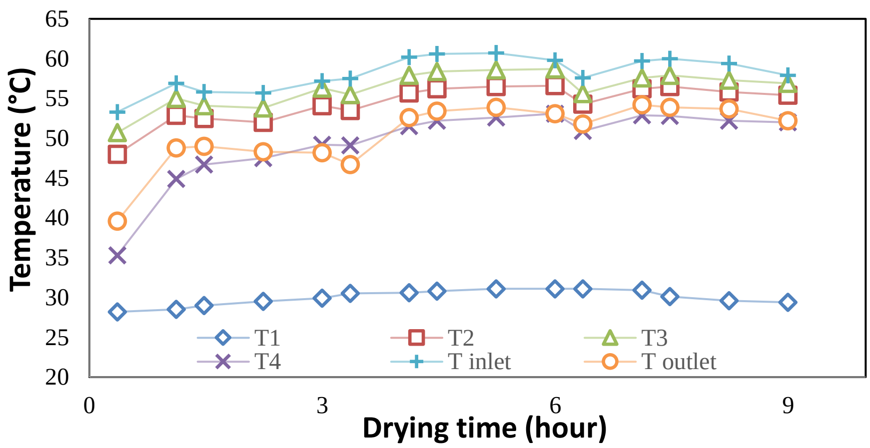

Fig. 18. The high temperature vs drying time at high temperature using 67° angle distributor

3.3 Comparison of the Swirling Fluidized Bed Drying Experiment Using Three Different Inclination Angle Distributors and Between Two Types of Drying

Table 11 compares the swirling fluidized bed dryer using three different distributors and conventional sun drying. The drying time was set to be 9 hours with a fluidized bed dryer and 3 days (27 hours) for the drying experiment under the sun. The final weight was recorded to be 395 g for experiments using perforated distributor, 313 g for experiments by using 45° distributor, 410 g for experiments by using 45° distributor and 329 g for investigations under the sun. Among the three distributors, most weight reduction is achieved by using 45°distributor at 68.7% weight loss and the least weight reduction by using 67° distributor at 59% weight loss.

The result of the conventional sun drying was set as a benchmark to achieve the final weight for the drying piper nigrum. After three days of drying under the sun, the remaining weight of piper nigrum was 329 g. When drying by using a fluidized bed dryer, it was recorded that the drying of piper nigrum in a swirling fluidized bed dryer operated with the 45° distributor reduced the final weight of conventional drying by 16g when the final weight was recorded to be 313 g. The piper nigrum change colour from green to black during the drying process. No colour difference was observed on the piper nigrum among the three distributors as shown in Figure 19. Observation on the colour of the piper nigrum in conventional drying experiments recorded to be in grey-black colour as the mould starts to form on the pepper after 3-days of drying.

Table 11
The comparison between swirling fluidized bed dryer using three different distributors and the conventional sun drying

	Perforated distributor	45° distributor	67° Distributor	Conventional sun drying
Experimental Drying Time	9 hours	9 hours	9 hours	27 Hours (3Days)
Initial weight (g)	1000	1000	1000	1000
Final weight (g)	395	313	410	329
Moisture ratio	0.315	0.215	0.330	0.238
Weight Loss	60.5%	68.7%	59%	67.1%
Colour	Black	Black	Black	Grey-Black
Visual Shape	More Shrink	More Shrink	More Shrink	Shrink

(a) (b)

Fig. 19. The comparison of visualization of dried piper nigrum (a) using conventional sun drying and (b) using swirling fluidized bed drying

4. Conclusions

The present study provides a better understanding of the performance characteristic of the swirling fluidized bed dryer operation. In general, it can be concluded that drying using swirling fluidized bed dryer is more convenient than conventional sun drying because the swirling fluidized bed dryer have an excellent particulate mixing and reduced drying time. The swirling fluidized bed dryer took a shorter time to dry the piper nigrum, which is only 9 hours compared to conventional sun drying which is 27 hours (3 days). The comparison between three different inclination angles of the distributor in swirling fluidized bed dryer shows that the drying of piper nigrum using 45° angle of distributor gives the best result compared to 67° angle distributor and the perforated distributor. Among the three distributors, most weight reduction is achieved by using 45°distributor at 68.7% weight loss followed by perforated plate at 60.5% weight reduction and the least weight reduction by using 67° distributor at 59% weight loss. The comparison of the drying using three different operating temperatures shows that the high operating temperature (47°C – 59°C) gives the best performance in drying the piper nigrum. This study concludes that the swirling fluidized bed dryer can be used in drying piper nigrum to reduce the drying time and preserve the quality of the piper nigrum.

