INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY COMPREHENSIVE RESEARCH

Optimization of The Vacuum Drying process for Bee Pollen Using the R method

Bui Quoc Khoa [1*], **Nguyen Hay** [2], **Le Anh Duc** [3], **Pham Huu Tam** [4]
[1] Van Lang University, Vietnam
[2] Nong Lam University Ho Chi Minh City, Vietnam
[3] Nong Lam University Ho Chi Minh City, Vietnam
[4] Viet Nam Green Industrial JSC, Vietnam

* Corresponding Author: **Bui Quoc Khoa**

Article Info

ISSN (online): 2583-5289
Volume: 03
Issue: 06
November-December 2024
Received: 03-10-2024
Accepted: 06-11-2024
Page No: 51-56

Abstract
Bee pollen, commonly known as pollen, is a product of exceptionally nutritrional and economic value. It has natural origin because harvested entirely by hand from beekeeping farms. Researching post-harvest techniques to process raw pollen into commerical products that meet requirements for moisture limits and vitamin C content is an urgent need. This study involves developing a pilot-scale vacuum drying equipment (5 kg/batch capacity) and investigating drying operational conditions using the response surface method. Based on the regression equations for vitamin C content and electricity consumption with respect to temperature and material thickness, optimized set drying parameters have been established that can be used for production scale in terms of energy savings and sustainability.

DOI: https://doi.org/10.54660/IJMCR.2024.3.6.51-56

Keywords: bee pollen, vacuum drying, response surface method, vitamine C, electric usage

1. Introduction

According to the Vietnam Beekeeping Association, the country currently has an estimated 1.6 million bee colonies with an annual output of over 80,000 tons of honey and over 2,000 tons of pollen. Products exploited from honeybees include not only honey but also many other products such as royal jelly, pollen, bee venom, propolis, beeswax and even the bodies of bees. Pollen alone has many applications in the food industry as a high-value nutritional additive because it contains many vitamins and biological compounds that are good for health (Li *et al*., 2018) [5]. The major challenge in producing finished pollen is in the processing of raw materials without altering the color and valuable nutritional components of the materials (Barajas *et al*., 2012; Isik *et al*., 2019) [1, 3]. Therefore, to preserve pollen, it is necessary to dry it in a drying cabinet or in the sun at a temperature not exceeding 40 °C to reduce the water content in the pollen to below 10% (w/w) in the shortest possible time, with less nutritional loss; it is possible to choose to quickly cool it and store it at 0 °C, freeze-drying can preserve it for a longer time and the quality will change less (Thakur *et al*., 2020; Khoa BQ, 2010; Huy, 2017) [7, 4, 2].

2. Theoretical basis

In this study, bee pollen was dried in a vacuum environment (P = -700 mmHg), at which point the partial pressure of water vapor in the material at the pollen surface is low, the evaporation process will take place quickly, and the pollen will dry faster. At the same time, the boiling process of water occurs on the entire pollen surface, so the moisture reduction process is also more uniform; the color, flavor, and structure of the material change evenly in the product after drying. The advantage of the vacuum drying method compared to conventional drying methods is to limit the impact of ultraviolet rays (outdoor drying), oxygen molecules oxidize pollen compounds (convection drying), and the temperature in the vacuum chamber is kept stable for a long time, helping to save energy. The question is what parameters the vacuum drying mode will include to optimize pollen drying to help maintain the vitamin C content (representing the product quality factor) as well as the lowest power consumption.

Optimization experiments using response surface methodology help reduce unnecessary experiments, thereby saving implementation costs, time, and effort, but still providing statistically satisfactory data to serve as a basis for application in actual production (Myers, 2009) [6].

3. Research methods

3.1. Material

Fresh pollen was harvested from Bao Loc (Lam Dong province). The material has a fragrant smell, bright yellow color, and initial humidity of 21.34% (w/w).

3.2. Vacuum drying equipment

The vacuum drying pollen dryer has two operating principles: continuous and cyclic. The continuous type is the vacuuming and heating process is continuous and continuous from the beginning to the end. As for the cyclic drying type, the vacuuming time and the heating time are alternated throughout the drying process, when heating is applied, there is no vacuuming and vice versa. The appearance of these two principles comes from the heating method in a vacuum environment.

