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RESEARCH ON THE FACTORS THAT AFFECT THE QUALITY IMPROVEMENT IN THE MICROWAVE-VACUUM DRYING PROCESS OF DURIAN (*DURIO ZIBETHINUS)*

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Abstract: Durian *(Durio Zibethinus)* is a value fruit which contents high amount of nutrition, special flavor and is very good for heath. In this study, the microwave-vacuum drying process was used to determine the factors influencing the durian's quality in manufacturing. The multi-objective optimization method determined the technology mode of drying durian. Under these conditions which were the size of durian of 16 mm, the pressure of 25.47kPa, the drying time of 16.45 minutes, the final product achieved to the best quality which contented the highest level of vitamin C of 94.5%, the moisture of 4.7%, and the organoleptic valueof 18.25. The final result istotally compatible with the experiments and meet the requirements to apply into industrial manufacture of microwave-vacuum drying durians. Durian after drying has yellow color, crispiness, aroma, sweetness and special flavor.

Keywords: Durian, optimization,microwave-vacuum, drying process

Introduction: Durian is a value fruit which contents high amount of nutrition and special flavor. The nutrition compositions in durian include lipid, protein, mineral, vitamin and high bioactive compounds. Hence, durian is very good for skin and heath protection, similar to the nature product from fruit and vegetables (Chun et al., 2005; Khan et al., 2007). Durian includes bioactive compounds relating to the antioxidants such as polyphenols, phenolic, flavonoids, anthocyanins that are very good for cardiovascular disease and are anti-atherosclerotic for seniors (Dauchet et al., 2006). There are 63 compounds to create the aroma, mainly are the esters. Moreover, durian has the high amount of vitamin C, which is higher than other fruits. These compounds have effect to prevent cancer, are anti-inflammatory and antibacterial well (Muhammad *et al.*, 2010).

Because of the seasonal characteristic of durian, the current preserve condition of durian is at -20^0C. On the other hand, in order to use or export easily, durian is processed into pieces of dried durian. Drying is one of separating moisture methods to create the snack product which is used conveniently and easily. The high quality product must ensure the standard of

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quality which depends on the user demand and preservationsuch as size, crispness, color, aroma, taste and the final moisture. Compared with the other drying methods, vacuum drying is a method that can fully meet the above quality requirements and shorten the drying time efficiently. Vacuum drying method has beenapplied to the slow drying or hard drying materials, which require high drying quality.

Microwave vacuum dryingis method drying materials at low temperature, and it uses the radiation to transfer heat in electromagnetic environment at the frequency of 2450 MHZ, significantly shortens the drying cycle (Piamkhla et al., 2004). The main driving force during the vacuum drying process is the pressure difference, which is generated by vacuum pumping, together with othersupporting devices such as condensers, moisture separatorand the measuring instruments. Theyallowed the options to achieve a deep vacuum, drying times and high quality product. On the other hand, at low vacuum condition, the steam temperature of water is very low that enhancing the process of separating moisture in dried materials, thus microwave-vacuum drying method canproceed at the temperatures lower than the ambient temperature. It helps to keep the structure, taste, nutrition, color and shape as fresh fruit. Hence, the microwave-vacuum drying method has the superior quality, compared with other drying methods (Piamkhla et al.,2004; Nurul et al., 2007). Moreover, it shortens the drying time andcreates a significant improvement in the quality of the product, compared with other hot drying methods (Swittra et al., 2011). A major advantage of vacuum microwave drying is the short drying time, energy saving, producing better quality products and not injuring the perishable nutrients such as vitamins, amino acids, active enzymatic and pigments (Fan et al., 2005).

We need to rapidly coolingthe materials to low temperature before drying. This method can be used in order to modify the structure of food. Thus, it will affect the drying kinetics which changes the structure and crispness of theproducts (Fan et al., 2005; Szeto et al., 2002). The optimizationalso can be added to select the best technology mode (Mohamadet al., 2011; Luc et al., 2013). Hence, the microwave vacuum drying method always keep the nutrient loss at the lowest to make the structure better and long lasting, less affected by external conditions.

