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Research Article

The Multi-objective Optimization by the Utopian Point Method to Determine the Technological Mode of Infrared Radiation Drying Process of Jackfruit Product in Viet Nam

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Abstract: The aim of this study was to determine the technological mode of the infrared radiation drying of jackfruit product. The infrared radiation drying process of jackfruit product was carried out by the experimental plans. Results obtained were to build the multi-objective optimization problem of the infrared radiation drying process of jackfruit product. By the Utopian Point Method (UPM), solving the multi-objective optimization problem was found out the technological mode of the infrared radiation drying process of jackfruit product as follow: the optimal temperature of infrared radiation drying chamber was 63.43°C, the time of the infrared radiation drying of jackfruit product was 7.13h and the infrared radiation intensity in drying process was 6.40kW/m^2. Corresponding to these optimal factors, the energy consumption for 1 kg final product reached the minimum value of 1.38kWh/kg, the residual water content in jackfruit product reached the minimum value of 5.13%, the loss of carbohydrate reached the minimum value of 7.72%.

Keywords: Food infrared radiation drying, jackfruit infrared radiation drying, optimization the infrared radiation drying, optimization the infrared radiation drying process of jackfruit, multi-objective optimization problem for infrared radiation drying process of jackfruit product, the upm, the utopian point method, the infrared radiation drying, the infrared radiation drying process of jackfruit

INTRODUCTION

Jackfruit is the fruit plants that are grown popular in Southeast Asia (such as Malaysia, Indonesia, Laos, Cambodia, Thailand and Vietnam), Sri Lanka, Madagascar and Brazil. In general, they are grown popular in Vietnam and tropical countries, (Hossain and Haq, 2006). In Vietnam, it is planted from north to south, from the coastal plain to the mountains. In southern, jackfruit is planted in Dong Nai, Binh Duong, Vinh Long, Dong Thap... with Cempedak, jackfruit technology, jackfruit coconut, jackfruit Status, jackfruit honey.


Fig. 1: The jackfruit product in Viet Nam

Jackfruit is a natural product that contains a lot of important nutritional substances for human's health such as protein, lipid, carbohydrate, mineral salts. In addition, it contains many bioactive compounds that have extremely good effect on human's health such as polysaccharides, vitamins and enzymes (Ong *et al.*, 2008; Swami *et al.*, 2012), the jackfruit product in Viet Nam can see in Fig. 1. The ratio of polysaccharides or carbohydrate components of dry weight in jackfruit is very high. According to analytical results of Lab room at *HCMC* University of Technology and Education, the basic chemical composition of jackfruit product in Viet Nam is presented in Table 1 to 3.

From Table 1 to 3, they are obvious that jackfruit product is rich in nutritional, with carbohydrate in jackfruit product have high ratio, about 25.2%. It is an advantageous environment in order that microorganism

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Table 1: The basic chemical composition of jackfruit product in Viet Nam

Substance	Unit	Its weight contents 100g of initial material
Water	g	72.34
Protein	g	1.56
Carbohydrate	g	25.2
(Minerals Ash)	g	0.9

Table 2: The vitamins composition of jackfruit product in Viet Nam

Substance	Unit	Its weight contents 100g of initial material
Vitamin A	µg%	110.0-126.0
Vitamin B1	mg%	0.03-0.09
Vitamin B2	mg%	0.05-0.42
Vitamin B6	mg%	22.0 -24.2
Vitamin B12	mg%	0.865-0.920
Vitamin E	mg%	0.32-0.34
Vitamin C	mg%	07.0 -10.0
Folate, total	mg%	12.0-14.0
Folate, food	mg%	13.0-14.5
Folate, DFE	mg%	13.7 -14.6
β-carotene	µg%	175.0-540.0
β-cryto-xanthin (µg)	µg%	4.50-5.00

Table 3: The minerals composition of carrot product in Viet Nam

Substance	Unit	Its weight contents 100g of initial material
Phosphore	mg%	38.0 -41
Magnesium	mg%	25.0-27.0
Kalium	mg%	191.0-407.0
Natrium	mg%	2.0 -41.0
Iron	mg%	7.0 -10.0
Calcium	mg%	12.0-14.0