In a vacuum environment, the convection heat exchange process is very poor, so if you want to dry continuously, you must use the heating method using microwave or high-frequency electricity. However, the microwave heating method is only suitable for small models, difficult to develop into industrial equipment. The high-frequency electric heating method is also very expensive, not suitable for current conditions. The pollen dryer using the method of heating by resistance, heat transfer by the principle of thermal radiation, is suitable for the feasibility of expanding capacity and competitive price. Therefore, the implementation team has manufactured a vacuum dryer with a capacity of 5 kg/batch located at the Center for Technology and Refrigeration Equipment of Ho Chi Minh City University of Agriculture and Forestry.

The structure of the vacuum dryer is as follows

- There are two main types of drying chambers: cylindrical and box-shaped. Due to the characteristics of the shape, each type has different advantages and disadvantages. The cylindrical type can withstand high pressure, the chamber structure is simpler but the usable volume is lower. The box-shaped type has a large usable space but has poor pressure resistance. The shape of the drying chamber should be selected based on actual production conditions such as: floor space, capacity, material price. To ensure pressure and vacuum resistance for the experimental drying process, the selected machine model has a cylindrical chamber shape, with a lid that opens and closes at the top. Inside the drying chamber, there are lights and heat trays. The heat trays provide heat for the drying process.
- The water tank is in the shape of a box and is used to contain the moisture condensation system including the cooling system and the moisture condenser. The moisture condensation system in the vacuum dryer is responsible for condensing the moisture from the drying chamber to protect the vacuum pump; reducing the volume of the steam sucked out of the drying chamber. The condenser is used to condense moisture and discharge water through the drain valve.
- The one-way valve is used to block air when the pump stops working.
- The vacuum pump is used to vacuum the drying chamber.

3.3. Investigation of the effect of material thickness on the moisture release capacity of pollen in vacuum drying environment

The experiment was conducted by spreading the pollen evenly on the drying tray to a thickness of 10–15–20 mm and drying the pollen at temperatures of 36–38–40–42–44 °C for 0–3–5–7–9 hours. Periodically take samples and measure to obtain the material moisture content (% w/w). The experiment was conducted once for each treatment.

3.4. Optimization of pollen drying process using response surface methodology

Based on the single experiments investigating the drying conditions suitable for pollen, the research team selected the drying temperature (representing the operating parameters) and the material thickness (representing the machine capacity) as two important factors of a drying regime in a vacuum environment. The surface was constructed to meet the vitamin C index (representing the product quality) and the power consumption (representing the equipment efficiency) by the central composite design (CCD) method with the experimental layout as shown in Table 1.

Table 1: Levels and ranges of input factors in the experiment optimizing the highest vitamin C content

Factor / Level	Drying temperature (X1) (°C)	Material thickness (X2) (mm)
+1,414	43	22
+1	42	20
0	40	15
-1	38	10
-1,414	37	8
Range of variation	2	5

4. Research results and discussion

4.1. Investigation of the effect of material thickness on the moisture release capacity of pollen in vacuum drying environment

The results showed that the higher the temperature, the faster the moisture content decreased and the color of the product after drying also changed more darker than at the beginning. When the material thickness was 10 mm, changing the drying temperature would lead to a very steady change in the moisture reduction rate at different temperatures, however, at a thickness of 15 mm and 20 mm, the temperature in the range of 40–44 °C had the same effect when making the pollen reduce moisture to 10% (w/w) after 9 hours.

