Low-Cost Herb Dryer using Infrared Lamps with Circulating Hot Air Blowers

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Abstract. *This paper proposes a low-cost herb dryer using infrared lamps with circulating hot air blowers. Detailed design, development and evaluation of the proposed dryer prototype were presented. The raw herbs from Rai Sodsai Thai Wapi Herb Farm, a well-known, local social entrepreneurship model for massive herbal production for Maha Sarakham city, Thailand. Three important herbs: Curcuma Longa Linn, Curcuma Aromatica, and Curcuma Comosa Roxb were used to evaluate the performance of the proposed dryer prototype compared to the traditional sun drying. The experimental test results showed that the proposed dryer achieved reducing drying time from3-5 hours to be about 4-6 hours. and provided the best quality with the controllable drying temperature in the range of 55-60 ^{o}C, which could not be easily achieved with the traditional sun drying that the farm currently used.*

Received by 1 August 2022
Revised by 14 September 2022
Accepted by 11 October 2022

Keywords:
herb dryer, hot air dryer, infrared lamps, low cost dryer

1. Introduction

Natural sun drying is the traditional technique for herb drying, which is simply by exposing the raw herbal materials to sunlight; and thus achieves the least production costs [1]. However, this drying technique has some drawbacks related to unpredictable availability and amount of sunlight dependence, as well as, the open drying space is required. These drawbacks cause risks of long drying time and uncontrollable drying temperature [2], as well as, difficulty of drying at the night time or during the rainy season. In addition, the open space can cause the contamination issues caused by dusts, numerous insects and germs. As a result, the dried products eventually have low quality and harm for the users; and consequently cause the low production capacity and delivery time issues that could not sufficiently serve the highly demands of the marketplaces [3].

One of the national goals for Maha Sarakham province is to be a medicinal city; and Rai Sodsai Tha Wapi Herb farm has known as a model of vast herb plots at the provincial and national level of Thailand. The head of this social entrepreneurship organization reported that many tons of dried herbs have been sole every year since 2019. The farm utilized the traditional sun drying for the drying process, and encounters some problems as others regarding low productivity and contamination. In addition, the farm must utilize the services on a regular basis that can cause the hidden costs such as drying costs, shipping costs, around 300-500 baht every round, takes approximately 3-5 days to dry and is dependent on sunlight. The drying temperature is high on day time when there is a lot of sunlight and thus dried rapidly. In turn, the goods will be dried slowly at the night time where the absent of the sun. The drying time a day is around 8-10 hours. In order to produce the dried herbs to meet the demands of the users while retaining high quality, the innovation and technology are highly needed in a cost effective way. The innovation or technology should be simple, low cost and ease to be used or maintenance since most farm members would lack of advance skills for high innovation and technology. Fig. 1 shows the photograph of the knowledge transfer under the activity of Erasmus +StepUP project at the farm.

Fig. 1 Rai Sodsai Thai Wapi Herb farm, social entrepreneurs in Maha Sarakham City, Thailand

2. Literature Reviews

There were some researches that have been developed to solve the above concerned issues on herb drying, which would have details as follows:

The experiment group used solely heat pump energy to achieve a reference speed of hot air velocity at the intake bed of 7 m/s. The drying time was 420 minutes for storage points with less than 12% moisture content [3]. The ensuing highest mean temperature was DT = 13.42 °C after 10 minutes, and the temperature variation between 60 and 420 minutes was quite tiny, roughly 1-2 °C. Patcharaporn I. and et al. [4] studied about the optimum drying air temperature of the oven for herbs under this research and found that the optimum temperature 47.83.9°C and 49.03.5°C, respectively. The drying period was 7 hours, and the moisture content of the product is according to a dried herb standard. On a dry basis, the moisture content of dried product was 10.600.85, 11.430.82, and 11.611.07, respectively. Furthermore, the drying product's quality was investigated. It was less than 0.60 in all drying modes and was in accordance with the requirement. For a color value, all four dried turmeric samples were colors of yellow-orange. Wasin R. [5] conducted the similar research to observe the results when adjust the temperature between 45 and 50 °C, and the evaporator bypass air ratio was altered between 60%- 80%. The best drying air temperature is at 50°C and 70% evaporation. The average drying and moisture extraction rates were 0.45 and 0.46 kg/h, respectively. The average specific moisture extraction rate was 0.26 kg/kw-h, and the heat pump coefficient was 2.98. The study was also found that the internal temperature control with evaporation could reduce the heat transfer of the drying system by adjusting the speed of the compressor motor. The internal rate of return in this study was 73.38%, and the payback period was 1.46 year. Anurak K. and et al. [6] studied different breadth, length, and weight of mulberry leaves of 17.10±1.97 cm, 22.60±2.69 cm, and 5.84±1.80 g, respectively. The fresh leaves had a color value of L = 37.6 a = -0.5 b = +15.2 and a moisture level of 75.07 %Mw, whereas dry leaves had 5.50 %Mw. Natural convection flat plate solar collector with the size of 100 x 200 x 14 cm was a dryer and solar hot water system. Within the scrap iron and copper pipe diameter (19 mm) and coated with glass thickness, the angle of ground level is 17 degrees (6 mm). The steel dryer is 80 x 100 x 180 cm and was covered with a smart board (6 mm). The diameter of the air chimney mount spinning ball stainless steel was 35 cm. The size of the stainless-steel shelves was 80 x 100 x 0.2 cm with 5 floors, and the sieve diameter was 3.2 mm. The volume of the stainless steel water tank encased with insulation was 0.15 m^3. The outside temperature was 33.20±3.94°C. The flat plate solar collector's interior temperature was 54.95±14.28°C. The dryer's inlet temperatures were 35.20±5.17°C, and the sun radiation incident on a plane intake was 19.55 MJ/m^2. Solar panels had a transient thermal efficiency of 53.25%. The dryer's heat usage was 503 kJ, and its thermal efficiency was 30%. According to the economic value, the machine cost was 24,121 Baht, the fixed cost was 27,286 Baht per year, and the variable cost was 87,236 Baht per year. Furthermore, the breakeven and payback periods are 111 kg/year and 154 days, respectively.

Budsabagorn K. and et. al [7] studied the weight and residual moisture when drying after an 8-hour drying period with the temperature inside the dryer at 40.2°C. The results demonstrated that drying by heat energy from LPG thermal energy was superior to drying by sun thermal energy. Curcuma Comosa's ultimate moisture content after drying with both LPG thermal energy and solar thermal energy was 8.31 and 11.73 %, respectively. Bhutharit V. R. and et al. [8] studied the drying rate of Jerusalem artichoke, Curcuma white, and Sago palm by using a direct type sun drier. In 3 days of drying, the moisture content of Jerusalem artichoke, Curcuma white, and Sago palm was reduced to 21.071.12, 21.72+1.81, and 19.88+0.72 % (w.b.), respectively, compared to the natural drying of 25.532.02, 26.22+1.78, and 24.831.33 %(w.b.). The low cost direct passive solar drier dried the Jerusalem artichoke, Curcuma white, and Sago palm quicker than the sun drying. The Jerusalem artichoke, Curcuma white, and Sago palm were totally shielded from insects and dust while drying in the low-cost passive solar drier. Rougrote G. and et al. [9] developed a solar dryer for cocoa beans for the community. The drying efficiency revealed that the average max temperature was 59.70°C within 16 hours, the solar drier reduced the original moisture content of cocoa beans from 55.6 to 6.89 %. S. Nabnean and et al. [10] studied on the parabolic solar dryer built with a polycarbonate plate cover on a flat plate collector. A polycarbonate cover helped decreasing heat losses while still allowing incident solar radiation to enter the dryer. The temperature of the drying air in the dryer ranged of 35-60 °C from 8:00 a.m. to 6:00 p.m., according to the findings. Within 4 days, the moisture content of the banana in the dryer was decreased from 72 to 28 %(w.b.), but the moisture content of the sun-dried samples was reduced to 40 %(w.b.). The solar dryer significantly reduced drying time as compared to natural sun drying, saving 48% of drying time. Solar dried product of high quality in terms of flavor, color, and texture was achieved. Arrisa S. and et al. [11] developed the drying using a 350-watt infrared heater. A hybrid grid and 100-watt solar cell was utilized in conjunction with a 100A, 12V battery. For the experiment, 200 grams of Piper Betel leaves were dried. The drying time at 50°C, 55°C, and 60°C was 3, 5, and 7 hours, respectively. The moisture content of the Piper Betel leaves was found to be much lower when dried for 180 minutes (3 hours) at 60°C. The solar batteries lasted 90 minutes when completely charged, and the moisture level of the Piper Betel herbal tea after drying was less than 5%. Gerametha S. [12] studied a temperature profile distribution in a vertical fluidized bed. Energy recovery from a heat pump was utilized to dry maize in a fluidized bed. The investigation concentrated on the dispersion of temperature profiles in a fluidized bed. Waste heat pump energy for recovery heat, however temperature profiles are not consistent owing to air conditioner control operating on-off of heat pump. The temperature profiles were not constant since the heater was controlled by a thermostat, but the recovery heat from the heat pump benefits free of charge from the waste energy of air conditioners. As a result, it could be applied to corn drying or tiny seeds. The experiment group consists of: 1. an air conditioner with capacity of 18,000 BTU per hour; 2. a one-horsepower blower; 3. fluidized bed; 4. damper for controlling hot air velocity at intake bed.