grows up and develops. If jackfruit product is not preserved, it will be easily decomposed or hydrolyzed and oxidized; it will be no longer value of use (Baliga *et al*., 2011a, 2011b). Currently, there are two methods that often use to preserve jackfruit product, those are the freezing method and the drying method. For the freezing method, jackfruit product after freezing process must be preserved in environment that has suitable temperature from -20 to -18°C and the range of this temperature must be maintained during use time and export time. As a result, it makes to increase the expenditure of preservation process of jackfruit product. For the drying method are used the most popular. The jackfruit product after the drying placed in nylon bags and seaming, it is preserved in usual environment of 25°C. For this reason, it will be not lost the expenditure for preservation process (Dzung and Ba, 2007; Haugvalstad *et al*., 2005). Now, there are many different drying methods. Although they can use to preserve jackfruit product, but in the study used the infrared radiation drying method to preserve jackfruit product because this method can reduce temperature of infrared radiation drying chamber, time of drying process and the energy consumption as well as reduce the loss of quality product, (Holman, 1986; Gebhart, 1993).

However, according to Baliga *et al*. (2011b), carbohydrate of jackfruit product will be easily lost in the drying process as well as in the preservation process. Therefore, the problem posed here is how to determine the technological mode for the infrared radiation drying process of jackfruit product in order that jackfruit product after drying have the best quality, the residual water content of final jackfruit product is under 6.0% (Obidul Huq *et al*., 2013), the energy consumption of 1 kg final product reaches the minimum value. This is a question that had not any research to mention for a long time ago. To answer this problem, in this study the multi-objective optimization problem describing about the relationship between objective functions, including:

y_1 (kWh/kg) : The energy consumption of 1 kg final jackfruit product of after infrared radiation drying.

y_2 (%) : The residual water content of final product after drying.

y_3 (%) : The loss of carbohydrate of final jackfruit product; with technological factors, including:

Z_1 (°C) : The temperature of infrared radiation drying chamber.

Z_2 (h) : The time of the infrared radiation drying process.

Z_3 (kW/m^2) : The infrared radiation intensity in drying process is built by experimental method (Fig. 2). The multi-objective optimization problem is expressed as follow: Finding $Z^{opt} = \{Z_1^{opt}, Z_2^{opt}, Z_3^{opt}\} \in \Omega_Z$ in order that $y_{jmin} = f(Z_1^{opt}, Z_2^{opt}, Z_3^{opt}) = \min\{f_j(Z_1, Z_2, Z_3)\}$. After that by the UPM (Dzung, 2011, 2012a, 2012b, 2014; Dzung *et al*., 2011a, 2011b, 2015; Dzung and Dzung, 2011; Dzung and Du, 2012; Luc *et al*., 2013), solving this multi-objective optimization problem is determined the technological mode for the freezing process of jackfruit product.

MATERIALS AND METHODS

Materials: The jackfruit materials are harvested in Viet Nam. It is processed to create jackfruit product as in Fig. 1. The basic composition of jackfruit product is presented in Table 1 to 3. After processing, the jackfruit product is used to carry out experiment to set up technological mode of the infrared radiation drying process by experimental plan method (Dzung, 2014).

Apparatus: Equipments used to research the technological mode for the infrared radiation drying process of jackfruit product are listed (Dzung, 2012a, 2012b, 2014; Dzung *et al*., 2012c, 2015; Dzung and Du, 2012; Luc *et al*., 2013):

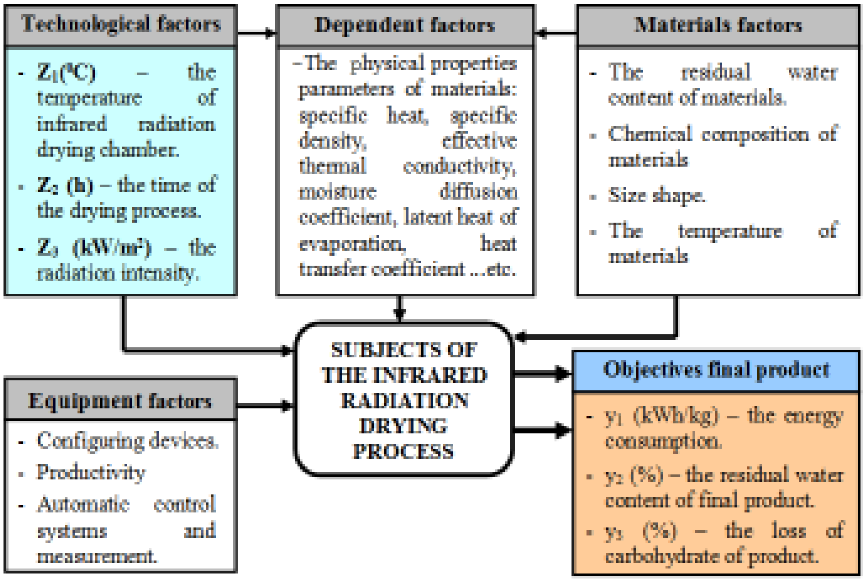

Fig. 2: Diagram of subjects of the infrared radiation drying process (Dzung and Ba, 2007)

