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Silkworm pupae drying using microwave combined with hot air

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Abstract

Silkworm pupae are by product derived from harvested cocoon. It is popular fried for consuming due to its good taste and high protein content. To avoid the frying, microwave drying process is interesting for health lovers. The objective of this research was to study the effect of microwave power combined with hot air on drying kinetics of silkworm pupae. The microwave powers of 143 270 323 and 394 watts were applied and combined with hot air at temperature of 60°C with air velocity of 1 m/s. These were compared with drying alone at air temperature of 60°C. The results showed that the increase in microwave power resulted in the higher drying rate and higher than only hot air drying. For colour assessment found that microwave combined with hot air drying provided lower lightness *(L^*)*, higher redness *(a^*)* and yellowness *(b^*)* than that drying with only hot air. For the specific energy consumption, the best drying condition of silkworm pupae is using microwave power of 323 watts combined with hot air. The drying time and energy consumption could be reduced by 98.74 and 98.11% when compared to only drying with hot air at 60°C.

Introduction

Eri Silk (*Philosoia ricinii, Attacus ricinii* or *P.cynthia*) is a species of moth pests. The purpose of eri culture is to produce the production of silk such as eri yarn or eri fiber. The original eri culture is in the North East of India. There is a large number of eri silkworm cultivation in Thailand, especially in the North and Northeast zone. Eri silkworm pupae are produced from silk and plenty. People in Japan, India, Thailand, China and Korea, etc. favour to eat silkworm pupae (Longvah *et al.*, 2011) and have many shops in the market for sell fried silkworm or insect. Food cooked from silkworm is nutritious and cheap. The problem is that the food made from silkworms cannot keep for long time. The pupae are caused rotten in a short shelf life. Processing productivity of silkworm pupae by drying method is another way that helps to keep the raw of silkworm pupae. It can be stored longer and reduced the weight and volume of product. As a result, the cost of transportation and storage are inexpensive (Soponronnarit, 1995). Sun drying is a traditional method used for drying agricultural products. This technique is low cost because it using thermal power from solar. The disadvantage of this system is that it cannot control the heat, cleanliness and drying time. Usub *et al.* (2008) studied and developed solar drying for silkworm pupae. They concluded that the time of drying decreased by about 40% compared with traditional methods of sun drying. Additionally, microwave drying is another system that can resolve and compensate for the disadvantages of solar drying. It can optimize the drying process and also take lower time. From the study of the structural changes of potatoes from microwave drying with hot air of Khraisheh and McMinn (2004) was found that the reduction of the period of drying potatoes reduced the loss or destruction of nutrients. It also helps to maintain the quality of the product, such as a change of colour and shrinkage. This microwave drying with hot air drying system is better than drying by convection only. For the reasons stated above, the microwave is used widely. This technique was used in drying agricultural products such as garlic (Sharma and Prasad, 2001), strawberry (Piotrowski *et al.*, 2004), banana (Masken, 2000), rice (Jiao *et al.*, 2014), longan (Varith *et al.* 2007) and mushrooms (Lombrana *et al.*, 2010) etc. The purpose of this research is to study the microwave power affecting drying kinetics and the specific energy consumption for drying silkworm pupae.

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Materials and Methods

Raw material

In the experiments, eri silkworm pupae from the Na Khu, Kalasin province were used. Pupae were blanched in boiling water for 3 minutes and stored by freezing. Before the experiment, frozen silkworm pupae were placed in a well-ventilated place to adjust the temperature of silkworm pupae equal to the ambient air temperature.

Moisture content determination

Samples of 20 g of eri silkworm pupae were dried in the oven at 103°C for 24 hours for finding moisture content of silkworm pupae.

Moisture is indicative of the amount of water contained in the material compared to the mass of the material. Moisture content (Dry basis, Md) calculated from equation (1) as follows;

$$M_d = \frac{(w-d)}{d} \times 100 \quad (1)$$

When M_d is dry basis moisture (%)
d is the dry mass of the material (g)
w is the initial weight (g)