Srima J. and et al [13] studied vacuum pressure used in the far-infrared vacuum dryer would be between 5 and 15 kPa. Temperatures were kept between 45-55 ^{o}C during drying with hot air. When compared to hot air drying, the drying by far-infrared vacuum drier at pressure of 5 kPa and drying temperature of 55 C took the least amount of time. Pressure and temperature effects on low-pressure and high-temperature drying result in shorter drying times. As a result, the vacuum coupled far-infrared approach dried faster than hot air drying at atmospheric pressure. The ideal drying conditions for galangal and kaffir lime leaves, in terms of drying pace and color quality, would be pressure of 15 kPa and temperatures of 55 and 45^{o}C, respectively. The volatile matter in galangal and kaffir lime leaves was 0.0928 and 0.7849%, respectively, by mass. Kanjana D. and et al [14] investigated the consumers from the nong-feuang-fa store were the target group, as they were sold in both the online and offline systems. Purposive sampling was used to choose target groups of 30 individuals. The research findings revealed that 1) The innovative digital technology was used to boost the product value of dried herb Thai vermicelli noodle by employing the drying technique in the tray oven, which included a low tray with a mesh compartment positioned below and an insulating machine. So that the hot air circulates in the cabinet at a wind speed of 0.5-5 m/s per square meter of tray surface area and had pipe or waffle system and to bring hot winds up to the top through each tray so that the air warms equally distributed. 2) As a consequence, the dried herb's product value has increased. Thai vermicelli noodle discovered seven types of herb plants used to extract the component noodles: jasmine rice, butterfly pea, Pandan leaf, watermelon, pumpkin, carrot, and brown rice. All 8 colors were Jasmine rice=natural white, Butterfly pea=blue, Butterfly pea lemon=purple Pandan leaf=green, watermelon=pink, pumpkin=yellow, carrot=orange, brown rice=brown. 3) The satisfaction of the consumers towards the dried herb Thai vermicelli noodle product found that the consumers who have consumed dried herb Thai vermicelli noodle was at high level.

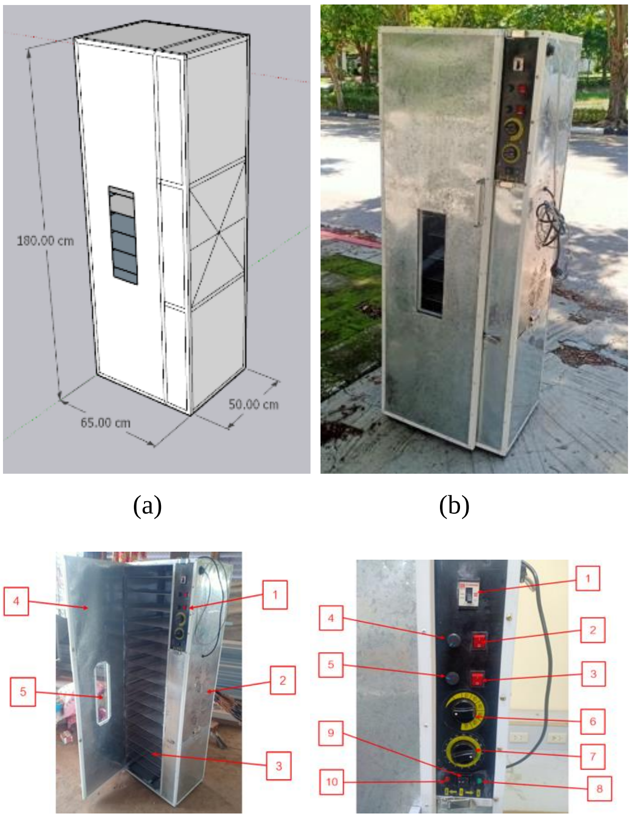
Umphisak T. and et al [15] studied factors that influenced on air flow within the solar dryer was investigated in order to guide the design and construction of high-performance solar dryers. Aspect ratios of 0.5, 1, 1.5, and 2 were studied, as well as heat fluxes of 400, 600, and 800 W/m^2. According to the study findings, the maximum air flow circulation within the dryer is 61.99% at condition aspect ratio 2 and heat flux 800 W/m^2. At a condition aspect ratio of 0.5 and a heat flux of 400 W/m^2, the minimum air circulation efficiency inside a solar dryer is 18.92%. Furthermore, the air circulation efficiency within the solar dryer rises as the aspect ratio and heat flux increase. Rawat K. and et al [16] investigated the infrared dryer and the vacuum system. To determine the temperature and distance between the infrared tubes and the relevant jackfruit. The dryer has a diameter of 0.51 m, a length of 0.8 m, and two 220 V. 250 W infrared heaters. The vacuum pump had a work rate of 13.42 m^3/hr. and the compressor of refrigeration system size was 0.252 kW. The sample for testing was 2 kg of the jackfruit. The sample standard before baking is 350-400% of dry basis. Baking the sample at 50, 55, and 60 °C, changing the absolute pressure to 1, 5, 10, and 15 kPa, and changing the distance from the infrared heater to the jackfruit to 12, 15, and 18 cm. Last moisture would be less than 19% of dry basis. The optimum conditions for jackfruit drying were the drying temperature at 60°C, 1 kPa, infrared heater distance to 12 cm shelves for minimum drying time of 480 minutes, lowest specific energy consumption of 21.67 MJ/kg, and the highest drying rate was 0.172 kg/hr.