Fig. 3: The infrared radiation drying system

- Equipments used to determine weigh of jackfruit product by Satoriusbasic Type BA310S: range scale (0 ÷ 350) g, error: ±0.1g = ±0.0001 kg.
- The infrared radiation drying system (Fig. 3) that was controlled automatically by computer. The temperature, the infrared radiation intensity in drying process and the time profile of infrared radiation drying process are measured by computer.
- HPLC is used to determine carbohydrate component of jackfruit product before and after drying, some equipment is used to determine the

residual water content of jackfruit product, to determine the energy consumption of 1 kg final jackfruit product.

Methods: Using in this study to include some method as follow (Dzung, 2012a, 2012b, 2014; Dzung *et al.*, 2012c; Dzung and Du, 2012; Luc *et al.*, 2013):

- Determining the temperature of infrared radiation drying chamber (Z_1, °C); the time of infrared radiation drying process (Z_2, h) and the infrared radiation intensity in drying process (Z_3, kW/m^2) by the automatic measure and control system on computer.
- Determining the energy consumption (y_1, *kWh/kg*) for 1 kg jackfruit product after drying process by the Eq. (1) (Figura and Teixeira, 2007; Heldman and Lund, 1992):

$$y_1 = \frac{P.\tau}{G} = \frac{U.I.\tau.\cos\varphi}{G} \tag{1}$$

where:

P (*kW*) : Number of Wattmeter
G (*kg*) : Weight of the final product
U (*V*) : Number of Voltmeter
I (*A*) : Number of Amperemeter
τ (*s*) : Second
cosφ : Power factor

- Determining the residual water content of the final jackfruit product after drying (y_2, %) by the mass sensor controlled by computer (Dzung, 2012a, 2012b, 2014):

$$y_2 = 100 - \frac{G_i}{G_e}\left(100 - W_i\right) \tag{2}$$

where:

G_i (kg) : Weight of the initial material of jackfruit product used for infrared radiation drying.
G_e (kg) : Weight of the final jackfruit product after infrared radiation drying.
W_i (%) : The residual water content of the initial material of jackfruit product.

- Determining the loss of total β-carotene in carrot of the final product (y_4, %) by HPLC method in TCVN 4715-90 (Figura and Teixeira, 2007; Dzung, 2011, 2012a, 2012b; Dzung and Dzung, 2011; Dzung *et al.*, 2011a, 2011b, 2012, 2015; Dzung and Du, 2012).
- Determining carbohydrate inside jackfruit product before and after infrared radiation drying by the HPLC/UV (High performance liquid chromatography/UV-vis) method (TK. AOAC 985.33), (Figura and Teixeira, 2007).
- Determining the loss of carbohydrate of the final product (y_3, %) by Eq. (3):

$$y_3 = \frac{m_1 - m_2}{m_1}100\% = \frac{\Delta m}{m_1}100\% \tag{3}$$

Where: the carbohydrate of the material initial and after infrared radiation drying respectively m_1 (%) and m_2 (%) were calculated according to weight of dry matter:

- Orthogonal experimental planning method with degree 2 (Dzung, 2011, 2012a, 2012b, 2014; Dzung and Dzung, 2011; Dzung and Du, 2012; Dzung *et al.*, 2011a, 2011b, 2012, 2015; Luc *et al.*, 2013).
- Using quadratic orthogonal experimental planning method (Dzung, 2011, 2014; Dzung and Dzung, 2011; Dzung *et al.*, 2015; Luc *et al.*, 2013) to build the mathematical model about relationships between y_j ($j = 1\div 3$) and technological factors effect on the infrared radiation drying process (Z_1, Z_2, Z_3). These mathematical models of y_j ($j = 1\div 3$) were written as follow (Dzung, 2011, 2014; Dzung and Dzung, 2011):

$$y_j = b_0 + \sum_{u=1}^{k} b_u x_u + \sum_{u\neq i;u,i=1}^{k} b_{ui} x_u x_i + \sum_{u=1}^{k} b_{uu}\left(x_u^2 - \lambda\right) \tag{4}$$

