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Development of Multi-Level Hot Air Temperature Dryer Cooperation with Biomass Heat Collection System for Longan Flesh

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ABSTRACT

This study investigates the drying of longan flesh through hot air energy derived from a biomass heat collection system. Three heating patterns were developed and selected for study. Next, the drying rate and specific energy consumption were measured and analyzed. The heat from the burner is transferred to the hydraulic oil, and the oil is pumped to the heat exchanger in the drying chamber. The temperature control system in the drying chamber used a temperature controller to stop the operation of the hydraulic oil pump motor. Three patterns of multistep temperature with an airflow velocity of 1.15 m/s were tested. The opening air outdoor system was 10%. Pattern 1 was dried at 80°C for 3 h, then at 70°C for 8 h; pattern 2 was dried at 80°C for 6 h, then at 70°C for 4 h; and pattern 3 was dried at 80°C for 5 h, then at 70°C for 3 h, and at 60°C for 4 h. 4 kg of longan flesh with an initial moisture content of 330.61 ± 7.03% dry basis was dried to a final moisture content of 17.37 ± 0.254% dry basis. The results showed that the drying rate of pattern 1 was 0.265 ± 0.0009 kg/h, and the specific energy consumption (*SEC*) was 68.34 ± 3.775 MJ/kg, while the drying rate of pattern 2 was 0.289 ± 0.0010 kg/h, and the *SEC* was 72.64 ± 5.906 MJ/kg. The drying rate of pattern 3 was 0.244 ± 0.0004 kg/h, and the *SEC* was 70.03 ± 6.436 MJ/kg. Finally, pattern 1 was the most suitable condition. It was low *SEC*, and the color quality was a golden color close to market standards.

Keywords: Drying; Hot hydraulic oil; Heat collection system from biomass; Longan flesh

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1. Introduction

The biomass fuel supply chain includes several stages: planting, harvesting, splitting, compacting, drying, storage, transportation, and management. These steps vary depending on the type of biomass and the end-use requirements for combustion, which in turn are influenced by the feedstock form, cost, and intended application [1]. The research team used biomass as the main heat source for the drying technology to reduce energy costs. For biomass in the form of leftover tree branches, the drying team [2] dried bananas using modified hot air that utilized waste heat from a 200-liter furnace. Subsequently, the development team [3] proposed a more efficient banana dryer using the heat from a 200-liter furnace. In addition, the research group [4] proposed a smoke treatment system for a powered dryer for honey-dried banana biomass. In the case of small biomass, Chunkaew [5] explored a hot air generation technology using a fluidized bed furnace with waste biomass, where the heat generated by combustion is transferred to an air chamber furnace connected to the fluidized bed combustion chamber. Next, the team [6] used hot air from the biomass fluidized bed furnace to provide heat for the dryer. In both cases, there is no heat storage part, so the utilization rate of biomass fuel is very high. The insulation method according to the academic report can be carried out as follows: Firstly, the use of insulation materials can reduce the heat loss of the material. Secondly, the buried copper pipes at different depths in the asphalt layer affect the thermal efficiency of the asphalt solar water heater [7]. Thirdly, using solar cells of high-efficiency technology converts electrical energy into thermal energy. For thermal storage systems, this is part of sustainable development and reducing energy consumption that affects the environment. This helps reduce electricity or fuel costs for heating by reducing the use of fuels that emit greenhouse gases and lessening environmental impact. This reduces production costs and improves the efficiency of industrial processes. Fourthly, thermal storage is used to store heat for later use. This is called a solar water heater and is used in slaughterhouses. Its system uses a heat pump to produce hot water, supplemented by power generation and solar thermal energy to reduce the electricity costs of slaughterhouses [8]. There is also a technology that uses solar panels, heat pipes, and heat pumps to produce hot water for hotel buildings [9]. Both studies use water as the thermal storage medium. When water is used with biomass energy, its phase may change to steam when the temperature exceeds 100°C. Therefore, there is an idea to use hydraulic oil in this research. Hydraulic oil has the property of being able to withstand high pressure. It is resistant to high temperatures and will not exceed limits that would cause loosening or wear. The hydraulic oil is corrosion resistant. It reduces the formation of bubbles in the system and is resistant to damage from sunlight, so it is suitable for storing heat from biomass combustion.