Kritsana C. and et al [17] studied on the creation of a solar oven with an automated hybrid system for agricultural product processing. The results revealed that facing north for all-day sunshine was the best direction for putting the solar oven. At 6 p.m., the photo switch may direct the infrared heater set and ventilators to begin functioning automatically. This operation might be employed at night and throughout the wet season. Temperatures of 40°C, 50°C, and 60°C were used to test the electric system. The results revealed that throughout an hour of testing, the electric system ran at 20, 35, and 50 minutes, respectively, with an electric current of 1.15 Amp. Nopporn P. and et al [18] investigated parboiled rice and drying to minimize humidity in rice Khaohang Gok by using a solar dryer with an infrared electromagnetic wave. The benefit of this strategy was that it reduced the product loss due to weather, rain, and dust. Prior to the parboiled procedure, solar hot water was utilized to pre-heat the water temperature to 70°C. The drying time required to reduce the moisture content of rice from 65 to 14% was compared. The dryer took 8.33 hours to dry naturally with sun, 7 hours to dry with solar, and 4.66 hours to dry using solar energy oven with infrared; similar research would be found in [19]-[22].

3. Dryer Prototype

3.1 Structure of the Dryer Prototype

Fig. 2(a)-(b) show the overall dimension and prototype while Fig.2(c)-(d) show the main components of the proposed low cost herb dryer under this research. The designed dryer had a compact size with the width, length and height of 50x65x180 cm. The core components shown in Fig.2(c) were 1) Control unit; 2) Electric air blowers; 3) 16-Herb trays; 4) Door; and 5) Inspection mirror. The components shown in Fig. 2(d) were the components of the control unit.



(a) (b)

(c) (d)

Fig. 2 Overall designed structure ((a),(b)) and components ((c),(d)) of the proposed low cost herb dryer with infrared lamps and circulating hot air blowers

Details of the components in Fig. 2(d) were as follows:

(1) A circuit breaker
(2) An on/off switch for infrared lamps 1 - 5
(3) An on/off switch for infrared lamps 6 - 10
(4) A dimmer for infrared lamps 1-5
(5) A dimmer for infrared lamps 6-10
(6) A thermostat for temperature control (0-90^{o}C)
(7) A timer (0-15 hours)
(8) A indicating light for dryer 'ON'
(9) A 3-way switch for the dryer
(10) A indicating light for timer 'ON'

3.2 Electric Control Circuit for the Dryer

The wiring diagrams of the lamp control circuit and the hot air blower control circuit are shown in Fig. 3-4. The proposed dryer utilized a halogen light control circuit is shown in Fig. 3. There were 10 50W-light bulbs, and total power of 500 W and the hot air blowers with power of 1,000 W. For the infrared lamp control circuit, there were 10 MR16 50W-220V$_{ac}$ halogen lamps with 3,000 hour lifetime capacity and mercury and UV-free used. These infrared lamps could be adjusted their light intensity 2 dimmers with maximum rated power-current of 2,000W-25A each while a 4msec circuit breaker and overload protection was also installed. For the hot air blower circuit, a stainless steel grad 304 (SUS304), 1,000W finned heater was used, while two sets of a 350W, stainless steel exhaust fan with size 12", wind power of 65 m^3/min and speed of 2800 rev/min was installed as the air blowers to dissipate heat from the heater for the dryer. The defrost timers were used to control the heater and the fans, as well as the thermostat for the temperature in the range of room temperature – 90 ^{o}C control.