Experimental Dryer

Microwave drying combined with hot air as shown in Figure 1 was built to study the drying of silkworm pupae by student and staff in Faculty of Engineering. Dryer has two heat sources of hot air. There are hot air from the heat coil and thermal energy from the microwave. Thus, this research conducted two approaches for drying silkworm pupae; drying in hot air only and drying in microwave combined with hot air. From the past research about the condition and heat transfer in oven (Illes and Harsanyi, 2009; Sansomboonsuk, 2009) in order to consider the dryer design, then detail of the dryer consists of the following sections. Size of drying room is 300 mm x 240 mm x 210 mm in width, length and height. The 800 watts magnetron was installed to generate microwave frequency at 2.45 GHz. Microwave power was tuned by Lux meter, air temperature in drying room was measured by thermocouple type T and transmitted signals to the PID temperature controller to control the air temperature in the drying room. Fan blades curve (Mitsubishi) 0.5 Hp, 10-inch diameter, was applied. Two items of 1,000-watt electric heating coils were installed for generating hot air. Drying temperature was controlled by Proportional-Integral-Derivative Controller. Thermostat is temperature sensor. Electric balancing (range 1-3200 g, error ±0.1 g) was used to weight the sample in drying room.

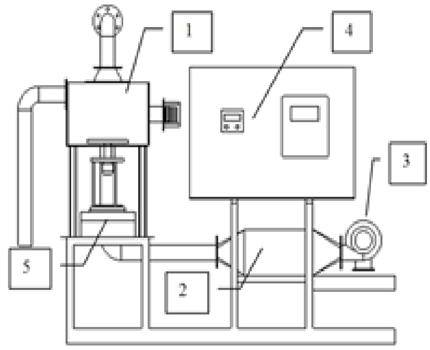


Figure 1. Microwave drying combined with hot air; (1) drying chamber and microwave; (2) the heater; (3) blower; (4) PID controller; (5) electronic balance

Drying Method

Pupae were weighed for 100 g before drying then placed them on a circular tray area of 85 square centimetres. Silkworm pupae were dried and recorded the weight left of the pupae every 2 minutes until the end of drying process. The experimental conditions of drying pupae by microwave combined with hot air were following; microwave power was adjusted to 143, 270, 323 and 394 watts, respectively, hot air at a temperature of 60 degrees Celsius, with air velocity of 1.0 meter per second was combined to microwave drying. Results of drying conditions above were compared with the drying results of hot air drying only at temperature 60°C at air velocity of 1.0 meters per second. To assess the colour and specific energy consumption, pupae was then dried until the final moisture content down to about 54-64% dry basis. This was equal to the moisture content of fried pupae from local market. The experimental drying for each condition was two duplications.

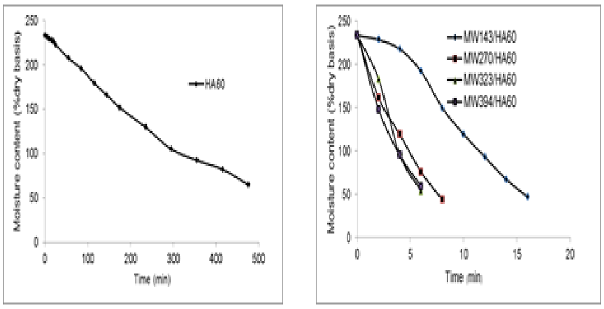
Colour assessment

Dried pupae were measured surface colour using a Hunter Lab Colourimeter (type Colour Flex, USA). The Hunter L^*, a^*, b^* scale gave measurement of colours in units of approximate visual uniformity throughout the solid. The L^* value measures lightness and varies from 100 for a perfect white and 0 for black, a^* and b^* when positive measure redness and yellowness, respectively.

Specific energy consumption

The specific energy consumption can be calculated from equation (2), when blower efficiency was 90%, heating efficiency was 80% and microwave efficiency was 50% (Decareau and Peterson, 1986 and Bufflur, 1993)

$$SEC = \frac{E_{microwave} + E_{blower} + E_{heater}}{(M_i - M_f)} \quad (2)$$



a) b)

Figure 2. The experimental results of pupae drying; (a) hot air drying only; (b) microwave drying combined with hot air

Figure 3. Pupae after drying from different conditions

When E is the electric power used (kW)

M_i is mass of initial product (kg)

M_f is mass of final product (kg)

