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Development of Black Pepper Rotary Drum Dryer System

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Abstract: Rotary drum dryer has been identified as hygienic and practical method to dry black pepper. The quality of black pepper is defined based on the chemical properties and moisture content. This research aims to develop a control system for black pepper rotary drum dryer. The dried pepper should meet the specific 12% moisture content while the heating temperature must be kept below 55^0C. The requirement of 12% moisture content is equivalent to 30% of the remaining weight of the pepper (final weight). The developed system uses Arduino Mega 2560 REV board as a microcontroller. A type K thermocouple with MAX6675 thermocouple amplifier and S-type load cells (TAS501) with HX711 load cell amplifier are used as input sensor to microcontroller. The system keeps measuring the current weight until it hit the targeted final weight. Two set of experiments that are using 500 g and 1500 g of pre-treated pepper were conducted to verify the system. As a result, the dryer was successful to work within the desired temperature and it stop operating just after the samples reached 12% of the moisture content. The finding has proven a shorten of drying time from 4 to 7 days when using the traditional method to the current 3 – 5 hours only when using the developed system. Hence, this is an improved method achieved to a quick drying of the black pepper.

Keywords: black pepper, rotary drum dryer, drying process, moisture content, pre-treatment

1. Introduction

The cultivation of pepper in Malaysia has started since 1856 and in the early 1900s, the plantation of pepper gets more extensive [1]. As shown in Fig. 1, Malaysia annual pepper export is increasing especially black pepper. The export value for black pepper is more than double of white pepper. In 2016, Malaysia ranks as the fifth largest pepper producer in the world [2]. Due to the market demand, farmers preferred to produce black pepper rather than white pepper [3].

The black pepper is produced from the almost-matured peppercorn or greenish looked. In order to ensure the black peppers are safe for storage and transportation, the peppercorn needs to go through an intensive drying process called dehydration. The peppercorn is usually dried under the sun. During the drying process, browning enzyme settles in and the phenolic compounds are then oxidized by atmospheric oxygen under the catalytic influence of the enzyme phenolase and eventually turning into green colour of matured pepper pigment to black [5], [6].

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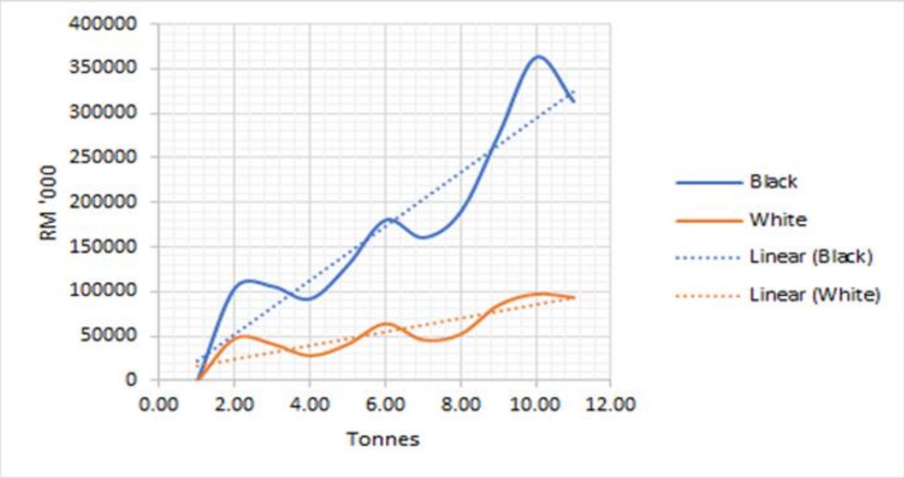

Fig. 1 - Malaysia Annual Pepper Export 2007-2016, from Ministry of Primary Industries (MPI) [4]

In food preservation, drying or dehydration is the process of removing water content from food by passing hot air through it to hinder any microbial growth that consequently improved the shelf life [7], [8]. Blanching is a pre-treatment process before drying fruits or vegetables. Basically, blanching can improve the drying and dehydration rate by relaxing the tissue walls so that moisture content can escape more rapidly [9]. The black pepper blanching process is conducted by dipping the pepper in a boiling water for approximately 5-10 minutes [10], [11]. However, blanching the peppercorn too long can deactivate the enzymes that are responsible for browning reaction and causes discolouration of black pepper [12]. In addition, the blanching process is also to remove any pesticide residue and reduce microbial load [13].