The northern fruit in Thailand is longan, which often yields a harvest every month between July and September in a fairly short time. It will be compelled to go out of season if no accelerator is installed. Typically, they are marketed in 4 grades based on the longan's size: AA, A, B, and C. Size AA is the largest longan. The longest and fleshiest longan measures 25 mm. The size of a grade A longan is 22-24 mm. Longan, grade B, measures 19-21 mm in diameter. The longan in grade C is 16-18 mm in size. The longan is in decline when output is overly high. Drying longans has 2 forms: form 1 is drying the whole fruit [10, 11], and form 2 is drying longan flesh only [12].

Investigated color changes in terms of color quality by providing data on the brightness values (L*), redness values (a*), and yellowness values (b*) of drying longan flesh only at high temperatures [13]. Drying times will be shortened by high temperatures, and the moisture is almost gone; it takes a very long time. It was discovered that the redness value (a*) and yellowness value (b*) increased as a result of the brown reaction, and the brightness value (L*) tended to decrease.

Utilizing biomass is a way to save energy expenses because it is inexpensive and widely accessible in the community. However, the combustion of biomass produces smoke, so the heat from combustion cannot be used directly. The research team on drying technology [3] developed and constructed a complete banana dryer out of eucalyptus wood and tested it at 60, 70, and 80°C and 1.8 m/s. It was discovered that the 70°C temperature was suitable due to the high drying rate and low specific energy consumption rate. However, the first thing to consider is that the color quality must be similar to the products sold in the market. The low specific energy rate is the second factor to take into account. Thus, the purpose of this research is to design and evaluate the effectiveness of a biomass heat storage system in conjunction with a multi-level hot air temperature dryer for drying longan flesh. Research is needed on the topic of multi-temperature drying of particular longan flesh using a hydraulic oil heat storage system and biomass dryer technology.

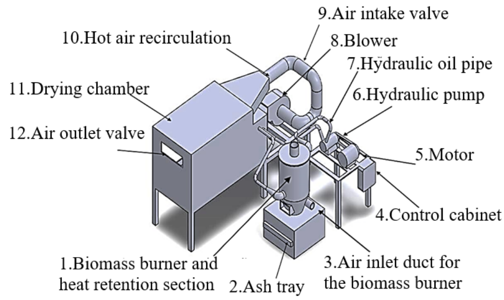


Fig. 1. Multi-stage hot air drying using a biomass heat collection system.

2. Research Methodology

2.1 Materials and methods

2.1.1 Development of a multi-level hot air-drying machine with heat storage system from biomass for longan flesh

As seen in Fig. 1, the main components of a drying machine are 1) a biomass burner and heat retention section, 2) an ash tray, 3) an air inlet duct for the biomass burner, 4) a control cabinet, 5) a motor 6) a hydraulic pump, 7) a hydraulic oil pipe, 8) a blower, 9) an air intake valve, 10) a hot air recirculation, 11) a drying chamber, and 12) an air outlet valve.

Fig. 2 shows the heat exchange from the hydraulic oil system and details of working principles. A blower is used to force air smoothly through the parallel trays in the dryer. Heat exchange equipment is situated before the drying chamber for increasing the temperature of the air by transferring heat from heated hydraulic oil of the hydraulic oil system. A biomass burner is included in the design of the heat exchange system to raise the temperature of the hot air by transferring heat through the burner wall and into the hot hydraulic oil surrounding the burner wall. The connecting pipes are made from stainless steel and are installed with heat exchange units of the heat retainer at the burner wall and heat exchanger in the