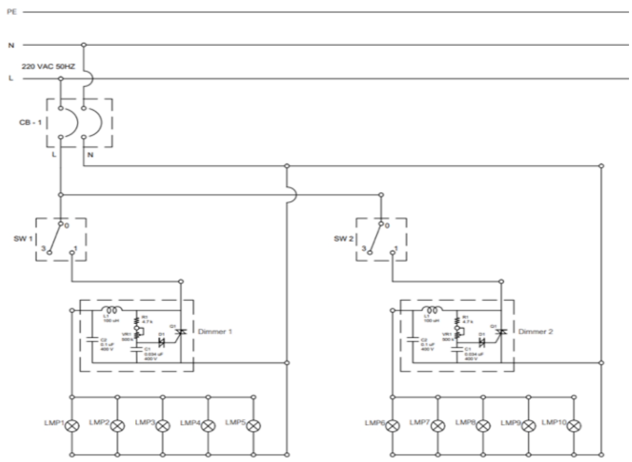


Fig. 3 Wiring diagram for the infrared lamp control circuit

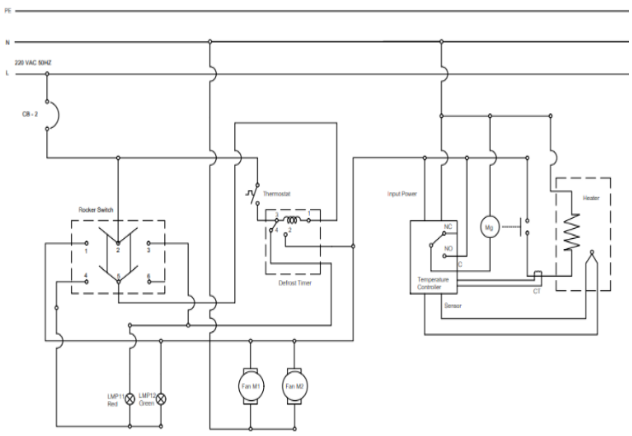


Fig. 4 Wiring diagram for the hot air blower control circuit

4. Experimental Test Design

This section presents the designed experimental tests for evaluating the performance of the proposed dryer. The selected herbs (Curcuma Longa Linn, Curcuma Aromatica, and Curcuma Comosa Roxb) for 3 kg each were tested by drying at their ideal temperature ranges of 45-50°C, 55-60°C, and 65-70°C for 6 hours. The experimental results were recorded every testing hour. The original features and their 2-3 mm thickness slide pieces of the selected 3 sample herbs are shown in Fig. 5(a)-(c), respectively.

(a)

(b)

(c)

Fig. 5 Examples of the origin feature and their slide pieces of (a) Curcuma Longa Linn, (b) Curcuma Aromatica and (c) Curcuma Comosa Roxb

5. Test Results and Analysis

5.1 Test Results

Table 1-3 show the test results in terms of the residual weight obtained from the proposed dryer for every particular testing hour of total 6 hours for the drying when the drying temperature were set at the range of 45-50°C, 55-60°C and 65-70°C, respectively. Figs. 6-8 show the respective plots of Tables 1-3. It could be concluded and summarized from Table 1-3 and Fig. 6-8 that:

(1) Only 4-5 hours drying with the temperature range of 45-50°C (see Table 1) the residual weight of the dried materials became less than 80-90%, which was equal to the weight when using natural sun drying for 3-4 days.

(2) About 3-4 hours would be used to dry the materials with temperature range of 55-60^{o}C to achieve 80-90% as 4 hour drying of 45-50°C.

(3) In turn, about 2-3 hours drying would be needed for the drying temperature range of 65-70^{o}C in order to achieve the same dried products with 80-90% weight as did the for 4 hour drying of 45-50°C.