Based on the above requirements, to ensure the quality of durian, the study conducted the microwave vacuum drying method, combined with experimental methods and analytical biochemistry, whichhas the support of mathematical tools and optimization algorithms in order to detectthe new properties. Italso determined the relationship between the quantitative and was proven by reality in order to determine the nutritional compositions and biochemical alterations of durian. It alsoestablished the factors that affect the product quality during microwave vacuum drying process, improved quality, ensured the color and significant flavor of durian.

Materials and Research Method

Materials: Durian used in the study is the durian Ri6. The characteristics are large, average weight about 2.0-2.5kg per one, high pulp ratio (25-30%), tallowy flavor, sweet and high aromatic.The medium-well durians were chosen from Thu Duc fruit granary and brought to the laboratory of the Food Technologydepartment of HCMC University of Technology and Education. They are separated pulps, peels and seeds and were frozen at -20^{0}C for preservation and research.

Research method: Research on the nutritional ingredients of durian: the protein, lipid, glucid, minerals, amino acids, moisture were evaluated by the AOAC. (2000), the amino acids were determined by the high performance liquid chromatography method (HPLC).

The research was performed on the microwave vacuum drying machine - Magic A71 Korea, capacity of 1300W. This equipment works at frequency of 2450MHz with three level of microwave pressure of 20 kPa, 25 kPa and

30kPa (corresponding to the boiling temperature at 60^0C, 65^0C and 70^0C). The vacuum pressure was monitored by a vacuum gage and a pressure regulating valve to maintain the pressure at desired levels.

The slice of durian was cut into pieces of 12mm, 15mm, 18 mm, andput into a microwave vacuum drying under three microwave pressure levels of 20 kPa, 25 kPa and 30 kPa, respectively. After every period of 14 minutes, 16 minutes and 18 minutes, we evaluated the changes in the content of moisture and vitamin C and the organoleptic. The raw material has the moisture of 58.49% and then was dried to final content of moistureof the product. The weight of each experiment batch was 50g, the other factors were considered as unchanged during the study.

The factors affecting the loss in product's quality during microwave vacuum drying are evaluated through the vitamin C indicators. The content of vitamin C is the number of mg of vitamin C in 100g product which was used to indicate the change of vitamin C during the drying process. On the other hand, the product qualitywas evaluated by organoleptic such as the structure, crispness, color, and taste. Based on these above evaluation, the scientific technology mode was selected to ensure the quality of microwave vacuum dried durian reach the maximum.

Optimization study: A quadratic regression model proposed for each response of y following optimization study (Canh., 2004)

$$y=b_0+\sum_{1\le j\le k} b_j x_j + \sum_{1\le j\le i\le k} b_{ji} x_j x_1 + \sum_{1\le j\le k} b_{jj} x_j^2 \quad (1)$$

where y was output; x_i was input; b_0 , b_j , $b_{j\,i}$, b_{ii} were the regression coefficients.

x_j: the variables of the objective function

$$j = 1\div 3 \quad (2)$$

The objective function y_1 was the content of Vitamin C. The content of moisture after drying was y_2. The organoleptic value after drying was y_3

The other factors relate to the objective function: size of durian x_1 (12, 15, 18mm); vacuum pressure x_2 (20, 25, 30kPa); drying time x_3(14, 16, 18 minutes). Other factors were constant.

As the consequences, in this study, the mathematical model was built by Box-Hunter (Canh., 2004) with k = 3, n_0 = 6 about the relations between y_1, y_2, y_3 with x_1, x_2, x_3.

Number of experiment in this method was determined as the equation follows:

$N = 2^k + 2.k + n_0 = 2^3 + 2\,x3 + 6 = 20$

In order to the experimental matrix is orthogonal, α was determined as follow:

$\alpha = 2^{k/4} = 1{,}682$

With limited domain is:

$$\Omega_x = (-1{,}682 \le x_1, x_2, x_3 \le 1{,}682) \quad (3)$$

Hence, need to solve the problem (1) to determine the relationship between the quantitative.

According to AOAC(2000), determining the content of Vitamin C was based on the oxidation of ascorbic acid with 2-6 dichloro phenol indophenol turns to dehydroascorbic acid. At this time, 2-6 dichloro phenol indophenol turns to the no color derivatives.

