**Drying prediction of banana slices using kriging surrogate model based on genetic algorithm**

**Watcharin Dongbang1 and Weerapon Nuantong2,\***

**Abstract**

This work presents the prediction of a Kriging surrogate model based on a genetic algorithm optimization search. Using optimal Latin hypercube sampling, a sequencing optimization based on simulated annealing was applied to the design of experiments of the drying of banana slices using a hot air technique. The independent variables were the temperature, banana slice thickness and drying time. The dependent variables were the final moisture content, shrinkage and drying energy. Under the relationship between independent variables and dependent variables, Kriging models approximated the objective function.   
A genetic algorithm optimization was applied to search for the optimal independent variables. Numerical results showed that the Kriging surrogate model with the relationship between the Gaussian function and the second−order polynomial function given by the function weights of *W1 W2* and *W3*at 0.80, 0.15 and 0.05, respectively, was the best function model. The optimal values of the independent variables were temperature of 70°C, banana slice thickness of 4 mm, and drying time of 155 min. The minimum average error of the multi−objective function was about 0.52% by comparing the prediction results with the experimental results. This optimization approach was to predict the drying of banana slices using a hot air technique.

**Keywords:** Drying, Banana slices, Hot air, Surrogate, Optimization

*Received: 9 January 2020, Accepted: 14 February 2020*

*1Department of Mechanical Engineering, Faculty of Engineering, Burapha University, Chonburi, 20131, Thailand*

*2Department of Mechatronics Engineering, Faculty of Engineering, Rajamangala University of Technology Isan Khon Kaen Campus, Khon Kaen, 40000, Thailand*

*\*Corresponding author E-mail address:* [*weerapon.nu@rmuti.ac.th*](mailto:weerapon.nu@rmuti.ac.th)*, Tel. 043-336370-1*

**1. Introduction**

The drying of products, such as fruits, is a process that increases product shelf−life, reduces the product volume, decreases storage space, and simplifies transport (Onwude *et al*., 2016). Products are dried by heat transfer using methods of radiation, conduction and convection (Dongbang and Matthujak, 2013; Dongbang and Nuantong, 2018; Khan *et al*., 2018; Koua *et al*., 2019; Nadery and Taghian, 2019; Nuantong and Dongbang, 2019). Studies of the drying process examined energy consumption, temperature, drying time, shrinkage, and color in order improve the quality of products (Nadery and Taghian, 2019). In experiments, mathematical models used the drying equation of Newton or Lewis (O’Callaghan *et al.,* 1971), Page (Page, 1949), Henderson (Hendorson, 1961), Logarithmic (Yagcioglu *et al*., 1999), Two term (Sharaf−Eldeen *et al.,* 1980), Midilli (Midilli *et al.,* 2002), Verma (Verma *et al.,* 1985) etc. For example, the Midilli equation revealed a good agreement with the change in moisture ratio of anchovy drying compared to other models (Dongbang and Pirompugd, 2015). The Page equation was the best model for glutinous rice drying using an infrared irradiation technique (Dongbang and Nuantong, 2018). In the drying of jujubes, the Weibull distribution equation best predicted the experimental values (Yi *et al.,* 2012). For the thin layer drying of lemongrass using hot air, the Weibull equation is the most suitable model (Nguyen *et al.,* 2019).

As in the research above, studies of product drying have used different drying models depending on the drying technique and product. Regression analysis was applied to analyze statistical data in linear and nonlinear forms. However, product drying is a complex process that demands energy and a long time for the experiment, which can significantly affect the quality of the dried product. In addition, the drying process and the efficiency of dryers are important to save costs in an experiment.

Thus, the aim of this work is to present a prediction for the drying of banana slices using a Kriging (KG) surrogate model based on a genetic algorithm (GA) optimization.   
This KG method fits the relationship between the Gaussian function and the polynomial function to estimate the multi−objective function. For the experiment, the drying of banana slices uses a hot air technique. The independent variables are the banana slice thickness, temperature and drying time. The dependent variables are the final moisture content, shrinkage and energy of banana drying. The optimal Latin hypercube sampling (OLHS) method using a sequencing optimization based on simulated annealing (SOBSA) is applied to the design of experiments. This approach is a new idea for predicting the drying of banana slices that saves costs of experiments with a small number of samples.

**2. Materials and Methods**

**2.1 Design of experiments**

The design of experiments (DoE) is a statistical approach to find the sampling distribution of parametric values or independent variables. In engineering development, DoE has become important to decease cost and time because it allows the assessment of a large number of independent variables in a small number of experiments.

In the last few years, DoE has developed a variety of methods, including optimal Latin hypercube sampling (OLHS). Thus, our work applies OLHS using a sequencing optimization based on simulated annealing (SOBSA) (Pholdee and Bureerat, 2015) to design the experiment of 16 sampling sets with three of independent variables (banana slicethickness, temperature and drying time). The dependent variables are the final moisture content, shrinkage and energy of banana drying. Under the conditions of DoE with OLHS using SOBSA, the lower and upper bounds of independent variables are defined as follow as

(1)

where *xi, j, k*is the parametric design, and *Li, j, k*and *Ui, j, k*are the lower and upper bounds of the banana slicethickness *(i),* temperature *(j)* and drying time *(k),* respectively. The lower and upper bounds are 2 and 6 mm for banana slice thickness, 60 and 70°C for drying temperature, and 100 and 200 min for drying time, respectively.