Time (hr.)		0	1	2	3	4	5	6	Average Weight (g.)
Temperature (°C)		28.9	43.9-47.1	44.1-47.5	44.5-47.8	45.1-49.0	45.2-49.5	45.3-50.1	
Herbal Type	Tray	Weight (g.)							
Curcuma longa Linn	1	250	202.3	154.4	120.3	80.4	69.6	63.9	63.38
	2	250	177.0	140.0	100.1	91.9	75.8	67.9	
	3	250	167.9	129.0	90.3	73.5	64.0	58.5	
	4	250	194.1	133.3	102.5	79.7	69.5	63.2	
Curcuma aromatica	5	250	202.5	148.9	121.3	103.2	94.0	88.3	89.28
	6	250	184.7	146.9	120.5	105.0	95.8	90.0	
	7	250	203.2	170.0	133.2	110.1	95.1	85.7	
	8	250	217.9	177.2	146.8	119.6	103.5	93.1	
Curcuma comosa Roxb	9	250	206.4	153.9	127.5	109.5	101.5	97.3	91.58
	10	250	183.9	151.6	120.5	105.8	96.6	91.4	
	11	250	190.0	162.3	128.2	110.0	98.8	90.5	
	12	250	214.4	158.7	128.8	104.8	93.2	87.1	

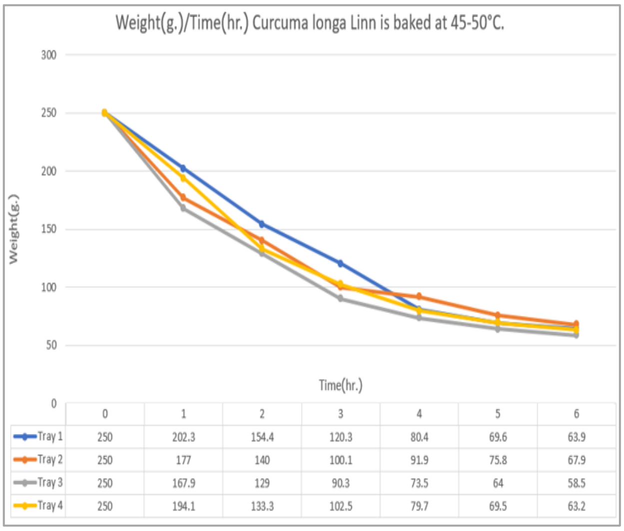
Table 1 Test results when the herbs were dried at temperature of 45-50°C

Time (hr.)		0	1	2	3	4	5	6	Average Weight (g.)
Temperature (°C)		29.2	51.9-59.0	52.1-59.0	52.5-59.8	53.6-60.5	55.2-61.5	55.3-61.9	
Herbal Type	Tray	Weight (g.)							
Curcuma longa Linn	1	250	198.6	144.1	107.7	69.8	53.5	48.1	48.83
	2	250	196.4	136.8	98.1	63.9	52.4	47.9	
	3	250	141.4	97.1	70.4	58.5	53.2	50.0	
	4	250	141.1	95.6	68.8	57.2	52.1	49.3	
Curcuma aromatica	5	250	187.5	145.5	122.6	103.3	94.7	89.8	87.38
	6	250	178	141.5	115.3	102.3	95.7	91.9	
	7	250	157.5	118.7	94.6	84.9	80	78.0	
	8	250	162.4	143.8	115.3	101.1	93.2	89.8	
Curcuma comosa Roxb	9	250	187.2	137.9	112.4	97.1	90	85.8	84.63
	10	250	163.3	125.4	101.6	93.8	90.3	89.5	
	11	250	162.4	119	90	78.1	73.1	70	
	12	250	190.1	147.2	114.4	101.1	95.4	93.2	

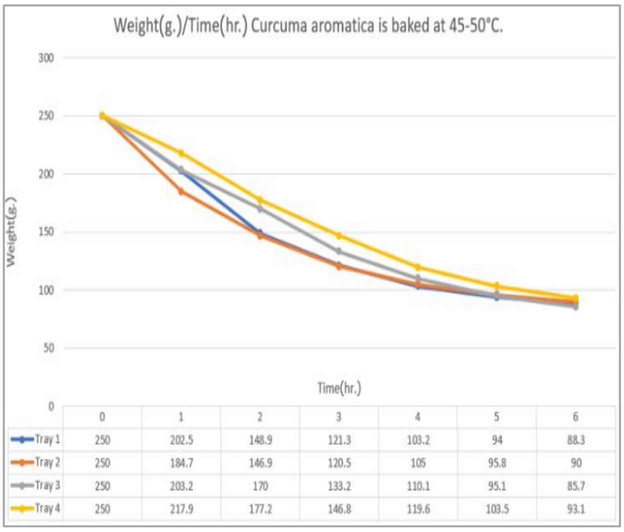
Table 2 Test results when the herbs were dried at temperature of 55-60°C