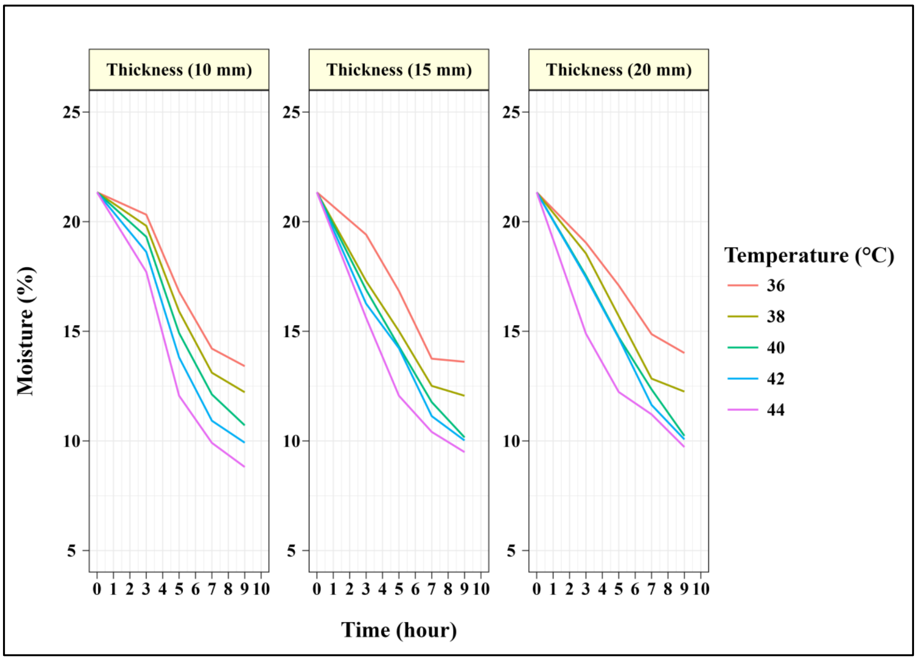

Fig 1: Investigation of the effect of material thickness on moisture loss through temperature levels over time

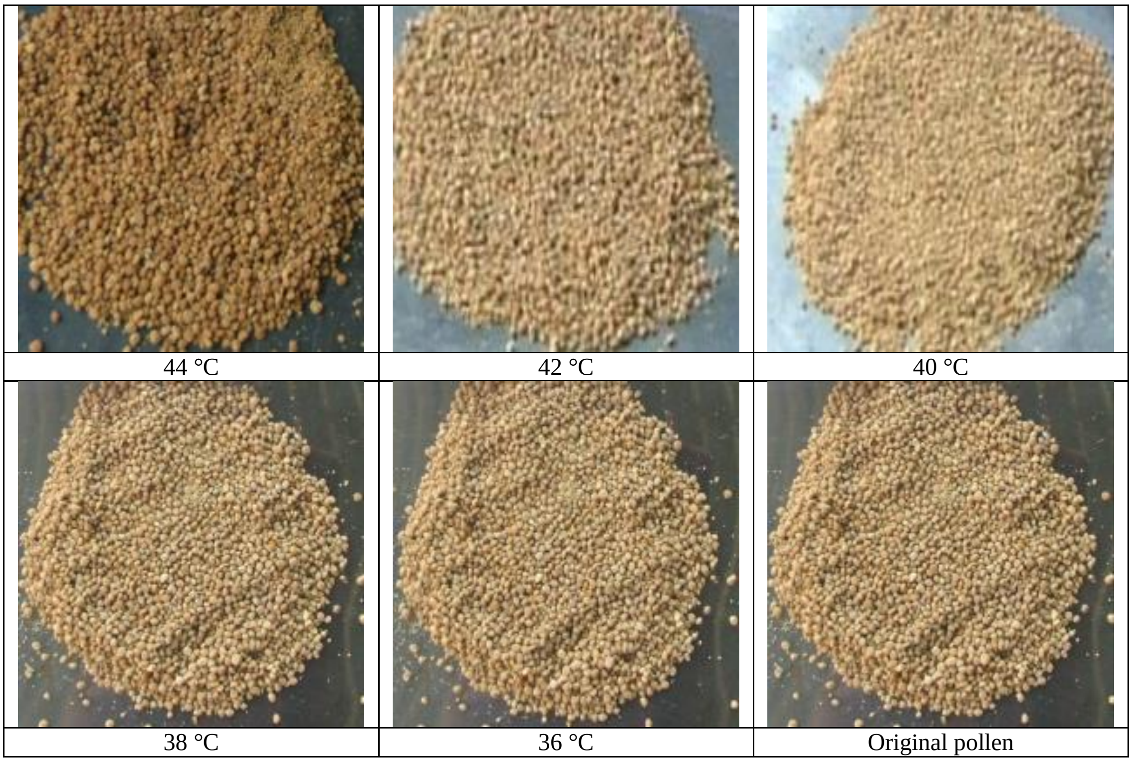
44 °C
42 °C
40 °C
38 °C
36 °C
Original pollen