In food dehydration process, temperature plays important role because as the air temperature increased, the moisture content removal rates also increased. Hence, this resulted into shorten drying time [14]. At the initial phase of the drying process, the air temperature can be relatively high that is 65^{0}C to 70^{0}C, as the surface moisture is gradually lost, the rate of evaporation started to slow down and therefore, the temperature is reduced [15]. By exposing the food with high temperature could degrade or even damage the product, in black pepper cases it will lose one of the aromatic flavours which is piperine [16], [17]. Each fruit and vegetable have their own critical temperature. The optimum temperature for black pepper drying is 55^{0}C [18].

Table 1 shows characteristics of ground black pepper based on Malaysian standard. The black pepper produced should have remaining 12% moisture content [20]. According to Nelson and Cannon-Eger [11], about 100 kg of peppercorn produced approximately 35 kg of black pepper. Furthermore, Rolland [19] found that 12% moisture content is equivalent to 70% of weight loss from the initial bulk mass.

Table 1 - Compositions of ground pepper (Piper Nigrum) [20]

No	Characteristics	Requirements	
		Ground black pepper	Ground white pepper
1.	Moisture, % v/w, max	12.0	12.0
2.	Total ash, % w/w, max, on dry basis	6.0	3.5
3.	Acid-insoluble ash, % w/w, max, on dry basis	1.0	0.3
4.	Volatile oil, % v/w, min, on dry basis	1.5	0.7
5.	Non-volatile ether extract, % w/w, min, on dry basis	6.5	7.0
6.	Crude fibre, % w/w, max, on dry basis	17.5	5.0

Historically, the sun, wind, and a smoky fire were used to discard water from fruits, meats, grains, and herbs [8]. There are four common type of drying technologies namely sun drying, oven drying, solar drying and freeze drying. Solar drying is the most traditional drying method that involves with direct exposure to the sun and have many hindrances. Presently more modern and low-cost drying technologies are available which include convective drying (hot air), spray drying, lyophilisation, infrared, microwave or radiofrequency drying, osmotic dehydration, fluidized bed, spouted bed, and desiccant drying [21], [22].

In Malaysia, many pepper producers use traditional method of drying which is direct sun drying. Peppers are spread on mats in a big space direct under the sunlight. However, the sun drying method is unable to produce uniform heat, thus the products need to be turned from time to time which is burdensome work [23]. The drying process varies depending on local weather and the bulk density of the peppercorn. It took approximately about 4 to 7 days depending on the sun intensity and hours of sunshine received and the duration can prolong during rainy days [24], [25]. In an open environment pepper is expose to the contaminants such as dirt, fungus, birds and insects. Therefore, an advanced automatic machine is necessary to reduce manual labour and shorten the drying process.

The rotary dryer is a drying method which circulate the hot air through the drying material in the rotary drum. The rotation of the drum helps to lifts the drying material in the dryer so more hot air passing through. Thus, rotary drum dryer improves heat and mass transfer [26], and drum rotation helps to increase the air flow in the drum [27].

Manual inspection to heating level and inspecting the pepper is not practical. Over-drying product can cause loss of volatile flavour components and loss of total weight of the dried pepper that consequently affect the farmers' income. If the peppers are not dried properly, they are exposed to mould and fungus attack. Hence, an accurate control system is needed to optimize the energy consumption. The aim of this project is to develop a feedback control system for an efficient rotary drum dryer.

2. Research Method

Summary of the overall research methodology of this project is shown in Fig. 2. The main purpose of the black pepper rotary drum dryer system is to ensure the drying process conducted in a controlled temperature, shorter drying time, meet the specific moisture content and less human intervention. The development covers both, hardware and software development of the system followed by system validation.