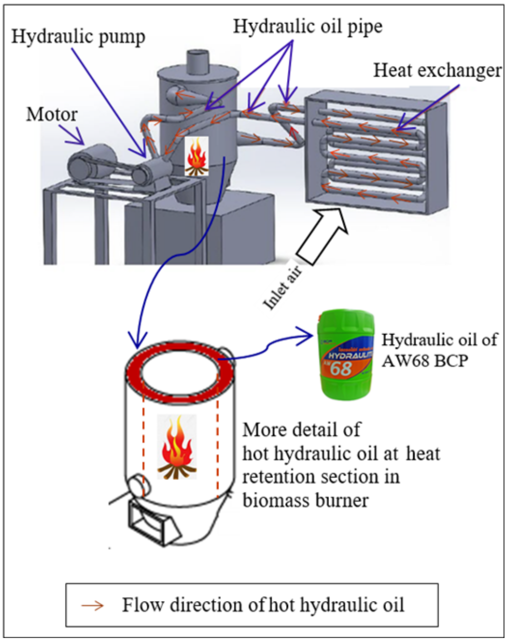


Fig. 2. The heat exchange from hydraulic oil system and details of working principles.

dryer. The heat can transfer from the heated hydraulic oil to the air inside the dryer. The heat exchanger's output is connected to the suction side input of the hydraulic oil pump. The hydraulic oil storage unit's top is connected to the hydraulic pump's outlet. The temperature control system within the drying chamber uses a temperature controller to govern how the hydraulic oil pump motor operates. The drying machine has the capacity to reach a high hot air temperature of 80°C at a velocity of 1.15 m/s and an airflow rate of 0.297 m^3/s, so this is the maximum limitation of the biomass dryer.

The hydraulic oil of AW68 BCP is selected for heat accumulation from biomass combustion in the biomass burner. The oil has a high viscosity index and is resistant to oxidation at high temperatures. It prevents pump wear and rust. Finally, it has a flash point of 248°C so it accumulates heat at temperatures higher than 100°C. Therefore, it is a liquid that can transfer heat at a high rate. The total cost of materials and equipment for dryer construction was approximately 50,000 baht.

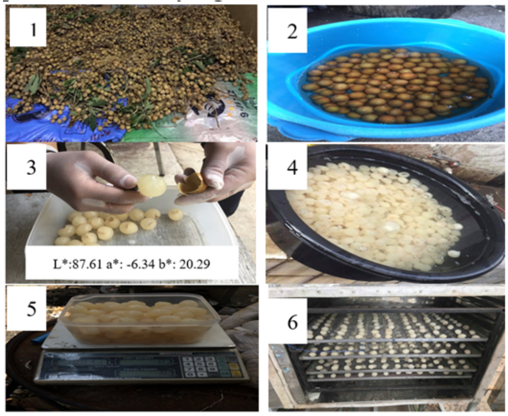


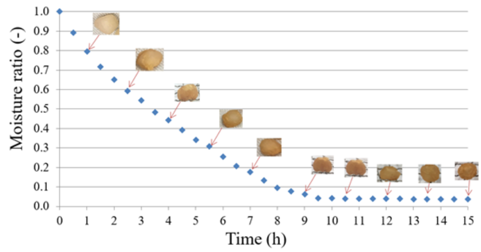
Fig. 3. Longan preparation process before the experiment.

2.1.2 Raw materials for testing

Grade A 'Dor' longans, 22-24 mm in diameter, were peeled and deseeded. Fig. 3 shows the longan preparation process before the experiment. Firstly, the longans were purchased from Bantak market at Tak, Thailand. Secondly, the Grade A 'Dor' longans, 22-24 mm in diameter, were washed with water. Thirdly, their seeds were removed and the longan flesh was selected for experiments. Fourthly, the longan flesh was cleaned with water. Fifthly, the longan flesh was weighed at 4 kg. Finally, it was arranged on trays and placed in the drying chamber.

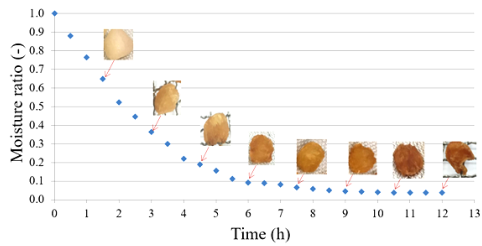
2.1.3 Finding a method to determine temperature reduction steps