These variables x_1, x_2 and x_3 were coded by variables of Z_1, Z_2 and Z_3 presented as follow:

$$x_i = (Z_i - Z_i^0)/\Delta Z_i;\ Z_i = x_i.\Delta Z_i + Z_i^0 \tag{5}$$

where,

$$Z_i^0 = (Z_i^{max} + Z_i^{min})/2$$

$$\Delta Z_i = (Z_i^{max} - Z_i^{min})/2 \tag{6}$$

$$Z_i^{min} \leq Z_i \leq Z_i^{max};\ i = 1 \text{ to } 3$$

The experimental number is determined, (Dzung *et al.*, 2011a, 2011b, 2015; Luc *et al.*, 2013; Dzung, 2014):

$$N = n_k + n_* + n_0 = 2^k + 2k + n_0 = 18 \tag{7}$$

With,

$k = 3$; $n_k = 2^k = 2^3 = 8$; $n_* = 2k = 2x3 = 6$; $n_0 = 4$

The value of the star point:

$$\alpha = \sqrt{\sqrt{N.2^{(k-2)}} - 2^{(k-1)}} = \sqrt{\sqrt{18.2^{(3-2)}} - 2^{(3-1)}} = 1.414 \quad (8)$$

The condition of the orthogonal matrix:

$$\lambda = \frac{1}{N}\left(2^{k} + 2\alpha^{2}\right) = \frac{1}{18}\left(2^{3} + 2\left(\sqrt{2}\right)^{2}\right) = 2/3 \quad (9)$$

- Establishing and solving 3-objective optimization problem by the UPM (Dzung, 2011, 2012a, 2012b, 2014; Dzung and Dzung, 2011; Dzung *et al.*, 2011a, 2011b, 2012; Dzung and Du, 2012; Luc *et al.*, 2013)
- Using the mathematical tools to solve the multi-objective optimization problem to determine the technological mode for the infrared radiation drying process of jackfruit product.

RESULTS AND DISCUSSION

Develop the mathematical models of the infrared radiation drying process of jackfruit product: The constituent objective functions of the infrared drying process including:

y_1 (kWh/kg) : The energy consumption of 1 kg final jackfruit product after drying.

y_2 (%) : The residual water content of jackfruit product after drying.

y_3 (%) : The loss of carbohydrate of jackfruit product after drying depended on the technological factors, including: temperature of drying chamber (Z_1, °C), time of drying process (Z_2, h), the infrared radiation intensity in drying process (Z_3, kW/m^2). Therefore, these constituent objective functions were determined by the experimental planning method with the quadratic orthogonal experimental matrix ($k = 3$, $n_0 = 4$). In addition, the experimental factors were established by conditions of the technological infrared radiation drying (Dzung and Ba, 2007; Dzung, 2011, 2012a, 2012b, 2014; Dzung and Dzung, 2011; Dzung *et al.*, 2011a, 2011b, 2012, 2015; Dzung and Du, 2012; Luc *et al.*, 2013), they were summarized in Table 4.

The experiments were carried out with all of the factor levels in Table 4 to determine the value of the objective functions that describe relationships between the energy consumption of 1 kg final jackfruit product of infrared radiation drying; the residual water content of final jackfruit product after drying; the loss of carbohydrate of the final jackfruit product after drying and technological factors, (Dzung, 2012a, 2012b, 2014; Dzung *et al.*, 2012, 2015; Dzung and Du, 2012; Luc *et al.*, 2013). The results were summarized in Table 5.

The mathematical model of regression equations (y_j, j = 1 to 3) from Eq. (10) to Eq. (13) were obtained

Table 4: The technological factors levels design

	Levels					
Parameters	- α (-1.414)	Low -1	Central 0	High +1	+ α (1.414)	Deviation ΔZ_i
Z_1,(°C)	52.93	55	60	65	67.07	5
Z_2, (h)	5.59	6	7	8	8.41	1
Z_3, (kW/m^2)	3.59	4	5	6	6.41	1

Table 5: The orthogonal experimental matrix level 2 ($k = 3$, $n_0 = 4$)