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References
[1] Yogendrarajah, Pratheeba, Simbarashe Samapundo, Frank Devlieghere, Sarah De Saeger, and Bruno De Meulenaer. "Moisture sorption isotherms and thermodynamic properties of whole black peppercorns (Piper nigrum L.)." *LWT-Food Science and Technology* 64, no. 1 (2015): 177-188. https://doi.org/10.1016/j.lwt.2015.05.045

[2] Akinoso, R., A. K. Aremu, and K. O. Okanlawon. "Physical properties of climbing black pepper (Piper nigrum) and alligator pepper (Aframomum melanguata) as affected by dehydration." *Nigerian Food Journal* 31, no. 1 (2013): 91-96. https://doi.org/10.1016/S0189-7241(15)30061-8

[3] Zhu, Fan, Reuben Mojel, and Guantian Li. "Physicochemical properties of black pepper (Piper nigrum) starch." *Carbohydrate Polymers* 181 (2018): 986-993. https://doi.org/10.1016/j.carbpol.2017.11.051

[4] Azmi, Mohamad Zaharan, Ibni Hajar Rukunudin, Hirun Azaman Ismail, and Aimi Athirah Aznan. "Specific Energy Consumption and Drying Efficiency Analysis of Commercial Mixed-Flow Batch Type Seed Drying System." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 55, no. 1 (2019): 39-50.