It is vital to comprehend the moisture reduction behavior at standard operating temperatures as well as the color change behavior of dried longan at different drying temperatures and moisture ratio levels to comprehend the drying behavior of longan flesh. This is easily evaluated by looking at the color that results. Specifically, the Linshang LS170 model colorimeter is used in this measurement technique. To use the colorimeter, firstly, switch on the device at the same time the LSColor app is open and activated via Bluetooth so that the colorimeter and the app can communicate. Values for L*, a*, and b* will be obtained from the color measurement. The a* and b* are color coefficients while L* stands for lightness. The red-green direction is indicated by the values of a* and b* (where +a* means red and -a* means green), and the yellow-blue direction is shown by the values of b* (where +b* means yellow and -b* means blue). Secondly, the hot air-drying experiments are carried out in a hot air-drying laboratory using the following techniques at 60, 70, and 80°C [14, 15] and 1.15 m/s of hot air velocity. The velocity of 1.15 m/s is the maximum hot air velocity of the dryer cooperation with the biomass heat collection system. From the literature review, the highest drying rate at the lowest specific energy consumption occurs when increasing velocity [2]. Thirdly, to conduct a longan flesh color change test during drying a sample of 30 grams was placed in a case in a hot air oven at a temperature of 60°C with an airflow velocity of 1.15 m/s. The weight loss was recorded every 30 minutes. The drying time was 15 hours to complete the process by reaching a final moisture content of 18% on a dry basis. The results of color changes and the reduction in moisture content ratio of the longan flesh are shown in Fig. 4. Fourthly, the sample of 30 grams was dried at a temperature of 70°C with an airflow velocity of 1.15 m/s for investigation of the color change similarly at the condition of 60°C, and the results are shown in Fig. 5. It takes 12 hours to complete the process of reaching a final moisture content of 18% on a dry basis.



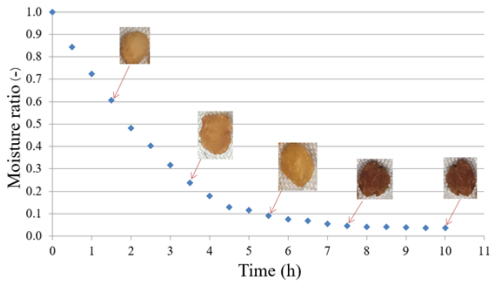
Hour at	Color value	Hour at	Color value
1	L*:82.19 a*:3.09 b*:23.86	9	L*:50.4 a*:17.0 b*:29.13
2.5	L*:70.05 a*:7.94 b*:36.75	10.5	L*:50.56 a*:16.18 b*:28.1
4	L*:61.19 a*:11.3 b*:34.42	12	L*:53.99 a*:5.88 b*:32.35
5.5	L*:59.83 a*:7.31 b*:34.1	13.5	L*:48.93 a*:9.6 b*:34.12
7	L*:53.13 a*:14.8 b*:37.5	15	L*:47.55 a*:12.29 b*:30.8

Fig. 4. The moisture ratio and color changes of longan flesh during drying hours at 60°C with an airflow velocity of 1.15 m/s.



Hour at	Color value	Hour at	Color value
1.5	L*:84.72 a*:3.28 b*:22.71	7.5	L*:55.62 a*:16.3 b*:44.21
3	L*:69.05 a*:8.96 b*:37.28	9	L*:53.89 a*:18.7 b*:42.75
4.5	L*:62.56 a*:10.5 b*:35.13	10.5	L*:42.88 a*:23.2 b*:27.98
6	L*:59.41 a*:13.2 b*:38.57	12	L*:33.88 a*:24.6 b*:35.29

Fig. 5. The moisture ratio and color changes of longan flesh during drying at 70°C with an airflow velocity of 1.15 m/s.



Hour at	Color value	Hour at	Color value
1.5	L*:62.57 a*:10.6 b*:34.61	7.5	L*:34.43 a*:19.5 b*:20.07
3.5	L*:58.5a*:15.7 b*:38.57	10	L*:29.19 a*:19.4 b*:20.46
5.5	L*:55.32 a*:16.6 b*:46.73		

Fig. 6. The moisture ratio and color changes of longan flesh during drying at 80°C with an airflow velocity of 1.15 m/s.

Finally, the sample of 30 grams was tested with a case of conditions at 80°C with an airflow velocity of 1.15 m/s, and the weight loss was recorded every 30 minutes. Fig. 6 shows the moisture ratio and color changes of longan flesh during drying.