The environment where the reaction will achieve the high result has thepH of 3-4. At this environment, if there was an excess drop ofthe 2-6 dichloro phenol indophenol, it will turn from green to red pink. Ground 3g of sample, add a sufficient amount of HCl 1% to adjust the pH environment, then transfer the entire mixture into 100ml volumetric flask and norms with HCl 1%, then shake to dissolve ascorbic acid completely. Get into the 10 ml Erlenmeyer from the flask, add a few drops of starch 1% and delimitated by a solution of KIO_3/KI 0.001N until turn to other colors.

The content of Vitamin C in the sample was calculated by the formula:

$$X = \frac{(a-b)x0.088x100}{10m}\% \quad (4)$$

While: a: ml of KIO_3/KI to delimitate the sample solution

b: ml of KIO_3/KI to delimitate the examined solution

m: amount of sample

0.088: mg of ascorbic acid, corresponding to 1ml of KIO_3/KI 0.001N
100: volume of the volumetric flask
Determine the content of moisture by AOAC (2000) method. The loss of moisture is the differences between the beginning sample and the dried one. Start drying the ceramic mug at 110^0C until constant mass. Put 1g of sample into a mug, weight carefully the mass of mug and material sample (m1). Dried the sample at 110^0C until constant mass ad then cool down in desiccator. Weight again the mass of mug anddried sample.
The content of moisture was calculated by the formula:

$$\% \text{ moisture} = \frac{m_1 - m_2}{m_1 - m_0} \times 100 \qquad (5)$$

While: m_0 (g): mass of mug
m_1 (g): mass of mug and beginning sample
m_2 (g): mass of mug and final sample

Determine the organoleptic values (y3) by the organoleptic method(Luc et al., 2013). It was built by the surveys from the specialists about the structure, crispness, color, aroma and taste and the highest mark was 20. The total standard was determined by the following formula:

$$y_3 = \frac{1}{n}\sum_{i=1}^{n} H_i \qquad (6)$$

While:
n : number of specialists who evaluating the organoleptic values
H_i: the specialists' marks of the organoleptic values.

Data processing method

Using the mathematical tools with the support of Microsoft Excel 2010, Matlab programming V.7.01 and was proven in practice.

Results and Discussion

Determine the nutritional composition of durian: The results of analysis of the chemical composition of durian flesh and the result was received as the figure 1.

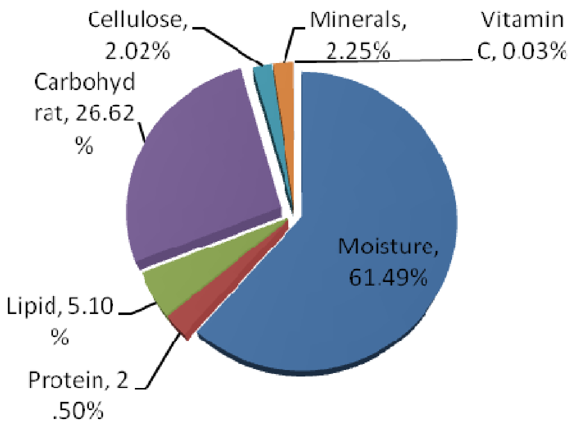

Figure 1. The nutritional composition of durian

The result in figure 1 showed that the nutritional composition of durian includes: 61.49% of moisture, 2.5% of protein, 5.1% of lipid, 26.62% of glucid, 2.02% of cellulose, 2.25% of mineral. The content of proteinin durian is 2.5%, compare to jackfruit (1.8%) and mangosteen (0.6%). The content of lipid and glucid of jackfruit is respectively 0.3% and 18.9% and is 0.5% and 14.7% in mangosteen while durian contents 5.1% of lipid and 26.62% of glucid. Moreover, the content of vitamin C in 100g durian is 33.61mg, lower than Khan et al's research of 37mg but higher than Muhammad et al's research of 18.7 -25.32mg in four types of durian (Khan et al., 2007; Muhammad et al., 2010).
Result analysis of the essential amino acid of durian fleshand the result was received as in Table 1 following