		Value of real variables			Value of coded variables				Value of objective functions		
N		Z_1	Z_2	Z_3	x_0	x_1	x_2	x_3	y_1	y_2	y_3
2^k	1	65	8	6	1	1	1	1	1.58	4.61	8.820
	2	55	8	6	1	-1	1	1	1.23	5.01	10.74
	3	65	6	6	1	1	-1	1	1.19	8.59	7.78
	4	55	6	6	1	-1	-1	1	1.00	9.18	10.48
	5	65	8	4	1	1	1	-1	1.22	7.58	12.34
	6	55	8	4	1	-1	1	-1	1.10	7.24	13.34
	7	65	6	4	1	1	-1	-1	1.06	7.86	12.57
	8	55	6	4	1	-1	-1	-1	0.83	9.87	13.54
2k	9	67.07	0	0	1	1.414	0	0	1.35	6.17	9.230
	10	52.93	0	0	1	-1.414	0	0	1.14	7.18	11.48
	11	0	8.41	0	1	0	1.414	0	1.54	7.93	11.40
	12	0	5.59	0	1	0	-1.414	0	1.11	8.74	9.050
	13	0	0	6.41	1	0	0	1.414	1.36	6.05	7.700
	14	0	0	3.59	1	0	0	-1.414	1.21	6.49	14.18
n_0	15	0	0	0	1	0	0	0	1.29	4.88	10.02
	16	0	0	0	1	0	0	0	1.26	5.39	9.540
	17	0	0	0	1	0	0	0	1.30	5.46	9.740
	18	0	0	0	1	0	0	0	1.23	4.98	9.510

Table 6: Minimum roots of each one-objective optimization problems

	Value of roots of one-objective optimization problems			
j	$x_1^{j\ opt}$	$x_2^{j\ opt}$	$x_3^{j\ opt}$	Value of functions y_{jmin}
1	-1.414	-1.414	-1.414	0.63
2	0.304	0.667	1.287	4.60
3	1.414	-0.494	1.414	7.28

after processing the experimental data, calculating the coefficients, testing the significance of the coefficients by the Student criterion and testing the regression equations for the fitness of the experimental results by Fisher criterion (Dzung, 2011, 2014; Dzung and Dzung, 2011; Dzung *et al*., 2011a, 2011b, 2015; Luc *et al*., 2013). Results received were the mathematical models as follow:

- The energy consumption of 1 kg final jackfruit product after infrared radiation drying process:

$$y_1 = f_1(x_1, x_2, x_3) = 1.249+0.1x_1+0.137x_2 +0.084x_3 - 0.06x_1^2 - 0.042x_3^2 \quad (10)$$

- The residual water content of final jackfruit product after infrared radiation drying process:

$$y_2 = f_2(x_1, x_2, x_3) = 5.677-0.341x_1-1.016x_2 -0.482x_3-0.655x_2x_3+0.561x_1^2+1.394x_2^2 +0.357x_3^2 \quad (11)$$

- The loss of carbohydrate of final jackfruit product after drying process:

$$y_3 = f_3(x_1, x_2, x_3) = 9.926-0.813x_1 +0.349x_2-1.928x_3-0.331x_1x_2+0.417x_1^2 +0.353x_2^2+0.712x_3^2 \quad (12)$$

Building and solving one-objective optimization problems for the infrared radiation drying process of jackfruit product: It was obvious that all objective functions (y_j, j = 1 to 3) for the infrared radiation drying process of jackfruit product depended on the technological parameters (x_i, i = 1 to 3). If every objective function was individually surveyed, these one-objective functions along with the technological parameters would constitute the one-objective optimization problems. Because all the one-objective functions were to find the minimal value, the one-objective optimization problems were restated as follow (Dzung, 2011, 2014; Dzung and Dzung, 2011; Dzung *et al*., 2011a, 2011b, 2015; Luc *et al*., 2013): Finding in common the test $x^{jopt} = (x_1^{jopt}, x_2^{jopt}, x_3^{jopt}) \in \Omega_x = \{-1.414 \le x_1, x_2, x_3 \le 1.414\}$ in order that:

$$\begin{cases} y_j = f_{jmin}\left(x_1^{jopt}, x_2^{jopt}, x_3^{jopt}\right) \\ \qquad = \min f_j\left(x_1, x_2, x_3\right) \\ \forall x \in \Omega_x = \{-1.414 \le x_1, x_2, x_3 \le 1.414\}; \\ y_2 \le 6;\ j = 1 \div 3 \end{cases} \quad (13)$$