2.2 Formatting multi-level hot air temperature

When longan flesh is heated to high temperatures and its moisture content is low, the dried longan flesh turns dark. Chunthaworn and research teams [13] investigated the color kinetics during hot air drying of longan flesh at high temperatures of 60, 80, 100, 110, 120, and 130°C with a constant air velocity of 0.7 m/s. The conditions of 60 and 80°C had to change consistent values L*, a*, and b* with the tests of this research . To preserve the color quality of dried longan flesh, the drying temperature must be used appropriately to suit the color changes of the longan flesh and must have a color similar to that in the market. As a result, the following 3 drying temperature settings were designed using the aforementioned test results:

Pattern 1 utilizes an 80°C temperature and requires 3 hours to dry, then lowers the temperature to 70°C and requires 8 hours to dry. The overall drying time is 11 hours.

In pattern 2, the temperature is set to 80°C for 6 hours, and the drying process is completed by lowering the temperature to 70°C for 4 hours. Ten hours are needed for drying in total.

Pattern 3 utilizes an 80°C temperature and requires 5 hours to dry; it next lowers the temperature to 70°C and requires 3 hours to dry; finally, it lowers the temperature to 60°C and requires 4 more hours to dry. It was discovered that drying required 12 hours.

2.3 Testing procedure

The longan samples were placed in a hot air-drying chamber that was tested at temperatures of 60, 70, and 80°C. At each temperature, the samples' weight and color were recorded. In order to eliminate moisture content from the longan flesh, the drying process involves employing a 0.5 horsepower centrifugal fan to force the hot air into the drying chamber and circulate it. A fuel-fired burner that burns eucalyptus wood and transfers heat to hydraulic oil served as the heat source for heating the air. The hydraulic oil tank is connected surrounding the burner. The input hydraulic oil tank is connected to the hydraulic pump, and the output hydraulic oil tank is connected to the heat exchanger in the dryer. A 0.5 horsepower pump powers the hydraulic oil circulation system, and the hydraulic oil serves as a heat transfer medium, which takes heat from the burner and sends it to the heat exchanger in the dryer for increasing air temperature. Hot air is then forced into the drying chamber through the heat

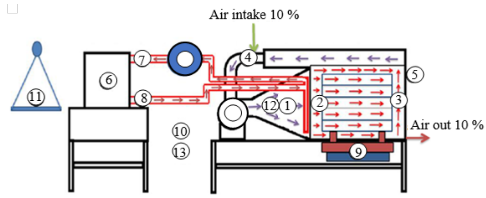


Fig. 7. Measurement positions during the testing of a multi-level hot air dryer combined with a biomass heat storage system for drying longan flesh.

exchanger by a blower. The air temperature is controlled by a temperature controller using a hydraulic pump motor. Installation of measuring instruments had the TM-1947SD temperature gauge with a resolution of 0.1°C/1°C, the relative humidity (RH) meter, the digital balance (precision ± 0.01 kg) for measuring the weight of longan flesh, and the weight WH-A08 scale (maximum capacity 40 kg, resolution 10 grams) for measuring the weight of charcoal, as shown in Fig. 7. In addition, the electrical power consumptions of the blower motor and hydraulic pump motor are measured using a kilowatt-hour meter.

In the dryer, the water from the longan flesh changes phase to vapor, which results in a high humidity ratio in the dryer. Then, the relative humidity in the dryer is increased. In past research, the drying rate was not affected by relative humidity in the range of 10 to 25% [16]. This research used a technique to release 10% [3] of hot air to prevent the equilibrium moisture content, which cannot reduce the longan flesh weight. The research supported the SEC; it was found that the SEC decreased when increasing the fraction of air recycled [17].