Fig 2: Sensory results of pollen after drying at different temperatures

4.2. Optimizing pollen drying process according to vitamin C content

Temperature and material thickness have different effects on vitamin C content, with higher temperatures having a negative effect on the amount of vitamin C obtained. The response surface equation is:

$$\text{Vitamin C} = 2043{,}97 + 108{,}909 \times X1 - 7{,}77941 \times X2 - 1{,}42216 \times X1^2 + 0{,}043532 \times X2^2$$

The highest vitamin C content reached 33.968 mg/100g when the drying temperature X1 was 39.8 °C and the material thickness X2 was 22 mm.

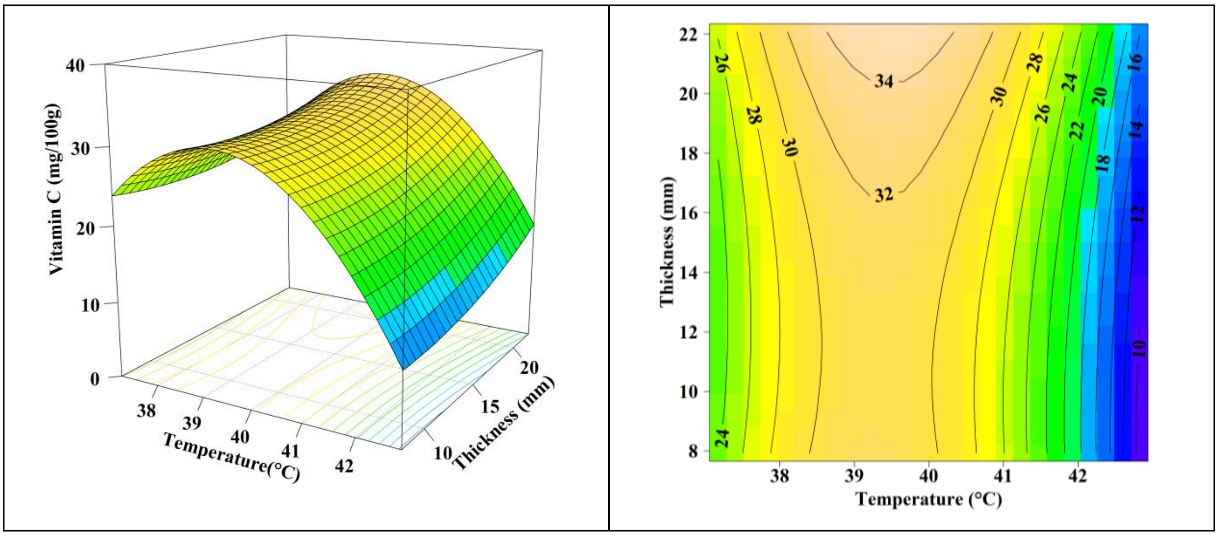

Fig 2: Response surface and contour plot for vitamin C content versus drying temperature and material thickness