Time (hr.)		0	1	2	3	4	5	6	Average Weight (g.)
Temperature (°C)		29.5	63.9-69.0	64.1-69.0	65.5-70.8	65.6-70.9	66.2-71.5	66.3-71.9	
Herbal Type	Tray	Weight (g.)							
Curcuma longa Linn	1	250	166.4	114.1	62.2	52.5	48.1	47.0	47.2
	2	250	168.6	116.3	63.3	53.4	49.6	47.3	
	3	250	131.4	95.7	57.6	53.2	50.0	48.1	
	4	250	121.1	92.1	53.9	52.1	49.1	46.4	
Curcuma aromatica	5	250	167.7	115.6	94.4	92.7	89.8	85.1	81.15
	6	250	158.2	111.4	91.2	89.7	88.7	85.7	
	7	250	147.3	98.5	84.7	80.0	78.8	75.8	
	8	250	142.8	103.2	87.3	83.2	81.7	78.0	
Curcuma comosa Roxb	9	250	167.3	117.8	89.7	87.3	85.8	82.8	75.9
	10	250	143.7	105.3	79.4	79.0	78.0	74.0	
	11	250	132.6	99.4	78.2	76.1	70.0	69.2	
	12	250	160.9	107.2	83.1	82.4	80.4	77.6	

Table 3 Test results when the herbs were dried at temperature of 65-70°C



(a)



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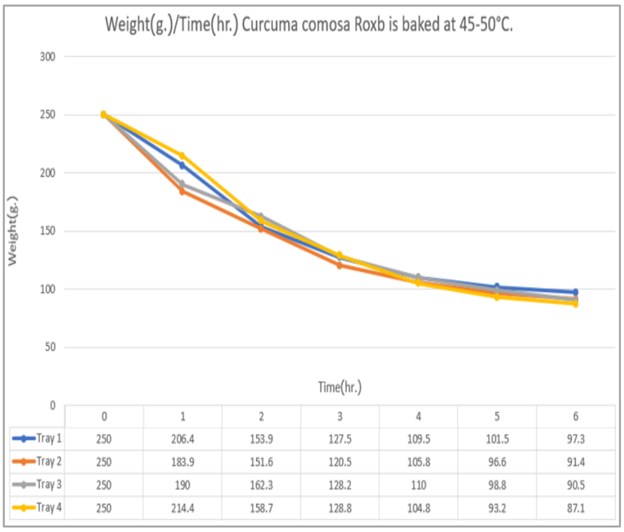
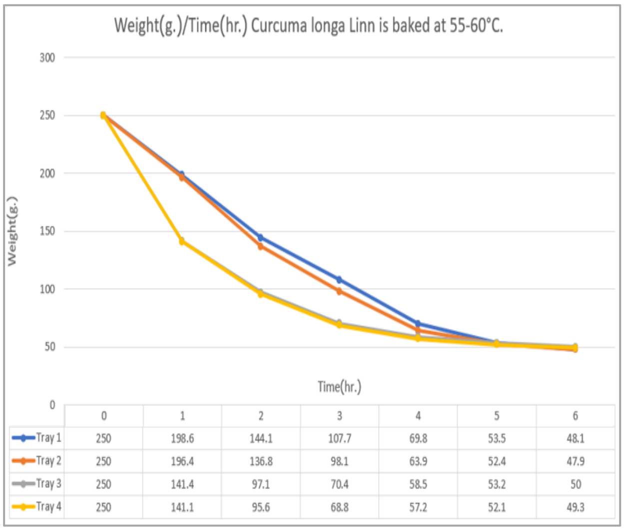


(c)

Fig. 6 Test result: weight (g)/time (hr.) when drying at 45-50°C: (a) Curcuma Longa Linn; (b) Curcuma Aromatica and (c) Curcuma Comosa Roxb