Table 1. The content of essential amino acid in durian

No	Amino acid	Content(mg/100g)
1	Isoleucine	87.8 ± 0.23
2	Leucine	123.6 ± 0.14
3	Lysine	114.2 ± 0.33
4	Methionine	65.6 ± 0.28
5	Histidine	58.2 ± 0.18
6	Cystine	66.8 ± 0.32
7	Phenylalanine	108.1 ± 0.41
8	Tyrosine	56.4 ± 0.22
9	Threonine	77.6 ± 0.26
10	Valine	102.3 ± 0.31

Results showed that the durian contents full of essential amino acids, compared with other fruits. Durian has high level of nutrition, high level of food value and has very special taste. This result is entirely consistent with research by Chun et al (2005)and Patricia etal (2008).

Building the modelling of drying process by mathematical model: Based on the approaches and systems analysis, the microwave vacuum drying process of durian always depends on the technology factors such as size of pieces of durian (x_1), drying pressure (x_2) and drying time (x_3), affecting directly to the objective function include: vitamin C, moisture and the organoleptic value after drying.

Therefore, determining the technology mode for microwave vacuum drying process for good quality durian means minimize the loss of nutrient composition to the lowest. Evaluating the amount of vitamin C after drying showed the loss of nutritional value. If the levels of vitamin C is the highest, the loss of nutrition is the lowest. Also the low moisture and the organoleptic values showed the preservation process and crispness, aroma and taste achieved the maximum. From the technological conditions and the experimental conditions, the domain of the factors affects the objective function were determined as the following table 2.

Table 2. Level of technological parameters in the experimental design

Parameters	Levels					Deviation ΔZi
	$-\alpha$	Low -1	Central 0	High +1	$+\alpha$	
x_1(mm)	9.954	12	15	18	20.046	3
x_2(kPa)	16.59	20	25	30	33.41	5
x_3(min)	12.636	14	16	18	19.364	2

The experiment was carried out with the level of technological parameters and the results of objectives at different levels were also presented in table 3.

Table 3. Matrix of Box Hunter's secondary orthogonal experimental method, 3 parameters

N		x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	x_1^2	x_2^2	x_3^2	y_1	y_2	y_3
2^k	1	1	+1	+1	+1	+1	+1	+1	+1	+1	+1	86.75	5.46	16.27
	2	1	-1	+1	+1	-1	+1	+1	+1	+1	+1	93.36	6.21	13.51
	3	1	+1	-1	+1	-1	+1	-1	+1	+1	+1	92.91	5.05	15.63
	4	1	-1	-1	+1	+1	-1	-1	+1	+1	+1	97.32	6.11	13.81
	5	1	+1	+1	-1	+1	-1	-1	+1	+1	+1	80.49	6.84	13.07
	6	1	-1	+1	-1	-1	+1	-1	+1	+1	+1	88.22	7.23	12.42
	7	1	+1	-1	-1	-1	-1	+1	+1	+1	+1	92.47	6.93	12.26
	8	1	-1	-1	-1	+	+1	+1	+1	+1	+1	89.16	7.31	12.33
2k	9	1	+1.682	0	0	0	0	0	2.829	0	0	85.73	5.62	16.62
	10	1	-1.682	0	0	0	0	0	2.829	0	0	92.33	6.50	12.18
	11	1	0	+1.682	0	0	0	0	0	2.829	0	87.23	6.47	15.18
	12	1	0	-1.682	0	0	0	0	0	2.829	0	94.42	5.55	14.34
	13	1	0	0	+1.682	0	0	0	0	0	2.829	92.39	5.02	17.09
	14	1	0	0	-1.682	0	0	0	0	0	2.829	86.39	7.56	12.37
n_0	15	1	0	0	0	0	0	0	0	0	0	92.65	4.93	17.65
	16	1	0	0	0	0	0	0	0	0	0	93.15	4.74	18.83
	17	1	0	0	0	0	0	0	0	0	0	93.11	4.82	17.17
	18	1	0	0	0	0	0	0	0	0	0	93.41	4.73	17.65
	19	1	0	0	0	0	0	0	0	0	0	91.55	4.55	17.86
	20	1	0	0	0	0	0	0	0	0	0	92.78	4.78	17.57