**2.2 Instruments and experiments**

The drying of banana slices is tested by experiments in the laboratory of the Faculty of Engineering, Burapha University, Thailand. A diagram of the experimental instruments is shown in Fig 1. It includes a hot air dryer operating at a velocity of 0.8 m/s. The drying chamber has dimensions of 40×40×40 cm3 and rock wool insulation. A heating coil   
(200–800 W) is installed on the side of the drying chamber, at a distance of about 5 cm from a blower fan. A PID controller (with accuracy of ±0.5%, manufacturer: Berme) is applied to control the air temperature, temperature sensor, and type K thermocouples (with accuracy of ±0.75%, manufacturer: [Hualon](http://hi-ip.com/en/hualon.html)) for measurement. The hot air dryer operates for 30 min to stabilize the temperature condition before the experiment. A digital balance meter (OHAUS, PA512, USA), with accuracy of ±0.01g, is installed under the drying chamber to record the weight loss.

In this work, cultivated banana with a ripeness level of 5 (green tip) and an initial moisture content of 300% [dry basis (d.b.)] is used in a case study of drying of banana slices. The banana slices are shown in Fig 2. The volume of the banana slices is about 3.62×10-4m3 for the sampling conditions in Table 1.

devide

**Fig 1** Schematic diagram of experiment

**Picture2**

**Fig 2** Banana slices for experiment

The statistical data of 16 sampling sets are shown in Table 1. The experimental results present the final moisture content, shrinkage and energy of dried banana slices. The final moisture content *Mf* is given by the following equation:

(2)

where *wi* and *wf* are the initial weight (unit: gram) and final weight (unit: gram) of banana slices of each drying experiment, respectively. *Mi* is the initial moisture content as a percentage of dry matter (dry basis (d.b.) is used in research on banana drying (Swasdisevi *et al.,* 2007)). The initial moisture content is given by the following equation:

(3)

where *W* is wet weight, and is dry weight.

The shrinkage of dried banana slices is given by the following equation (Swasdisevi *et al.,* 2007):

(4)

where *Vi* is the initial volume (unit: m3), and *V* is the final volume (unit: m3) of each drying experiment. The energy of the drying of banana slices is given by the following equation (Nuantong and Dongbang, 2019):

(5)

where *P* is the power load (unit: kW) of the drying temperature, and *t* is the drying time   
(unit: min) of each experiment.

**Table 1** Statistical data of 16 sampling experiments

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Sampling** | **Independent variables** | | | **Dependent variables** | | |
| **No.** | **Temp.**  **(°C)** | **Thickness**  **(mm)** | ***t***  **(min)** | ***Mf***  **(% d.b.)** | **Shrinkage**  **(%)** | **Energy**  **(kWh)** |
| 1 | 65 | 4 | 100 | 39.00 | 42.13 | 1.07 |
| 2 | 70 | 2 | 190 | 4.20 | 8.25 | 2.35 |
| 3 | 70 | 4 | 180 | 6.00 | 9.80 | 2.22 |
| 4 | 70 | 2 | 150 | 7.50 | 14.73 | 1.85 |
| 5 | 60 | 4 | 150 | 18.00 | 13.53 | 1.35 |
| 6 | 65 | 6 | 170 | 9.00 | 8.84 | 1.82 |
| 7 | 65 | 4 | 160 | 9.00 | 9.72 | 1.71 |
| 8 | 60 | 2 | 140 | 19.00 | 15.81 | 1.26 |
| 9 | 65 | 2 | 120 | 21.00 | 27.42 | 1.28 |
| 10 | 60 | 6 | 180 | 11.00 | 7.18 | 1.62 |
| 11 | 65 | 6 | 190 | 7.00 | 7.07 | 2.03 |
| 12 | 60 | 4 | 110 | 46.00 | 34.59 | 0.99 |
| 13 | 70 | 4 | 120 | 16.00 | 26.13 | 1.48 |
| 14 | 70 | 6 | 130 | 14.00 | 20.27 | 1.61 |
| 15 | 65 | 2 | 200 | 4.20 | 5.48 | 2.14 |
| 16 | 65 | 6 | 140 | 17.00 | 16.70 | 1.50 |

**2.3 Optimization method**

To study the dependent variables of the drying of banana slices, the final moisture content should be about 7% d.b., which is known to be the optimal value of dried banana slices (Swasdisevi *et al*., 2007). The shrinkage and energy are predicted in the drying process. The experimental data of 16 sampling sets from Table 1 are applied to predict the objective function using the Kriging surrogate model in the following equation:

(6)

where *K(X)* is the Kriging function, *P(X)* is the polynomial function of the known points, and *C(X)* is the stochastic function based on the Gaussian distribution with zero mean and variance  (Madhan Kumar *et al.,* 2017). The objective function has a correlation between the dependent and independent variables as follows:

(7)

where  is the objective function of control values, and  is the independent variables. The GA technique is applied to find the optimal independent variables under control conditions of the final moisture content of 7% d.b. and minimum values for shrinkage and energy.   
The multi-objective function is defined as follows:

(8)

where is the total objective function, and *W1, W2 and W3* are the weights of functions of moisture content, shrinkage and energy, respectively *f1, f2* and *f3*are the functions of moisture content, shrinkage and energy, respectively.