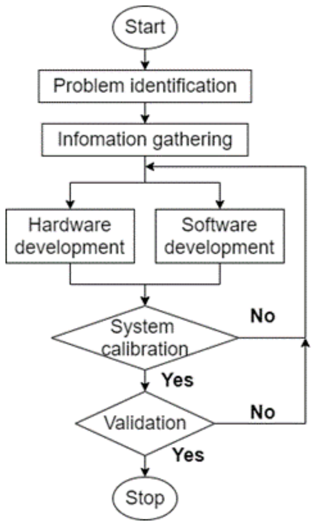

Fig. 2 - Flow process of the methodology

2.1. Hardware Development

Fig. 3 shows the schematic drawing of the black pepper rotary drum dryer used in this project. AC motor with 0.75 kW and variable frequency drive (VFD), Delta VFD007L21A is used to control motor speed by varying the frequency and voltage of its power supply together with belting system to rotate the drum. The drum made from perforated stainless-steel sheet that can accommodate up to three kilograms of pepper at once. Electrical heater is used to generate heat in the drying chamber. The drying chamber has insulator to preserve heat while the small holes at the top of the chamber are to release moisture from the system.

Arduino Mega 2560 REV3 board is chosen as the microcontroller to execute the instructions operation in this project. The Arduino based board is chosen because it is an open-source software. Temperature control system consist of type K thermocouple along with MAX6675 thermocouple amplifier, solid-state relay (SSR) and heater. SSR is used because it has low power consumption compared to the mechanical relay [28]. The relay act as a switch to turn ON and OFF the heating element and the ON-OFF periods of the heater is triggered by thermocouple so that the dryer chamber can maintain the optimum temperature of 55°C. Four S-type (TAS501) load cells along with HX711 load cell amplifier were placed at specific location underneath the dryer to measure weight of the peppercorn during drying process.

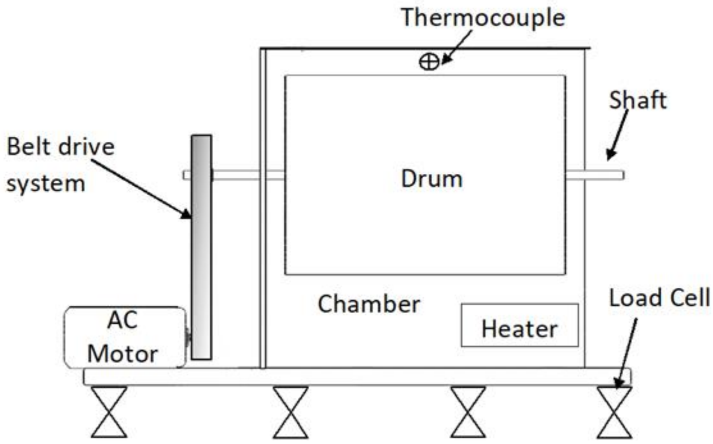

Fig. 3 - Schematic diagram for rotary drum dryer

2.2. Software Development

Fig. 4 presents the whole process flow of the programming. The ON button is first pressed to initiate the program loop. The program sequence started with measuring the initial weight, W_i of the peppercorn that has been placed into the drum. After a stable initial weight reading is attained, the motor will start automatically. The motor starts to rotate the drum and took about 45 seconds to achieve stable rotational velocity. Thus, 45 seconds delay was set before the program starts reading the current weight, W_c of the peppercorn. Then the value of W_c can be computed and compared to the desired W_f. The value W_i is utilised to obtain the final weight, W_f of the peppercorn during drying process. The value W_f can be obtained using equation (1).

$$W_f = 0.3 \times W_i \tag{1}$$

Concurrently, the sequence continues with temperature controlling program by reading the chamber surrounding temperature with thermocouple sensor. The condition is programmed such that if the temperature value is less than 55°C, the relay will be triggered to complete the circuit and the heater is functioning. If the temperature exceeds the limit, the relay will turn off the heater. The condition was programmed if W_c is less than or equal to W_f the motor and heater will be turned off and the program will be terminated. Time interval for the data logger was set to 10 seconds.