According to the results of Dzung (2011), Dzung and Dzung (2011) and Dzung *et al*. (2011a, 2011b), if all the one-objective optimization problems (13) have the same roots: $(x_1^{jopt}, x_2^{jopt}, x_3^{jopt}) = (x_1^{kopt}, x_2^{kopt}, x_3^{kopt})$ with k ≠ j, these roots called are utopian roots and also roots of multi-objective optimization problem (13). The optimal plan of utopian roots called is utopian plan. If the utopian roots and the utopian plan do not exist, multi-objective optimization problem (13) will be solved to find the optimal *Pareto* roots and the optimal *Pareto* plan. Therefore, solving one-objective optimization problems (13) were found to achieve: $y_{jmin} = \min f_j(x_1, x_2, x_3)$, $j = 1 \div 3$, with the identified domain $\Omega_x = \{-1.414 \le x_1, x_2, x_3 \le 1.414\}$. By using the meshing method programmed in Matlab R2008a software, the results of the optimal parameters of every objective function from (10) to (12) limited in the experimental domain were summarized in Table 6, (Dzung, 2011, 2012a, 2012b, 2014; Dzung and Dzung, 2011; Dzung *et al*., 2011a, 2011b, 2012, 2015; Dzung and Du, 2012; Luc *et al*., 2013):

In the Table 6, it was obvious that the utopian point was indentified: $f^{UT} = (f_{1min}, f_{2min}, f_{3min}) = (0.63, 4.60, 7.28)$. However, the utopian root and the utopian plan did not exist, because of $x^{jopt} = (x_1^{jopt}, x_2^{jopt}, x_3^{jopt}) \ne x^{kopt} = (x_1^{kopt}, x_2^{kopt}, x_3^{kopt})$ with $j, k = 1 \div 3$, $j \ne k$. From results of solving one-objective optimization problems (13), it was obvious that the utopian root and utopian plan do not exist. Therefore, multi-objective optimization problems (13) need to have to be solved to find the optimal *Pareto* root and the optimal Pareto plan in order that optimal Pareto effect $y_P^S = (y_{1P}^S, y_{2P}^S, y_{3P}^S)$ closest to the utopian point f^{UT}.

Building and solving multi-objective optimization problems for infrared radiation drying process of jackfruit product: It was obvious that the multi-objective optimization problem during the infrared radiation drying of jackfruit product appeared in this case. The technological parameters (x_1, x_2 and x_3) of the infrared radiation drying process of jackfruit product have simultaneously influenced on three objective functions (y_j, $j = 1 \div 3$) with the identified domain $\Omega_x = \{-1.414 \le x_1, x_2, x_3 \le 1.414\}$. Therefore, the mathematical model of three-objective optimization problem to determine the technological mode of the infrared radiation drying process of jackfruit product was restated as follow: Finding in common the root $x = (x_1^{opt}, x_2^{opt}, x_3^{opt}) \in \Omega_x = \{-1.414 \le x_1, x_2, x_3 \le 1.414\}$ in order that (Dzung, 2011, 2014; Dzung and Dzung, 2011):

Table 7: Minimum roots of multi-objective optimization problem

Value of optimal Pareto roots of multi-objective optimization problem			Minimun value of S-objective combination function	Value of the optimal Pareto effects of multi-objective optimization problem		
x_1^S	x_2^S	x_3^S	$S_{min}(x)$	y_{1P}^S	y_{2P}^S	y_{3P}^S
0.686	0.127	1.396	1.02	1.38	5.13	7.72

$$\begin{cases} y_j = f_{j\min}\left(x_1^{opt}, x_2^{opt}, x_3^{opt}\right) \\ \qquad = \min f_j\left(x_1, x_2, x_3\right) \\ \forall x \in \Omega_x = \{-1.414 \le x_1, x_2, x_3 \le 1.414\}; \\ y_2 < 6.0;\ \ j = 1 \div 3 \end{cases} \tag{14}$$

The purpose of the experiment was to reach the targets of the freeze drying process which were expressed by 3 regression equations from (10) to (12), but the tests satisfying all function values (y_{1min}, y_{2min}, y_{3min}) could not be found. Hence, the idea of the multi-objective optimization problem (14) was to find the optimal Pareto root for $y_P^S = (y_{1P}^S, y_{2P}^S, y_{3P}^S)$ closest to the utopian point (Dzung, 2011, 2014; Dzung and Dzung, 2011; Dzung *et al.*, 2015; Luc *et al.*, 2013). By the UPM (utopian point method), solving the multi-objective optimization problem of the infrared radiation drying (14) as the followings: Establishing the S-objective combination function $S(y_1, y_2, y_3) = S(x_1, x_2, x_3) = S(x)$ as follow, (Dzung, 2014; Dzung *et al.*, 2011a, 2011b, 2015; Luc *et al.*, 2013):

$$\begin{cases} S(x) = S(x_1, x_2, x_3) \\ \quad = \sqrt{\sum_{j=1}^{3}\left(y_j - y_{j\min}\right)^2} \\ \Omega_x = \{-1.414 \le x_1,\ x_2,\ x_3 \le 1.414\}; \\ x = (x_1, x_2, x_3) \end{cases} \tag{15}$$