**3. Results and discussion**

Optimal results are found using KG based on a GA optimization search for parameter values of temperature, banana slice thickness and drying time. The output of the   
multi−objective function based on various weights with variable values for the final moisture content, shrinkage and energy of banana drying is shown in Table 2. Table 3 shows the experimental resultsand the error of prediction using the optimization results.

**Table 2** Optimization results of multi-objective function based on various weights

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Model** | **Poly.** | **Weight** | | | **Optimal** | | | **Prediction** | | |
| **Order** | ***W1*** | ***W2*** | ***W3*** | **Temp.**  **(°C)** | **Thickness**  **(mm)** | ***t***  **(min)** | ***Mf***  **(% d.b.)** | **Shrinkage**  **(%)** | **Energy**  **(kWh)** |
| 1 | 2 | 0.80 | 0.15 | 0.05 | 70 | 4 | 155 | 7 | 12.79 | 1.88 |
| 2 | 1 | 70 | 2 | 160 | 7 | 13.04 | 1.92 |
| 3 | 2 | 0.70 | 0.20 | 0.10 | 70 | 3 | 150 | 7 | 13.93 | 1.87 |
| 4 | 1 | 70 | 5 | 170 | 7 | 12.07 | 2.07 |
| 5 | 2 | 0.60 | 0.25 | 0.15 | 70 | 3 | 150 | 7 | 14.07 | 1.86 |
| 6 | 1 | 70 | 5 | 165 | 7 | 12.83 | 2 |

Table 2 shows the prediction results for various weights on the objective function for control of the final moisture content to 7% d.b. of all models. The shrinkage and drying energy have different values. For the models 3 and 5, the variables of temperature, banana slice thickness and drying time have the same values. The accuracy of the prediction results is compared to the experimental results in the final column (average error) in Table 3. The minimum value of the average error is 0.52% for the first model. Under the objective function of KG prediction, the relationship between the Gaussian function and the second-order polynomial function is given by the weights *W1, W2* and *W3* being equal to 0.80, 0.15 and 0.05, respectively. The prediction results for the final moisture content of 7% d.b. are shrinkage of 12.79% and drying energy of 1.88 kWh. The experimental results for the final moisture content of 7.3% d.b. are shrinkage of 11.84% and drying energy of 1.91 kWh. The optimal values for the drying of banana slices are temperature of 70°C, banana slice thickness of 4 mm, and drying time of 155 min.

**Table 3** Experimental resultsand error of prediction

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Model** | **Experimental** | | | **Error (%)** | | | **Average**  **Error (%)** |
| ***Mf***  **(% d.b.)** | ***Shrinkage***  **(%)** | ***Energy***  **(kWh)** | ***Mf***  **(% d.b.)** | **Shrinkage**  **(%)** | **Energy**  **(kWh)** |
| 1 | 7.30 | 11.84 | 1.91 | -4.29 | 7.43 | -1.6 | 0.52 |
| 2 | 6.50 | 12.77 | 1.98 | 7.14 | 2.07 | -3.13 | 2.03 |
| 3 | 7.65 | 13.74 | 1.85 | -9.29 | 1.36 | 1.07 | -2.28 |
| 4 | 6.52 | 10.02 | 2.10 | 6.86 | 16.98 | -1.45 | 7.46 |
| 5 | 7.65 | 13.74 | 1.85 | -9.29 | 2.35 | 0.54 | -2.13 |
| 6 | 6.50 | 11.20 | 2.04 | 7.14 | 12.7 | -2 | 5.95 |

**4.** **Conclusion**

This work of the drying of banana slices using a hot air technique presented the prediction of a KG surrogate model based on a GA optimization search. OLHS using SOBSA was applied in the design of experiment. The KG surrogate model has a relationship between the Gaussian function and the second-order polynomial function based on a GA optimization search with the function weights *W1, W2* and *W3* being equal to 0.80, 0.15 and 0.05, respectively. Numerical results revealed a minimum error average of 0.52% of the prediction function in comparison to experimental results.

Thus, the KG surrogate model was the best model. This approach was efficient to predict the relationship between the independent variables (temperature, banana slice thickness and drying time) and the dependent variables (final moisture content, shrinkage and energy). However, to ensure the good quality of dried banana slices, the color and hardness should be verified in further studies.

**Acknowledgements**

The authors are grateful for the support from the Faculty of Engineering, Burapha University, Thailand.

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