[5] Sivakumar, R., R. Saravanan, A. Elaya Perumal, and S. Iniyan. "Fluidized bed drying of some agro products-A review." *Renewable and Sustainable Energy Reviews* 61 (2016): 280-301. https://doi.org/10.1016/j.rser.2016.04.014
[6] Jayatunga, G. K., and B. M. W. P. K. Amarasinghe. "Drying kinetics, quality and moisture diffusivity of spouted bed dried Sri Lankan black pepper." *Journal of Food Engineering* 263 (2019): 38-45. https://doi.org/10.1016/j.jfoodeng.2019.05.023
[7] Koua, Blaise Kamenan, Paul Magloire Ekoun Koffi, and Prosper Gbaha. "Evolution of shrinkage, real density, porosity, heat and mass transfer coefficients during indirect solar drying of cocoa beans." *Journal of the Saudi Society of Agricultural Sciences* 18, no. 1 (2019): 72-82. https://doi.org/10.1016/j.jssas.2017.01.002
[8] Mobolade, Adesina Jacobs, Nameirakpam Bunindro, Dinabandhu Sahoo, and Yallappa Rajashekar. "Traditional methods of food grains preservation and storage in Nigeria and India." *Annals of Agricultural Sciences* 64, no. 2 (2019): 196-205. https://doi.org/10.1016/j.aoas.2019.12.003
[9] El-Sebaii, A. A., and S. M. Shalaby. "Solar drying of agricultural products: A review." *Renewable and Sustainable Energy Reviews* 16, no. 1 (2012): 37-43. https://doi.org/10.1016/j.rser.2011.07.134
[10] Tiwari, Anupam. "A review on solar drying of agricultural produce." *Journal of Food Processing & Technology* 7, no. 9 (2016): 1-12. https://doi.org/10.4172/2157-7110.1000623
[11] Chokphoemphun, Susama, and Suriya Chokphoemphun. "Moisture content prediction of paddy drying in a fluidized-bed drier with a vortex flow generator using an artificial neural network." *Applied Thermal Engineering* 145 (2018): 630-636. https://doi.org/10.1016/j.applthermaleng.2018.09.087
[12] Badaoui, Ouassila, Salah Hanini, Ahmed Djebli, Brahim Haddad, and Amina Benhamou. "Experimental and modelling study of tomato pomace waste drying in a new solar greenhouse: Evaluation of new drying models." *Renewable Energy* 133 (2019): 144-155. https://doi.org/10.1016/j.renene.2018.10.020
[13] Abd Latif, Muhammad Lutfi, Mohd Al Hafiz Mohd Nawi, Wan Azani Mustafa, Mohd Sharizan Md Sarip, Mohd Aminudin Jamlos, Masniezam Ahmad, Ku Mohammad Yazid Ku Ibrahim, and Hazizul Hussein. "Numerical analysis of velocity magnitude in a swirling fluidized bed with spiral blade distributor." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 59, no. 1 (2019): 38-44.
[14] Haron, Nazrul Syaif, Jamal Hazri Zakaria, and Mohd Faizal Mohideen Batcha. "Hydrodynamics study on drying of pepper in swirling fluidized bed dryer (SFBD)." In *IOP Conference Series: Materials Science and Engineering*, vol. 226, no. 1, p. 012053. IOP Publishing, 2017. https://doi.org/10.1088/1757-899X/226/1/012053
[15] Halim, Luqman Abdul, M. F. Basrawi, Ahmmad Shukrie Md Yudin, and Siti Norazualina Faizal. "Fluidized bed drying of stingless bee pot-pollen: Performance of swirling distributor." In *IOP Conference Series: Materials Science and Engineering*, vol. 863, no. 1, p. 012006. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/863/1/012006
[16] Haron, N. S., J. H. Zakaria, and M. F. Mohideen Batcha. "Recent advances in fluidized bed drying." In *IOP Conference Series: Materials Science and Engineering*, vol. 243, no. 1, p. 012038. IOP Publishing, 2017. https://doi.org/10.1088/1757-899X/243/1/012038
[17] Roslan, N. F. M., and A. S. M. Yudin. "Drying process of black pepper in a swirling fluidized bed dryer using experimental method." In *IOP Conference Series: Materials Science and Engineering*, vol. 863, no. 1, p. 012047. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/863/1/012047
[18] Basrawi, M. F., F. Redzlan, T. K. Ibrahim, and A. S. M. Yudin. "Experimental study on the effect of bed aspect ratio to the drying rate of chilli for swirling fluidized bed dryer." In *IOP Conference Series: Materials Science and Engineering*, vol. 863, no. 1, p. 012044. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/863/1/012044
[19] Shabanian, Jaber, and Jamal Chaouki. "Effects of temperature, pressure, and interparticle forces on the hydrodynamics of a gas-solid fluidized bed." *Chemical Engineering Journal* 313 (2017): 580-590. https://doi.org/10.1016/j.cej.2016.12.061
[20] Srinivasakannan, Chandrasekar, and N. Balasubramanian. "An analysis on modeling of fluidized bed drying of granular material." *Advanced Powder Technology* 19, no. 1 (2008): 73-82. https://doi.org/10.1163/156855208X291774
[21] Zulkarnain, M. A., M. K. Shahriman, and A. S. M. Yudin. "Experimental study of drying characteristics of cocoa bean in a swirling fluidized bed dryer." In *IOP Conference Series: Materials Science and Engineering*, vol. 863, no. 1, p. 012048. IOP Publishing, 2020. https://doi.org/10.1088/1757-899X/863/1/012048
[22] Chen, Hao, Subham Rustagi, Emily Diep, Timothy AG Langrish, and Benjamin J. Glasser. "Scale-up of fluidized bed drying: Impact of process and design parameters." *Powder Technology* 339 (2018): 8-16. https://doi.org/10.1016/j.powtec.2018.07.087
[23] Halim, Luqman Abdul, Firdaus Basrawi, Jia Zheng Chong, Ahmed Nurye Oumer, Ahmmad Shukrie Md Yudin, Mohd Hazwan bin Yusof, and Shaharin A. Sulaiman. "Preliminary Study on Drying of Stingless Bee Pot Pollen Using Novel Fluidized Bed Dryer with Swirling Distributor." In *MATEC Web of Conferences*, vol. 225, p. 04007. EDP Sciences, 2018. https://doi.org/10.1051/matecconf/201822504007
[24] Shukrie, Ahmmad, Shahrani Anuar, and Azri Alias. "Heat transfer of alumina sands in fluidized bed combustor with

novel circular edge segments air distributor." *Energy Procedia* 75 (2015): 1752-1757. https://doi.org/10.1016/j.egypro.2015.07.453

[25] Misha, Suhaimi, Sohif Mat, Mohd Hafidz Ruslan, Elias Salleh, and Kamaruzzaman Sopian. "A Study of Drying Uniformity in a New Design of Tray Dryer." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 52, no. 2 (2018): 129-138.

[26] Aymen, E. L., Ilhem Hamdi, Sami Kooli, and Amenallah Guizani. "Drying of red pepper slices in a solar greenhouse dryer and under open sun: Experimental and mathematical investigations." *Innovative Food Science & Emerging Technologies* 52 (2019): 262-270. https://doi.org/10.1016/j.ifset.2019.01.001

[27] Seremet, Liliana, Elisabeta Botez, Oana-Viorela Nistor, Doina Georgeta Andronoiu, and Gabriel-Danut Mocanu. "Effect of different drying methods on moisture ratio and rehydration of pumpkin slices." *Food Chemistry* 195 (2016): 104-109. https://doi.org/10.1016/j.foodchem.2015.03.125