By choosing S(x) as the objective function (15), the m-objective optimization problem (14) is restated as: Find $x^S = (x_1^S, x_2^S, x_3^S) \in \Omega_x$ in order that S(x) reaches the minimum value (Dzung, 2011, 2012a, 2012b, 2014; Dzung and Dzung, 2011; Dzung *et al.*, 2011a, 2011b, 2012, 2015; Dzung and Du, 2012; Luc *et al.*, 2013):

$$\begin{cases} S_{min}(x) = S(x^S) = \mathrm{Min}\{S(x_1, x_2, x_3)\} \\ \quad = \mathrm{Min}\left\{\sqrt{\sum_{j=1}^{3}\left(y_j - y_{j\min}\right)^2}\right\} \\ \Omega_x = \{-1.414 \le x_1,\ x_2,\ x_3 \le 1.414\}; \\ x = (x_1, x_2, x_3) \end{cases} \tag{16}$$

The three-objective optimization problem needed to indentify $x^S = (x_1^S, x_2^S, x_3^S) \in \Omega_x$ in order that $S(x_1^S, x_2^S, x_3^S) = \mathrm{Min}\{S(x_1, x_2, x_3)\}$. The minimum value of (16) was determined by the meshing method programmed in Matlab R2008a software (Dzung, 2011, 2012a, 2012b; Dzung and Dzung, 2011; Dzung *et al.*, 2011a, 2011b, 2012; Dzung and Du, 2012; Luc *et al.*, 2013; Tri, 2008):

From Table 7, variables of (x_1^S, x_2^S, x_3^S) are transformed into real variables of (Z_1^{opt}, Z_2^{opt}, Z_2^{opt}) as follows:

$Z_1^{opt} = 63.43°C$
$Z_2^{opt} = 7.13h$
$Z_3^{opt} = 6.40kW/m^2$

For this reason, through the calculation from the experimental models from Eq. (10) to (12), technological parameters of the infrared radiation drying process of jackfruit product which satisfied the minimum S-optimal combination criterion were determined as: temperature of drying chamber was $Z_1^{opt} = 63.43^0C$, time of drying process was $Z_2^{opt} = 7.13h$, the infrared radiation intensity in drying process was was $Z_3^{opt} = 6.40h$. Corresponding to: the energy consumption of 1 kg final product was $y_{1P}^S = 1.38$ kWh/kg; the residual water content of the final product was $y_{2P}^S = 5.13\%$ (< 6.0%); the loss of carbohydrate of the final product was $y_{3P}^S = 7.72\%$. Compared with the experimental results from the Table 5, these results above were suitable and satisfying with the objectives of the problem.

Experiment to test the optimal Pareto root of multi-objective optimization problem: Carrying out the infrared radiation drying process of jackfruit product at the optimal Pareto root: temperature of drying chamber of $Z_1^{opt} = 63.43°C$, time of drying process of $Z_2^{opt} = 7.13h$ and the infrared radiation intensity in drying process of $Z_3^{opt} = 6.40kW/m^2$, the experimental results were determined as: energy consumption of 1 kg final product was $y_1 = 1.43kWh/kg$; the residual water content of the final product was $y_2 = 5.12\%$ (<6.0%); the loss of carbohydrate of the final product was $y_3 = 7.74\%$.

Consequently, it was very noticeable that the results from the optimization problems of the freeze drying process had the approximation to the experimental results. When the time of drying process was fixed : $x_2 = 0.127$, respectively $Z_2 = 7.13h$, the relationship between y_1, y_2, y_3, with 2 variables x_1, x_3 was performed geometrically in 3D and 2D (Fig. 4 to 9).