2.4 Competency assessment

The performance of most dryers is determined by selecting the specific energy consumption, which is used to select conditions for providing the highest performance. The specific energy consumption is the amount of total energy from the blower motor and biomass per water removed from the longan flesh, as shown in Eq. (2.1).

$$SEC = \frac{Total\ energy}{Water}, \frac{MJ}{kg_{water}}. \quad (2.1)$$

Next, the drying rate (DR) which is the amount of moisture extracted from the longan flesh per unit time is taken into secondary consideration as defined by Eq. 2.2).

$$DR = \frac{Water}{Drying\ time} \cdot \frac{kg_{water}}{h}. \quad (2.2)$$

Note: The values shown in the test results are the averages from 3 repeated tests.

Selection of the appropriate conditions should consider the quality of dried longan flesh for the first option, and for the next option, the specific moisture extraction rate should consider the secondary value. The color quality of the dried longan flesh used in this investigation is nearly up to market requirements.

2.5 Statistics for data analysis

Based on repeated testing, the results are presented using the average and the standard deviation.

3. Study Results and Discussion

3.1 Results of changes in the drying rate (DR)

Pattern 1, which dried at 80°C for 3 hours and then lowered the temperature to 70°C for an extra eight hours, had a drying rate of 0.265 ± 0.0009 kg/h. In pattern 2, the temperature was set to 80°C for 6 hours,

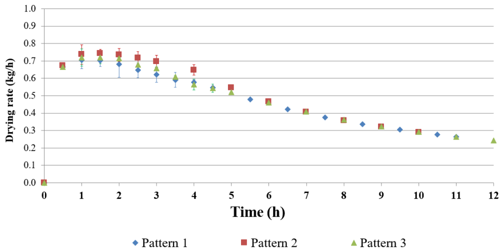


Fig. 8. Comparison of drying rate of 3 patterns with time.

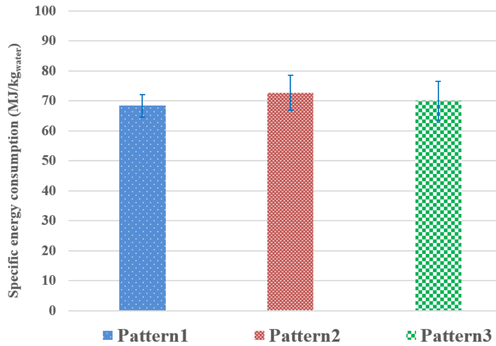


Fig. 9. Comparison of specific energy consumption for 3 patterns.

and after that it was lowered to 70°C for an extra 4 hours. The drying rate was 0.289 ± 0.0010 kg/h. In pattern 3, the temperature was set at 80°C for 5 hours, then lowered to 70°C for 3 hours, and lowered to 60°C for 4 more hours. The result of a drying rate was 0.244 ± 0.0004 kg/h, as shown in Fig. 8 and Table 1. As a result, pattern 2 uses high temperature so the drying rate increases, and the drying time is reduced with the high temperature because water can evaporate from the longan more quickly at the high temperatures. Pattern 2 shows higher *SEC* despite shorter drying time because it must use more biomass during high-temperature periods. A comparison with published research [15], which dried golden longan by controlling the temperature at 60°C for 10 hours and followed by 70°C for 2 hours, found that pattern 1 and pattern 2 in this study required a drying time of less than 12 hours.

3.2 Effect of 3 patterns of multistep temperature on specific energy consumption (*SEC*)

In Fig. 9, it can be seen that pattern 1, pattern 2, and pattern 3 use specific energy consumption of 68.34 ± 3.775, 72.64 ± 5.906, and 70.03 ± 6.436 MJ/kg$_{water}$, respectively which depends on controlling the air intake to match the temperature in the drying chamber. If the air intake to the burner is increased, it causes the fuel to burn faster and raises the temperature of the hydraulic oil. As the temperature in the drying chamber increases, the drying time can be reduced. Therefore, pattern 2, which uses the multistep temperature at 80°C for 6 hours and then lowers to 70°C for 4 hours, has the highest specific energy consumption because it requires more biomass for transferring heat to the upper air temperature.