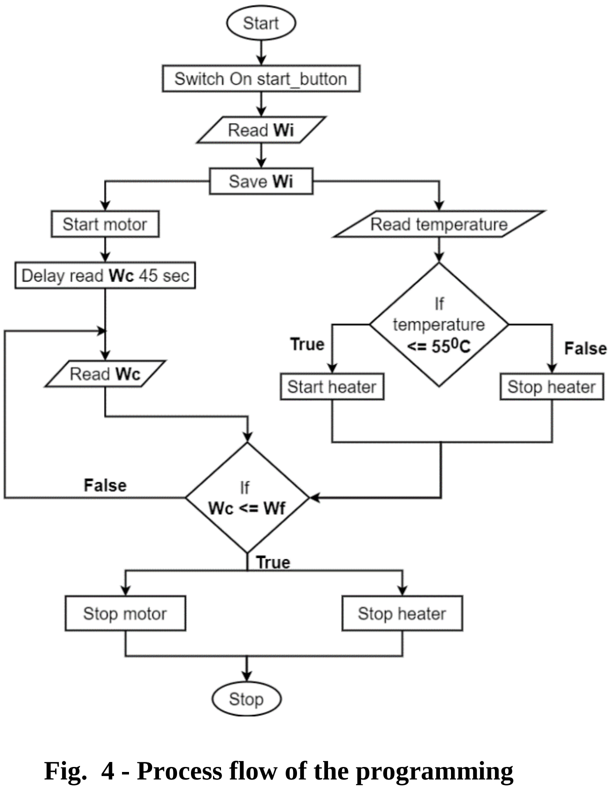

Fig. 4 - Process flow of the programming

2.3. System Calibration

System calibration is a critical process that must be conducted to ensure accuracy of the measurement devices used in the system. For the temperature control, thermocouple is used to measure the temperature. However, the signal produced by thermocouple is very small. Thus, MAX6675 thermocouple amplifier is required to amplify the signals produced and provide equivalent data of temperature. From the data collected, a simple calibration is done on the thermocouple by checking the freezing and boiling point of water.

Meanwhile, calibration factor for load cells (weight sensor) is needed to convert the signal from the strain gauge to the desired standard measuring units. The calibration factor has to consider type of load cell, combination of load cells and the weight of the platform used. The calibration factor was determined by placing a known mass on the load cell platform, then the value can be calibrated and obtained in a serial output form. The S-type TAS501 load cell comes with four wire, red for Excitation+ (E+), black for Excitation- (E-), white for Signal+ (S+) and green for Signal- (S-). As shown in Fig. 5, the cells are connected in parallel where all the corresponding signals are connected such that Excitation to Excitation and Signal to Signal with respective polarity. The connections produce results of average signal from all the sensing elements.

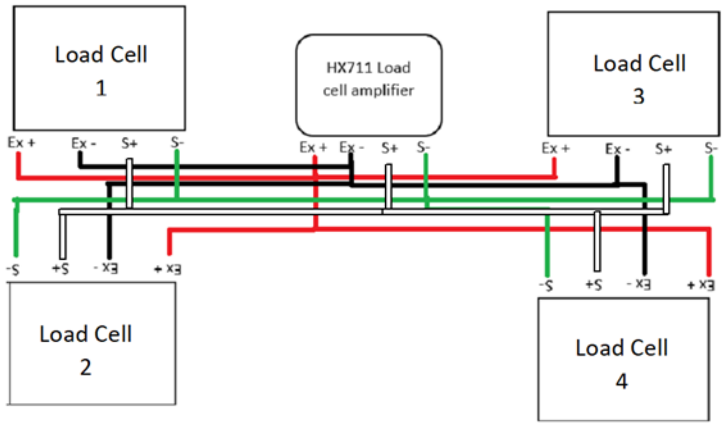

Fig. 5 - Circuit diagrams for S-type TAS501 load cells

2.4. System Validation

Two set of experiments were conducted to validate the system programme. The experimental procedures can be summarized as follows:

i. Weigh fresh pepper using electronic weight scale and record as W_i.
ii. Soak the pepper in boiling water for 10 minutes.
iii. Drain the pre-treated sample.
iv. Put the sample in drum of the rotary drum dryer.
v. Switch ON the dryer.
vi. Switch OFF the dryer once the motor stop.
vii. Take out the sample from the drum.
viii. Measure the dried sample using electronic weight and record as W_f.
ix. Compare the W_f with the analytical value from equation (1).

3. Results and Analysis

The implementation of Arduino libraries helps to simplify the programming sequences in this research. These libraries are collection of complex code and turn it into a simplified function intended to help new user. The most critical Arduino libraries in this research is the ‘millisDelay’ library as shown in line 3 on Fig. 6. The ‘millisDelay’ is a timer interrupt function library and this timer is an interrupt function that signal the processor to promptly stop what it is doing to handle high priority processing [29]. This function allows Arduino to conduct multi-tasking sequences.

```
#include "HX711.h"
#include "max6675.h"
#include <millisDelay.h>

#define calibration_factor -2400
#define zero_factor -421966
#define DOUT  46
#define CLK  48

int vccHX711Pin = 50;
int gndHX711Pin = 44;
int gndPin = 22;
const int BUTTON = 24;
int tareButton = 52;
int vfdRelay = 30;
int heaterRelay = 28;
int buttonState = 0;
```

Fig. 6 - Example Sketch for Arduino board

A validation experiment is conducted to verify whether the temperature control system is successfully able to maintain the surrounding temperature of 55ºC inside the chamber. The result of temperature control is summarized in Fig. 7. The result shows the system has some noise which is likely have low steady-state error. The actual temperature is seen within the set point temperature which is acceptable.