Results and Discussion

Kinetics of pupae drying

Experimental results of silkworm pupae drying are shown in Figure 2 (a), (b), which present all experiment in the graphs between the temperature and time. The initial moisture content of silkworm pupae was approximately 233% dry basis and after drying process the moisture content was decreased to the range of 54-65% dry basis. Figure 2 (a) shows that when dried silkworm pupae by hot air drying only at 60°C, the drying rate was reduced. Therefore, it required a long drying time. When compared pupae which were dried by hot air drying only with pupae which dried in a microwave combined with hot air as shown in Figure 2 (b), it found that the only constant drying rate was occurred when drying with combined microwave and hot air. The outer appearance of surface of pupae silkworm was hard, but within the pupae, it still had high moisture content. From drying pupae with hot air only, it was found that the mass of water slowly transferred to the outer surface. Therefore, the drying efficiency was low. For microwave drying, microwave penetrated into the pupae and generated heat within the pupae. The mass transfer of water within silk worm to the outer surface occurred faster. Hence, the efficiency of microwave drying combined with hot air was better than hot air drying only. The result is shown in Figure 2. This finding was agreed with the studied of Jiao *et al.* (2014) that the combined microwave-hot air drying decreased the drying time required compared to hot air alone.

Table 1. Colour of dried pupae from different drying conditions

Drying conditions	L*	a*	b*
HA60	21.04 ± 1.47^{a}	3.35 ± 0.45^{b}	3.72 ± 0.75^{b}
MW143/HA60	16.73 ± 0.95^{b}	5.18 ± 0.73^{a}	5.08 ± 0.67^{a}
MW270/HA60	17.69 ± 1.01^{b}	5.07 ± 0.98^{a}	5.16 ± 0.65^{a}
MW323/HA60	17.71 ± 0.90^{b}	5.52 ± 0.77^{a}	5.43 ± 1.00^{a}
MW394/HA60	18.10 ± 1.69^{b}	5.50 ± 0.81^{a}	5.99 ± 1.68^{a}

Means with the different letter within a column are significantly different ($p \leq 0.05$) by DMRT

Colour assessment

Assessment of colour L^* a^* b^* values are presented in Table 1. The L^* defines the brightness of dried pupae, when the microwave power increased, the pupae were more darkening but not significantly different. The drying with microwave could enhance the heat within pupae leading to the increase in browning colour of pupae. The a^* and b* values indicate the redness and yellowness of the surface colour of dried pupae. The trend of a^* and b* was slightly increased when the microwave power increased but not significantly different among the microwave powers. This due to a change of colour surface was caused by heating inside pupae.

The pictures of dried pupae from different drying conditions are shown in Figure 3. By visual assessment, it can be seen that the combined microwave and hot air drying caused the puffing in dried pupae which is the desirable characteristic.

The specific energy consumption in the drying (SEC)

The specific energy consumption of silkworm pupae drying silk in various experimental conditions was shown in Figure 4. From Figure 4, it can be explained that when the microwave power increased the drying rate was increased leading to lesser drying time. The specific energy consumption for drying silkworm pupae also reduced. This result was consistent with the results of previous research

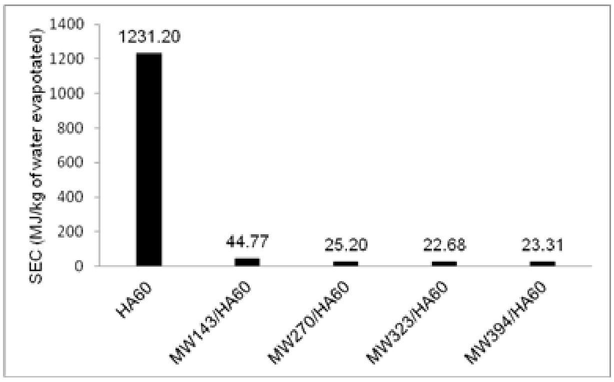


Figure 4. The specific energy consumption (SEC) of the silkworm pupae drying by microwave energy combined with hot air

of (Varith *et al.*, 2007 and Choicharoen *et al.*, 2011). Therefore, the best condition for drying silkworm pupae was microwave power 323 Watts combined with hot air at 60°C. In this condition, the specific energy consumption was minimal 22.68 MJ / kg of water evaporated.

Conclusion

From the experimental results of silkworm pupae drying by microwave drying combined with hot air, it can be concluded that the microwave power affected the kinetics of drying of silkworm pupae. The drying time was faster when microwave power increased. While the specific energy consumption for drying silkworm pupae was reduced. For colour assessment found that microwave combined with hot air drying provided lower lightness *(L^*)*, higher redness *(a^*)* and yellowness *(b^*)* than that dying with only hot air. The best conditions of silkworm pupae drying was 323 watts of microwave power combined with hot air and the minimum specific energy of drying silkworm pupae was equal to 22.68 MJ / kg MJ / kg of water evaporated.

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