3.3 Summary of the performance test of a drying machine for longan flesh by using multiple hot air temperatures with biomass and a heat storage system comparison with other dryers

Table 1 shows that 3 drying strategies can reduce the raw longan flesh's moisture content to less than 18% dry basis. Pattern 2 has the maximum drying rate because of minimal drying time and has the maximum specific moisture extraction rate because the biomass required to increase the air temperature is more than in pattern 3 and pattern 1. Next, the other dryer for drying longan flesh by biomass burner as a heat source with air flow reversal at 80°C [16] found that the drying time increased with increasing loading capacity. Finally, drying longan flesh by heat pump dryer at 55°C 0.7 m/s with 60-80% of bypass air at the evaporator [18] found that the drying times were

20-24 h. From Table 1, the parts of DR and *SEC* cannot compare because initial conditions are not the same. The results of the drying time comparison showed that this research took less time than the presented research.

3.4 Color quality of dried longan flesh

Fig. 10 shows that pattern 1 used the ideal drying temperature; the dried longan flesh had a golden yellow color that was most like that of products found in stores. It utilized 80°C for 3 hours, then dropped to 70°C for eight more hours. This resulted in an 11 hour drying period.

In pattern 2, the color of the longan flesh is darker brown compared to patterns 1 and 3 because it used an initial temperature of 80°C for a longer duration than in patterns 1 and 3. It used 80°C for 6 hours, then reduced the temperature to 70°C for an additional 4 hours, totaling 10 hours of drying time.

In pattern 3, the color of the longan flesh is lighter yellow compared to pattern 1. It used 80°C for 5 hours, then reduced the temperature to 70°C for 3 hours and further reduced the temperature to 60°C for an additional 4 hours, resulting in a total drying time of 12 hours. The high temperature in the low moisture content range of drying longan flesh caused more color change.

Fig. 11 shows a comparison of the color quality of dried longan with market standards and the temperature control method of pattern 1. Considering the color quality of the dried peeled longan, it was found that pattern 1 and pattern 3 produced dried longan with a color close to market standards. The final product quality is comparable to commercially dried longan flesh of golden yellowness. Next, the appropriate condition was the pattern 1 because of that it had the lowest *SEC*.

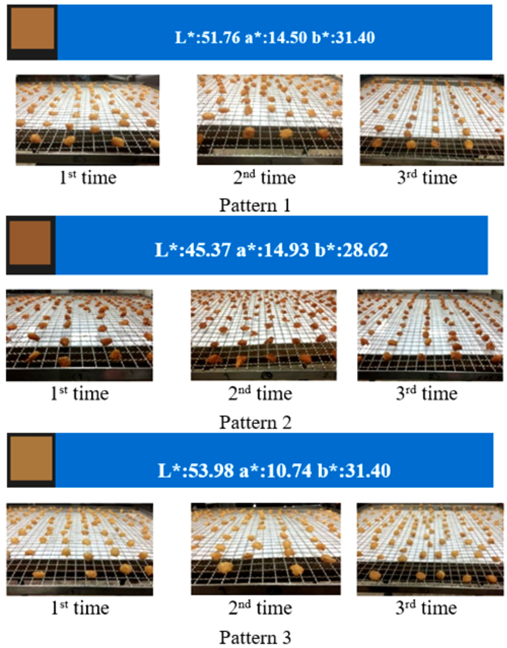


Fig. 10. Comparison of color quality for all 3 temperature control patterns.

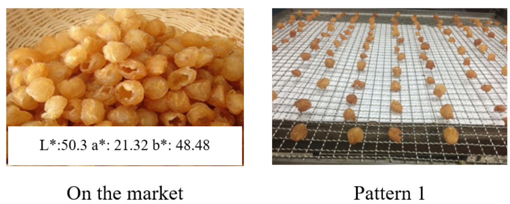


Fig. 11. Comparison of the color quality of dried longan on the market and the temperature control method of pattern 1.

4. Conclusion

Longan flesh was dried by using a biomass dryer and multiple hot air temperature settings. The 4 kilograms of longan flesh were utilized as the raw material for the drying test. The 4 trays with dimensions of 0.63×0.72 m^2 for the longan flesh could be placed inside the $0.2 \times 1.2 \times 0.63$ m^3 drying chamber. In order to eliminate moisture from the longan flesh, the drying concept required employing a 0.5 horsepower centrifugal fan to introduce hot air into the drying chamber and circulate it. A burner that

Table 1. Summary of the performance test for a multi-level hot air-drying machine with a biomass heat storage system for drying longan flesh comparison with other dryers.