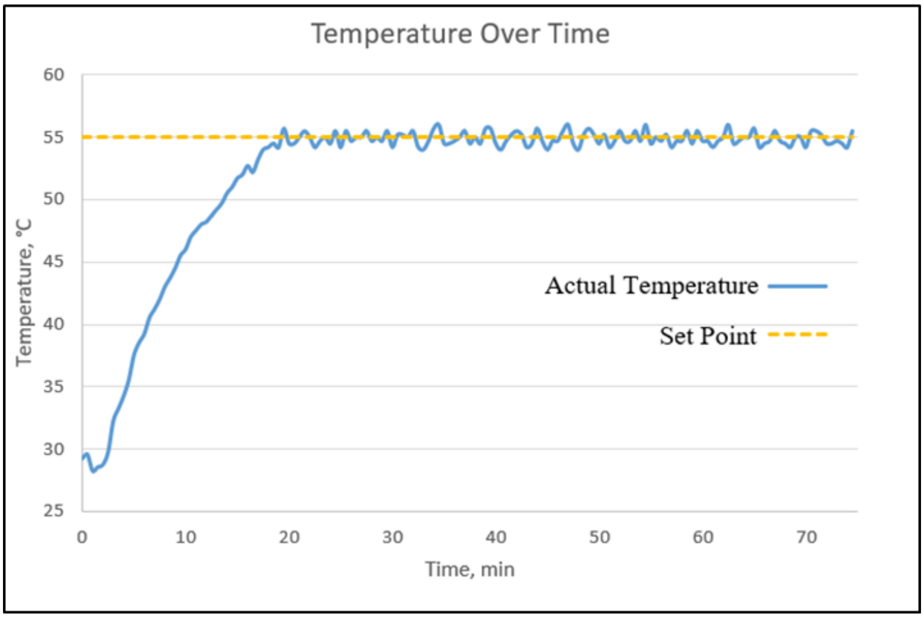

Fig. 7 - Temperature control result

The initial and final weight of pepper berries before and during drying is an essential aspect to be analysed. The final weight of the peppercorn should be equivalent to 30% of the initial mass in order to meet the 12% moisture content [11], [19]. Hence, the final weight of peppercorn is a crucial measure in this research. In order to ensure accurate weight measurement, a simple experiment was conducted to measure the system error. The experiment begins with measuring the initial and final weight of the pepper using load cells of the dryer and the results are compared with the electronic scale (as a control experiment). Table 2 shows the results of the percentage errors of pepper berries weight between electronic digital scale and load cell. The findings show the percentage errors for both experiments do not exceed 10% which is acceptable [30].

Table 2 - Result of weight measuring using electronic digital scale and load cell

	Initial Mass			Final Mass		
Experiment	**Weighted using digital scale (g)**	**Weighted using dryer load cell (g)**	**Percentage Error (%)**	**Weighted using digital scale (g)**	**Weighted using dryer load cell (g)**	**Percentage Error (%)**
1	501	520	3.80	165	155	6.06
2	1530	1515	0.98	468	446	4.7

Fig. 8 shows the weight loss of the pepper samples during drying time obtained from the two experiments. Experiment 1 and Experiment 2 use 500 g and 1500 g of fresh pepper. Basically, the two samples show similar trend, a dropped of sample weight as the drying time increase. Towards the end of the curve, the weight loss trend becomes constant. The program immediately stopped when the weight loss reached 30% of the initial weight of the peppercorn. Theoretically the final weight of the samples with 12% moisture content is equivalent to 150 g and 450 g respectively. 3 and 5 hours of drying time are needed to obtain 12% moisture content. More peppers required longer drying time, but the drying trend is not proportionate.