The result in table 3 was calculated by using Microsoft Excel 2010 to determine coefficients of the experimental model (the regression equations). Subsequently, these coefficients were checked about the significance by Student standard and about the compatible of the regression equation by Fisher standard (Canh ., 2004). The result built the experimental model as following:

The regression equation determined the content of vitamin C:

$y_1 = 94.32 + 0.62x_1 - 0.58x_2 + 0.43x_3 - 1.14x_1^2 - 1.08x_2^2 - 1.19x_3^2$ (7)

The regression equation determined the content of moisture:

$y_2 = 4.75 - 0.3x_1 - 0.71x_2 + 0.5x_1^2 + 0.48x_2^2 + 0.58x_3^2$(8)

The regression equation determined the organoleptic value of product's quality:

$y_3 = 17.79 + 0.92x_1 + 1.25x_3 - 1.35x_1^2 - 1.23x_2^2 - 1.24x_3^2$(9)

Solving the single objective optimization problem: Solving the single objective optimization problem means to find the root $x = (x_1^{jopt}, x_2^{jopt}, x_3^{jopt}) \in \Omega_x$ with $j = 1 \div 3$ in order to $I_{1min} = I_1(x_1^{1opt}, x_2^{1opt}, x_3^{1opt})$; $I_{2min} = I_2(x_1^{2opt}, x_2^{2opt}, x_3^{2opt})$; $I_{3min} = I_3(x_1^{3opt}, x_2^{3opt}, x_3^{3opt})$. By using meshing method (Luc et al., 2008 programmed in Matlab 7.01 software, the single objective optimization problem was solved. The results were presented in table 4.

Table 4. Roots of the single objective optimization problems

No	y_i	x_1^{opt}	x_2^{opt}	x_3^{opt}
1	94.53	0.272	-0.268	0.205
2	4.44	0.299	0.74	0
3	18.26	0.34	0	0.505

Results of single objective optimization problem showed that maximum level of the content of vitamin C was 94.53% at $x = (x_1^{jopt}, x_2^{jopt}, x_3^{jopt}) = (0.272; -0.268; 0.205)$. The content of moisture reached the maximum value of 4.44% at $x = (x_1^{jopt}, x_2^{jopt}, x_3^{jopt}) = (0.299; 0.74; 0)$. The organoleptic value reached the maximum value of 18.26 at $x = (x_1^{jopt}, x_2^{jopt}, x_3^{jopt}) = (0.34, 0, 0.505)$.

Building and solving the multi-objective optimization problem: Due to the parameters affected the objective functions in the same technological subject; therefore, the effects of x_1, x_2, x_3 on all objective functions were determined simultaneously. As a consequence, it could be seen that the single objective optimization problems did not exist the same roots, thus the multi-objective optimization problem (three objectives) had appeared.

The three objectives optimization problem was written as follow:

Finding the root xjopt = ($x_1$opt, $x_2$opt, $x_3$opt) Є Ωx = {$-1,682 \le x_1, x_2, x_3 \le 1,682$} to

$\{y_{jmin} = f_j(x^{opt}) = \min f_j(x_1, x_2, x_3)$ with $j = 1 \div 3\}$

$$\begin{cases} y_{1min} = f_1(x^{opt}) = \min f_1(x_1, x_2, x_3) \\ y_{2min} = f_2(x^{opt}) = \min f_2(x_1, x_2, x_3) \\ y_{3min} = f_3(x^{opt}) = \min f_3(x_1, x_2, x_3) \end{cases} \quad (10)$$

According to Canh 2004 and Luc et al 2008, to find root of three objective optimization problem (10), the utopian method should be applied. The three objective optimization problem (7), (8), (9) needed to be solved to find optimal Pareto root $I^p = (I_1, I_2, I_3)$ so that the distance between optimal Pareto efficiency IPS and utopian point $I^{UT} = (I_{1min}, I_{2min}, I_{3min})$ was the closest. This method proposed S- optimal combination criterion, it is distance between the point in optimal pareto efficiency set and the utopian point and can be written as follow:

$S(I_1, I_2, I_3) = S(y_1, y_2, y_3) = S(x_1, x_2, x_3) = S(x) =$

$$\left\{\sum_{j=1}^{3}\left(I_j - I_{jmin}\right)^2\right\}^{1/2} \quad (11)$$

Or: $S(x) = \{(I_1 - I_{1min})^2 + (I_2 \quad I_{2min})^2 \quad + (I_3 - I_{3min})^2\}^{1/2}$ (12)

$\forall x = (x_1, x_2, x_3) = \{-1,682 \le x_1, x_2, x_3 \le 1,682\} \in \Omega_x$

If S(x) was chosen as objective function, the multi- objective optimization problem (12) would be present as follow: to find optimal pareto root xS = (x_1S, x_2S, x_3S) = {$-1.682 \le x_1$,

x_2, $x_3 \le 1.682\} \in \Omega_x$ in order to:

$$\begin{cases} S_{min} = S(x_1S, x_2S, x_3S) = Min\{S(x_1, x_2, x_3)\} = Min\left\{\sum_{j=1}^{3}(I_j - I_{jmin})^2\right\}^{1/2} \\ \forall x = (x_1S, x_2S, x_3S) = \{-1.682 \le x_1, x_2, x_3 \le 1.682\} \in \Omega_x \end{cases} \quad (13)$$

The multi-objective optimization problem was solved by mesh method with the support of Matlab 7.01 software. The result had found roots as follow:

S_{min}=0.293 at x_1S=0.303, x_2S=0.094, x_3S=0.225(14)

Subtitute (14) into (7), (8) and (9) to find the optimal pareto root as follow:

I_1PS=94.37, I_2PS=4.67, I_3PS=18.15 (15)

Corresponding to change into the real root: x_1 = 15.91mm, x_2 = 25.47 kPa, x_3 = 16.45 minutes

The dried durian was optimized under these conditions: length of the durian was 16mm, the pressure was 25.47 kPa, the drying time was 16.45 minutes. The final product achieved the best quality which contented the highest level of Vitamin C of 94.37%, the moistureof 4.67% and the organoleptic value of 18.25

Comments:With optimal pareto roots x_1S = -0.303, x_2S = 0.094, x_3S = 0.225 (the real roots were: x_1 = 15.91 mm, x_2 = 25.47 kPa, x_3 = 16.45 minutes, respectively) of the multi-objective optimization problem (10) or (13), the mathematical model about the microwave vacuum drying process was built with optimal pareto efficiency IPS = (I_1PS, I_2PS, I_3PS) = (94.37, 4.67, 18.15) and reached the I^{UT} = (I_{1min}, I_{2min}, I_{3min}) = 0.293 at the nearest. It could be seen in (10) or (13) that when one objective increased, the other objectives decreased.

Therefore, the effects of parameters on objective functions in (10) or (13) should be carried out simultaneously. The results showed that optimal pareto roots did not reduce value of any objective functions. Therefore, it could be used to establish technological mode for the microwave vacuum drying process of durian.

From the results, it could be said that optimal pareto roots and optimal pareto efficiency were completely compatible with results in table 3. The final products have the best organoleptic values, the shortest drying time; the content of Vitamin C is higher than the other drying method. Durian has yellow color, crispiness, aroma, sweetness and special flavor.

Experiment confirm optimal pareto root: When the microwave vacuum drying process of durian was carried out at optimal pareto root with durian size of 16mm, drying pressure of 25.47 kPa, drying time of 16.45 minutes. The optimal content of vitamin C was 4.7 and the organoleptic value was 18.25. In comparison with optimal pareto efficiency (I_1PS = 94.37, I_2PS= 4.67, I_3PS = 18.15) the optimal pareto roots were completely compatible with the experimental data.