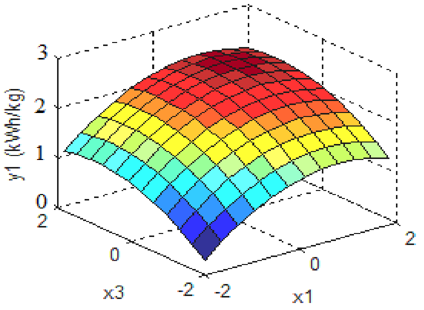

Fig. 4: Relationship between y_1 and x_1, x_3 in 3D

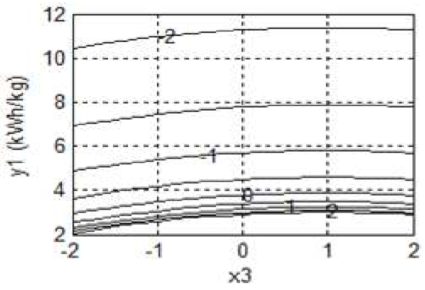

Fig. 5: Relationship between y_1 and x_3 in 2D

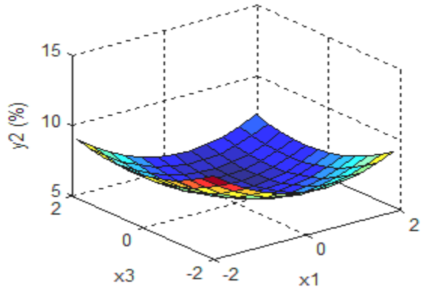

Fig. 6: Relationship between y_2 and x_1, x_3 in 3D

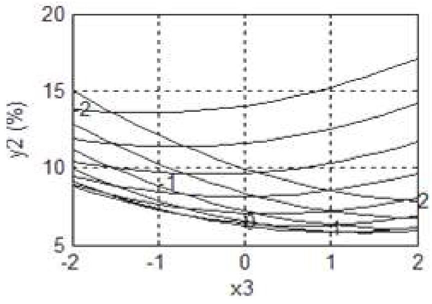

Fig. 7: Relationship between y_2 and x_3 in 2D

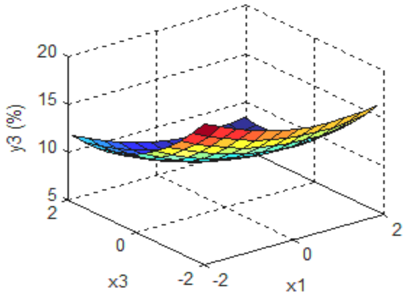

Fig. 8: Relationship between y_3 and x_1, x_3 in 3D

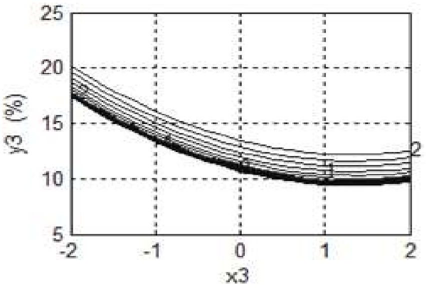

Fig. 9: Relationship between y_3 and x_3 in 2D

Fig. 10: Jackfruit products in the form of plates was dried by infrared radiation

Fig. 11: Jackfruit products in the form of fibers were dried by infrared radiation

All Figures on above was obvious that objective functions were were completely suitable with experimental results. Therefore, it proved that relationships between objective functions with effect factors very well described for the infrared radiation drying process of jackfruit product.

Table 8: The technological mode of the infrared radiation drying process of jackfruit product

No	Technological Parameters	Symbol and unit	Value
1	The temperature of the drying environment	$Z_1 = T_{\infty}$, (°C)	63.43
2	The time of drying process	$Z_2 = \tau$, (h)	7.13
3	The radiation intensity	$Z_3 = E$, (kW/m^2)	6.40
The standards of final jackfruit product after drying			
4	The energy consumption of 1 kg final product	y_{1P}^S, (kWh/kg)	1.38
5	The residual water content of final product	y_{2P}^S, (%)	5.13
6	The loss of carbohydrate of final product	y_{3P}^S, (%)	7.72

Determining technological mode of cold drying process of carrot product: From results on above, it allowed to set up the technological mode during the cold drying process of carrot product in Table 8 as follow:

From Table 8, it was obvious when jackfruit product was carried out at the optimal technological mode of infrared radiation drying process. The quality of jackfruit product after drying had very good quality (Fig. 10 and 11). The technological mode of infrared radiation drying process of jackfruit product was found out on the above, it can be completely applied for jackfruit product preservation in order to be prolonged use time and export time.

CONCLUSION

The mathematical models (10) to (12) which were established from the experiments quite well described the relationship between the temperature of drying chamber; the time of drying process; the infrared radiation intensity in drying process of jackfruit product with the energy consumption of 1 kg final jackfruit product; the residual water content of final jackfruit product; the loss of carbohydrate of final jackfruit product.

The system of Eq. (14) was the multi-objective optimization problems of the infrared radiation drying process of jackfruit product. This mathematical model was suitably used for calculating and setting up the technological mode of the infrared radiation drying process of jackfruit product. Solving the multi-objective optimization problems (14) determined the technological mode of the infrared radiation drying process of jackfruit product (Dzung, 2011, 2014; Dzung and Dzung, 2011). The results were presented in Table 8.

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