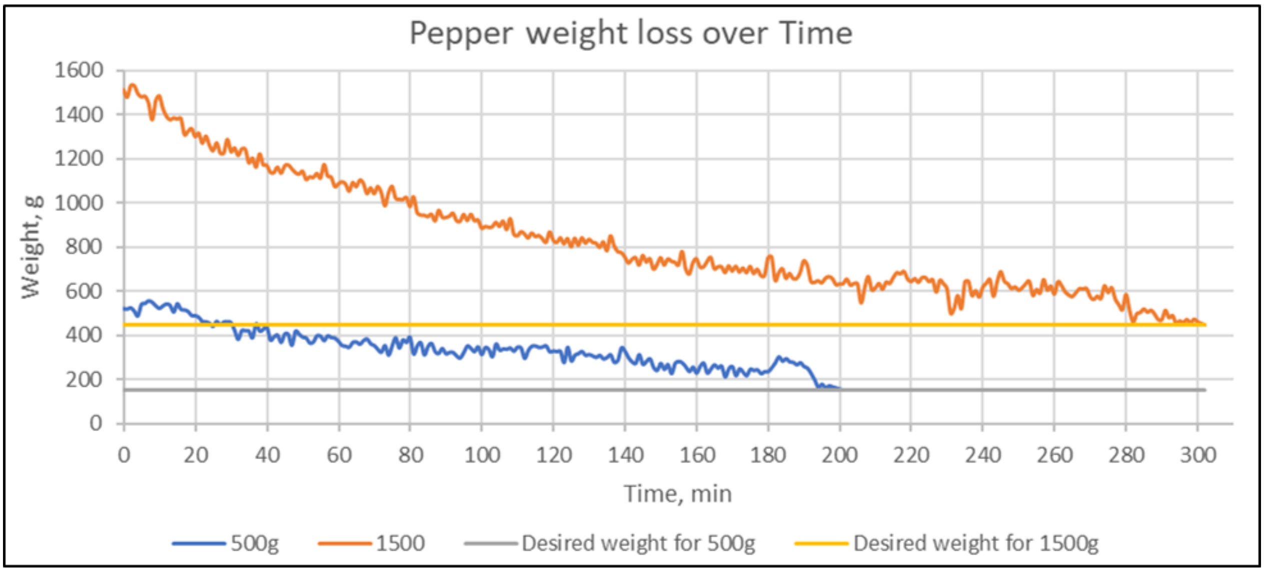

Fig. 8 - Weight loss during drying process using load cell

The results obtained from the data logger and the electronic weight scale show small difference as shown in Table 3. The left column shows the pepper weight from the experiment conducted in Section 2.3. The right column shows the results from data logger. Data logger displayed the average value of pepper weight measured by all four load cells. Percentage of weight loss was calculated based on targeted final weight which is 30% from the initial weight. Both experiments are consistent with the results from Nelson and Cannon-Eger [11] and Rolland [19] 65% and 70% of weight loss, respectively. Hence, the developed system is conformed with the targeted condition set for the operating system. From the validation experiment, it shows that the dryer has simplify the drying process and improve the traditional drying method. Overall, the dryer has improved the drying time from 4-7 days traditionally to 3 – 5 hours only.

Table 3 - Result of weight loss measured using digital scale and load cell

	Digital scale			Data logger (load cell)		
Experiment	Initial weight, W_i (g)	Final Weight, W_f (g)	Percentage of weight loss (%)	Initial weight, W_i (g)	Final Weight, W_f (g)	Percentage of weight loss (%)
1	501	165	67.1	520	155	70.2
2	1530	468	69.4	1515	446	70.6

4. Conclusion

The purpose of developing the control system for the black pepper rotary drum dryer is to ensure the dryer works within the desired drying temperature, meet the specific moisture content and shorten the drying time with less human intervention. Application of the right sensors and correct programme allow for system optimization. The use of thermocouple and feedback system enable the pepper to perfectly dried under controlled temperature. As the pepper reached the 12% moisture content, the system immediately stopped to avoid over-drying. The developed system has been validated with two set of experiments. The developed system was conformed when it was able to meet the desired moisture content as percentage of weight loss were between 67-70% which is consistent with the prior researches. The control system of the rotary drum dryer allows for minimum supervision compared to the traditional drying method. In addition, the rotary drum dryer managed to shorten the drying time. Each treated sample of 500 and 1500 grams only took 3 - 5 hours drying time respectively.

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