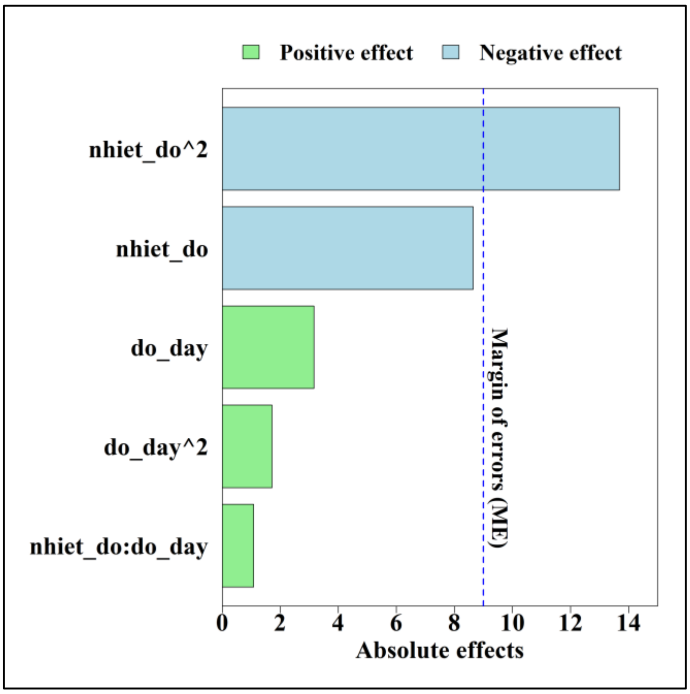

Fig 3: Pareto graph of the influence of input factors on vitamin C

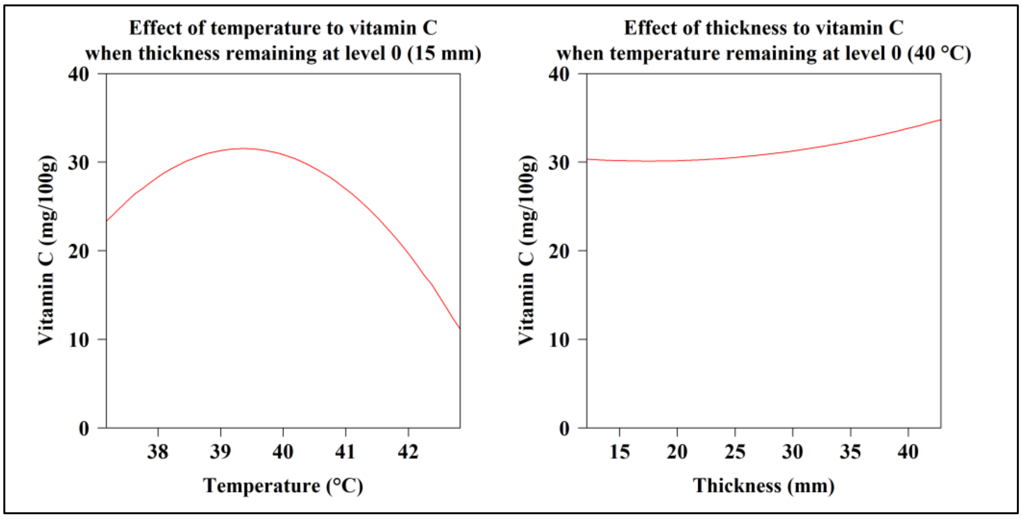

Fig 4: Effect of temperature and material thickness on vitamin C when the remaining factor is fixed at 0

4.3. Optimizing pollen drying process according to power consumption

Temperature and material thickness have a positive effect on power consumption, where the higher the temperature, the greater the power consumption. The response surface equation is:

$$\mathbf{Ar = 13,5743 - 0,626857 \times X1 - 0,0749216 \times X2 + 0,00827 \times X1^2 + 0,001 \times X2^2}$$

The lowest power consumption is 1.534 kWh/kg when the drying temperature X1 is 37 °C and the material thickness X2 is 12.53 mm.