Results of this research			
Items	**Pattern 1**	**Pattern 2**	**Pattern 3**
Initial weight of the material, (kg)	4	4	4
Final weight of the longan	1.09	1.11	1.07
flesh only, (kg)	0.01	0.01	0.0058
Initial moisture content of	330.25	323.45	338.13
the material, (% dry basis)	3.94	3.81	2.49
Final moisture content,	17.51	17.18	17.44
(% dry basis)	0.29	0.12	0.27
Drying rate, (kg/h)	0.265	0.289	0.244
	0.0009	0.001	0.0004
Specific energy consumption,	68.34	72.64	70.03
(MJ/kg$_{water}$)	3.775	5.906	6.436
Drying time (h)	11	10	12
Biomass for burning, (kg)	10.7	11.3	11
	0.558	0.889	0.995
Drying longan flesh by biomass burner as a heat source with air flow reversal [16]			
Items	**Initial weight**	**Initial weight**	**Initial weight**
Loading capacity, (kg)	1,000	1,500	2,000
Initial moisture content of the material, (% wet basis)	74	74	74
Hot air temperature (°C)	80	80	80
Drying time (h)	48	54	60
Drying rate, (kg/h)	No information	No information	No information
Specific energy consumption, (MJ/kg$_{water}$)	No information	No information	No information
Drying longan flesh by heat pump dryer at 55°C 0.7 m/s [18]			
Items	**bypass air at the evaporator of 60 %**	**bypass air at the evaporator of 70 %**	**bypass air at the evaporator of 80 %**
Initial weight of the material, (kg)	7.7-9	7.7-9	7.7-9
Initial moisture content of the material, (% dry basis)	551-658	551-658	551-658
Final moisture content, (% dry basis)	18	18	18
Drying rate, (kg/h)	0.302	0.28	0.368
specific moisture extraction rate, (kg$_{water}$/kW-h)	0.3021	0.322	0.443
Drying time (h)	24	24	20
performance of heat pump (COP$_{hused}$)	1.86	1.68	1.52

employed eucalyptus wood as fuel for combustion to transfer heat to the hydraulic oil served as the heat source for heating the air. The hydraulic oil pump was controlled by a temperature controller that was part of the drying chamber's temperature control system.

Three hot air control models were tested, and the findings showed that pattern 1 had the temperature set at 80°C for 3 hours and then dropped to 70°C for eight hours. Pattern 1 had a specific energy consumption of 68.34 ± 3.775 MJ/kg and a drying rate of 0.265 ± 0.0009 kg/h; pattern 1 produced longan flesh that was the closest to the market's characteristic yellow color. Pattern 2 involved setting the temperature to 80°C for 6 hours and then lowering it to 70°C for 4 hours. In comparison to pattern 1, pattern 2's longan flesh was a darker brown color, and its specific energy consumption was 72.64 ± 5.906 MJ/kg. Its drying rate was 0.289 ± 0.0010 kg/h.

In pattern 3, the initial temperature of 80°C was longer than that of pattern 1, which at 80°C was used for 5 hours. Then the temperature was reduced to 70°C for 3 hours and further reduced to 60°C for 4 hours. The drying rate of pattern 3 was 0.244 ± 0.0004 kg/h, and the specific energy consumption of pattern 3 was 70.03 ± 6.436 MJ/kg. The yellow color of the longan flesh was lighter than that of pattern 1.

It was found that pattern 1 was the most suitable condition due to its low specific energy consumption and golden color of the dried longan flesh.

Recommendations: the heat transfer system should be insulated and a safety valve should be installed in case the biomass burner is overheated beyond the hydraulic oil's capacity. The hydraulic oil pump should be a maintenance requirement for long-term operation.

In future work, the physicochemical changes during the drying process, and the temperature distribution on the surface of dried longan flesh should be investigated. Next, different longan varieties or other fruits, biomass quality, and the other qualities of dried longan flesh should be investigated. Finally, scaling up should be done by mathematical modeling to find the heat rate requirement and biomass heat collection efficiency for industrial use, and the payback period should be analyzed.

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