The response surface of the microwave vacuum drying of durian was shown as the figure 2,figure 3,figure 4 and figure 5

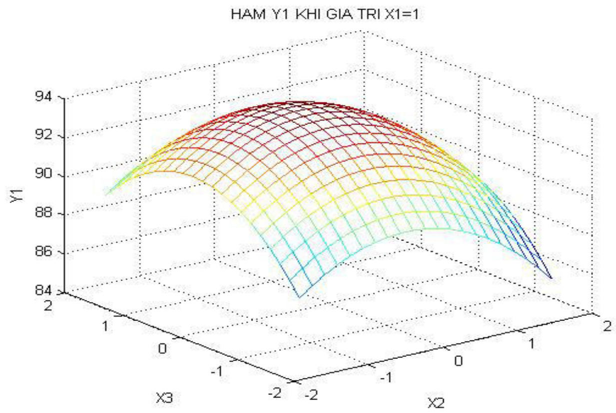

Figure 2. Response surface of function y_1

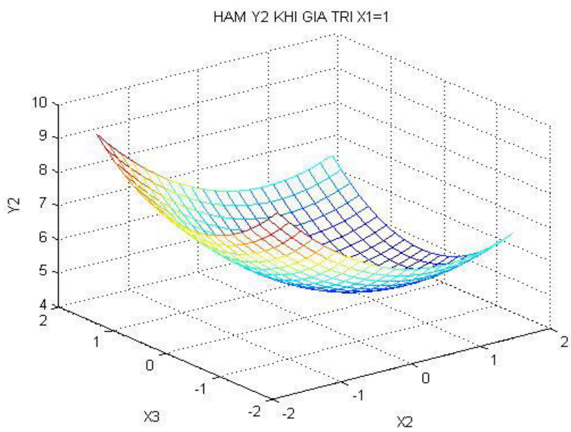

Figure 3. Response surface of function y_2

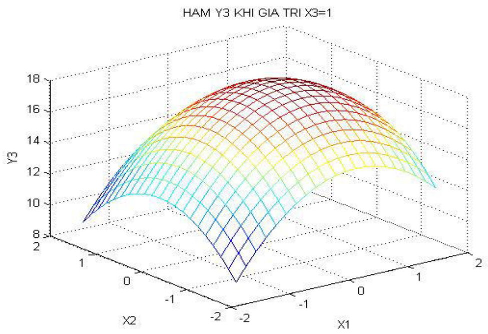

Figure 4. Response surface of function y_3

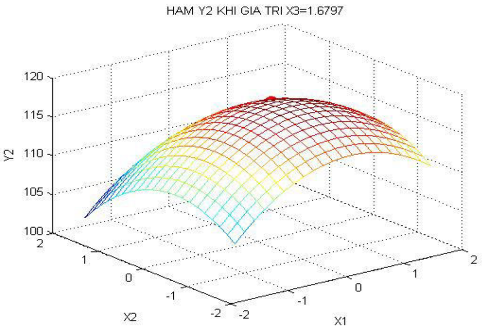

Figure 5. Response surface of aggregate function

The simulation of the mathematical models of the objective functions (7), (8), (9) and (14) in 3D were performed in figure 2. It showed that the optimal root and optimization value of the objective functions were totally compatible with the solution of the multi-objective functions problems (10) or (14).

When evaluating the experiments with the microwave vacuum drying process of durian in the optimal mode, the product can be stored in vacuum packaging in three months and the quality of products are kept in stability. The microwave vacuum dried durian has natural yellow color, sweetness, porosity, crispiness, and special favor taste.

Conclusion: The nutritional composition of Ri6 durian was determined which are moisture of 61.49%, protein of 2.5%, lipid of 5.1%, glucid of 26.62%, mineral of 2.25% and 33.6 mg of vitamin C. Durian includes many of essential amino acids with high nutritional value.

The drying process depends on many factors such as the size of durian's piece, drying pressure, temperature and time. All factors will affect the quality of durian after drying.

Multi-objective optimization built the technology mode of drying durian in microwave vacuum with the size piece of 16 mm, pressure of 25.47 kPa and drying time of 16.45 minutes. Those conditions will make the best product's quality with optimal levels of vitamin C of 94.50%, moisture of 4.7% and the organoleptic value of 18.25.

From the above results, it showed that the mathematical model hasclearly expressed the durian drying process to produce the best quality products and preservation time will be extended. The dried product has a natural yellow color, sweetness, good quality and still retains its special flavor of durian.

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