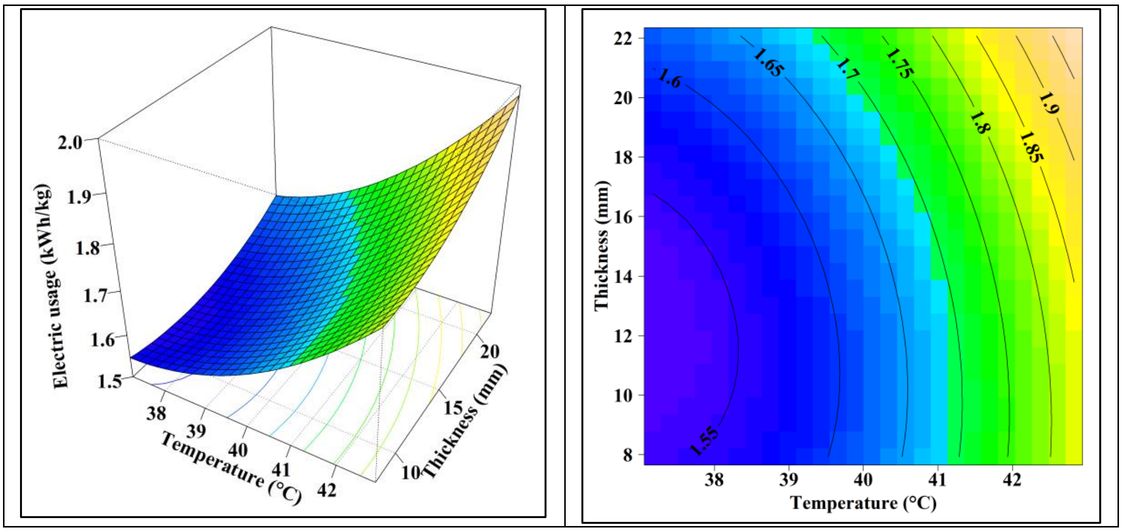

Fig 5: Response surface and contour plot for power consumption versus drying temperature and material thickness

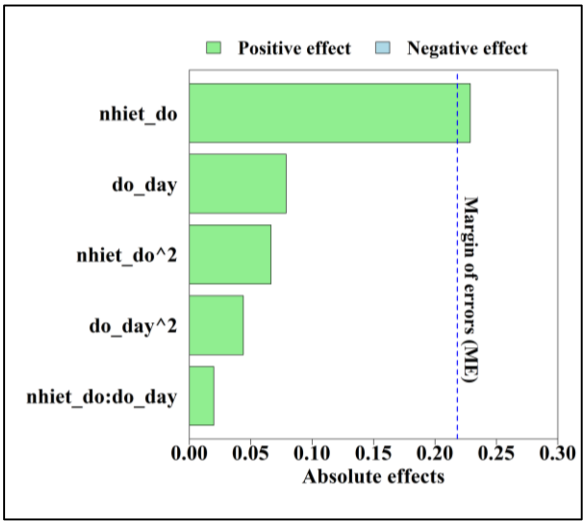

Fig 6: Pareto chart of the influence of input factors on power consumption

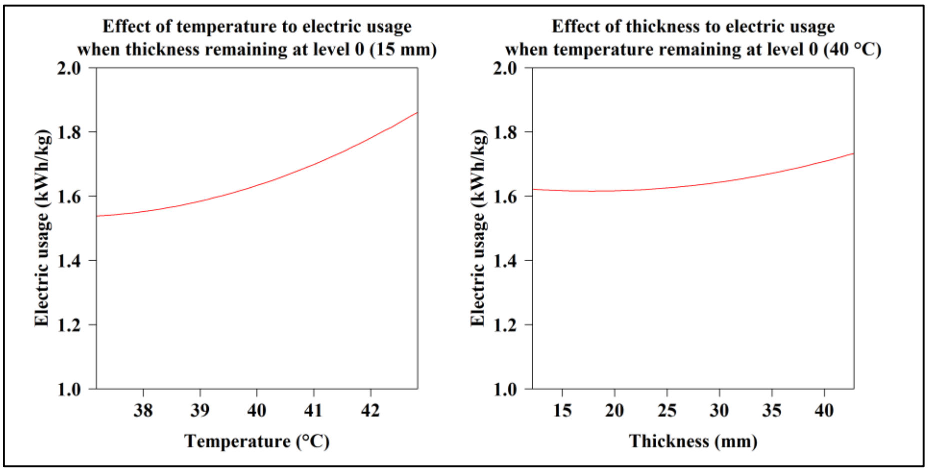

Fig 7: Effect of temperature and material thickness on power consumption when fixing the remaining factors at 0

5. Conclusion and Recommendations

The research on the vacuum drying device using the thermal radiation resistor has achieved the goal of clarifying the pollen drying process as well as providing the necessary data to serve as a basis for application to the production scale. The optimization experiment shows that the vacuum chamber temperature is a decisive factor for the vitamin C content and power consumption while the material thickness can reach 22 mm, ensuring that the pollen after drying meets the requirements for moisture and product quality.

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