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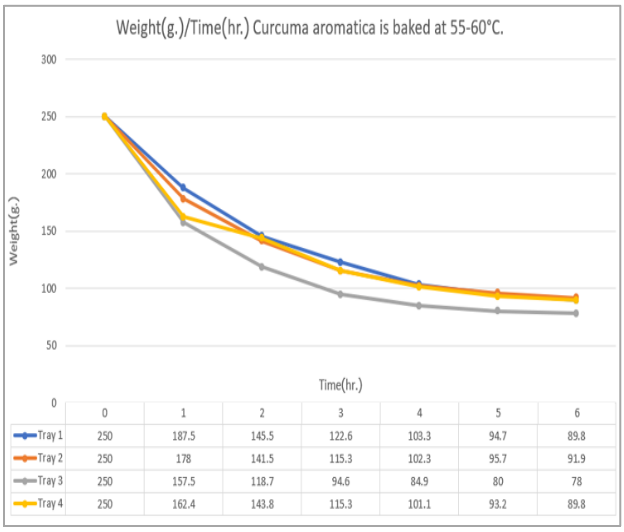
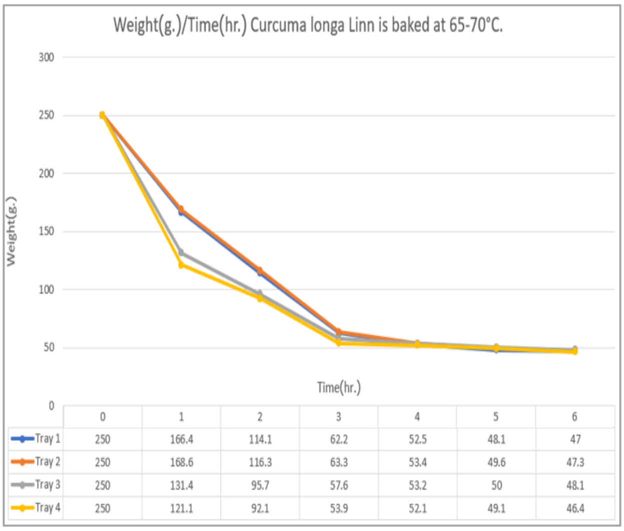


(b)

(c)

Fig. 7 Test result: weight (g)/time (hr.) when drying at 55-60°C: (a) Curcuma Longa Linn; (b) Curcuma Aromatica and (c) Curcuma Comosa Roxb



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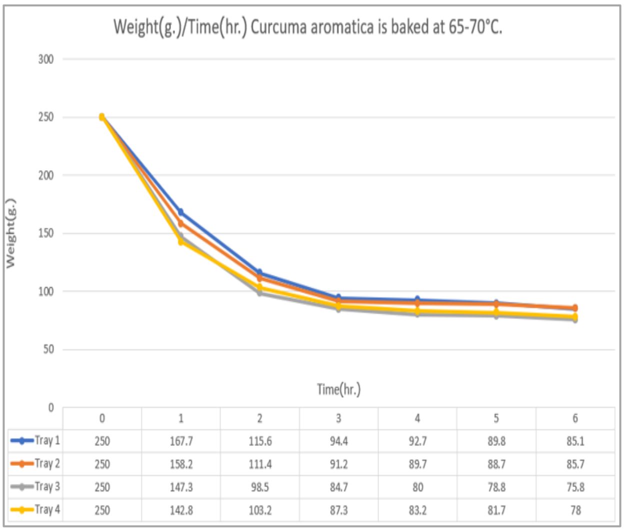

(b)

(c)

Fig. 8 Test result: weight (g)/time (hr.) when drying at 65-70°C: (a) Curcuma Longa Linn; (b) Curcuma Aromatica and (c) Curcuma Comosa Roxb

6. Conclusions

This presents design, develop and evaluation of the proposed low-cost herb dryer with infrared lamps and circulating hot air blowers. Three commercial herbal products provided by Rai Sodsai Thai Wapi Herb Farm, the social entrepreneur model for herbs for Maha Sarakham city, Thailand were used to test the performance of the dryer prototype; which were Curcuma Longa Linn, Curcuma Aromatica, and Curcuma Comosa Roxb. The experimental tests were performed by preparing the slide materials of herbs for 3 kg each, then put into the proposed dryer for 6 hours for different drying temperature ranges of 45-50, 55-60, and 65-70°C. The residual weights of the dried products were measured and the data then were analyzed and compared to the traditional natural sun drying method. Based on the test results of the 45-50°C trial, the dryer took time to dry the Curcuma Longa Linn, Curcuma Aromatica and Curcuma Comosa Roxb to have the average residual weight of 63.38, 89.28 and 91.58 by around 4-6 hours. The optimum drying quality was attained at a temperature of 55-60°C, when achieved the average residual weight of 48.83, 87.38 and 84.63 g for the drying time of 4-5 hours. In turn, drying with temperature of 65-70°C provided the average residual weight of 47.2, 81.15 and 75.9 g with the drying time of 3-4 hours. The proposed dryer achieved faster drying time of about 4-5 hours compared to 3-4 days of the traditional natural sun drying.

Acknowledgements

The researchers would like to thank the Solar Energy and Energy Resources Research Unit, Faculty of Engineering, Mahasarakham University, Thailand, and Rai Sodsai Thai Wapi Herb Farm for the materials for the tests and the Erasmus+ StepUP project under the cofounded by European Union.

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