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EXPERIMENTAL STUDY ON THE MAIN PARAMETERS DETERMINATION FOR GAC FRUIT ARIL ON THE HEAT PUMP DRYER

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Abstract:-

The paper presents the results of experimental research to determine the technological parameters of Gac fruit aril drying process in the heat pump dryer. The experiments were carried out according to the 2-level orthogonal experimental plan, combined with multiple response optimization according to Response Surface method (RSM) to determine the optimal parameters (Temperature of air drying, temperature of moisture condensation, air velocity) in the Gac aril drying process. As the result, the optimal parameters were determined such as: Temperature of air drying was $t_g^{opt} = 44.16^\circ C$, temperature of moisture condensation $t_f^{opt} = 14.03^\circ C$, air ^{velocity} was $V_g^{opt} = 2.6$ m/s. Corresponding to these optimal parameters, the objective functions reached the minimum value, including the drying time $\tau^{min} = 11.27$ hours, the specific energy consumption $Ne^{min} = 4.363$ kWh/kg vapor and the loss of beta-carotene in Gac aril of the finished product $B^{min} = 4.394\%$.

Keywords: - *Heat pump, Gac fruit, Gac fruit aril drying, cold drying, multiple factor experiment, Multiple Response Optimization*

I. INTRODUCTION

Gac (*M omordi ca coc hi nchi nensi s Spreng.*) is a popular fruit in Vietnam and Southeast Asia, which has high carotenoids and lycopene content and these bioactive compounds mainly concentrate on the aril surrounding the seed [9]. These compounds act as natural sources of vitamin A, a good antioxidant for human health and resisting cancer. Studies have reported that carotenoids and lycopene content are 10 times higher with carrot, 68 times the tomato [10].Currently, global demand for Gac consumption is increasing, but the ability of post-harvest preservation is poor and product quality is not high and non-uniform due to limited method of processing. Because Gac is the seasonal harvest fruit, it is necessary to find down the good postharvest preservation method, that the products have high quality, uni formity and meeting human needs.

The important nutrient components of the Gac aril are heat-sensitive, increasing the drying temperature to over 60^0C with the oxygen in the drying agent (Air hot) and the drying time is more than 16 hours will make the substances decay quickly [4,8]. This decomposition causes the process of liposuction, which changes the color in a negative direction, reducing the nutritional and sensory value of the product. Freeze storage method can preserve the properties of the materials, but the higher energy and transport costs. The sublimation or vacuum drying method can also give the good quality of the material, but much unnecessarily costs. Gac aril almost is not affected by the temperature lower than 60^0C so heat pump drying can be more suitable, less expensive and higher efficiency [7].

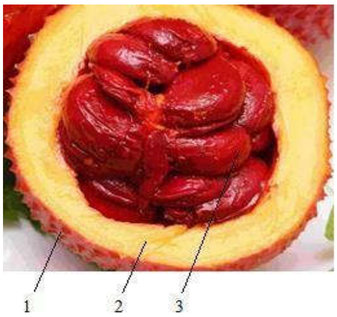


Fig 1. Gac fruit. 1: skin, 2: pul p, 3: aril

There have been reports of drying of Gac fruit aril, one of them is the report of Tuyen, C. K. on drying by spray method at temperature 120^0C for good quality but this method needs to crush the material and add Maltodextrin 10% to protect the bioactive compounds in the material [8]. This method reduces the natural feature of the product which is not proper to the requirement, not using additives in processing. Author Dzung at al (2011) [7] achieved the mathematical model of drying Gac aril by cold drying with the temperature of drying chamber 37.18^0Cwithin 16.257 hours and the velocity of drying agent of 9.38 m/s, corresponding to these optimal parameters, the objective functions reached the minimum value, including the energy consumption is 66.98 kWh/kg, the loss of betacarotene is 5.04% and the moisture content of the final product is 7.45%. Consequently, the energy consumption per one kilogram of product is too high, too much energy consumption can be attributed to the excessive velocity of drying agent.

Using high capacity fans while drying at low temperatures is good for the product, but prolonged time increases energy costs when the production scale is extended. Kubola, J. at al (2013) [6] reported the Lycopene and beta carotene concentration in aril oil of gac as influenced by arildrying process by three different methods: hot-air (HA), low relative humidity air drying (LRH) and far-infrared radiation (FIR) at 50 ^{0}C, drying agent velocity 1.5 m/s, indicating that the drying temperature for the gac aril need not be too low. Hawlader M. N. A. at al (2006) [5] studied heat pump drying with apples, guava and potatoes, indicating that the drying agent temperature (nitrogen or cabon dioxide) of 45 ^{0}C, air humidity of 10% obtained the best physical properties (porosity, color, rechargeability) similar to vacuum drying and freeze drying.

Auisakchaiyoung at al (2015) [1] dried gac aril by grinding and adding 1.5% methylcellulose foaming agent, the foam stabilizing time is 25 minutes, then put the mixture into thin trays to dry. The results showed that beta carotene and lycopene content were highest, the best color appeared at 70^0C, time 1h with 1mm foaming membrane thickness. Thus, when drying at temperatures above 60^0C to preserve the bioactive compounds and color of Gac aril, it is necessary to process materials by both mechanical and chemical methods.

The purpose of this study was to determine the suitable heat pump drying mode for Gac fruit aril without using chemical as well as reducing power consumption. Factors that need to be optimized include the drying time which is encoded Y1 with its unit is hour; the specific energy consumption which is encoded Y2 with its unit is kWh/kg vapour and the loss of beta carotene in final product it is encoded Y3 with its unit is % at the lowest value. These factors are highly dependent on the temperature of air drying it is encoded Z1 with its unit is 0C, the temperature of moisture condensation which is encoded Z2 with its unit is 0C) and the air drying velocity which is encoded Z3 with its unit m/s.

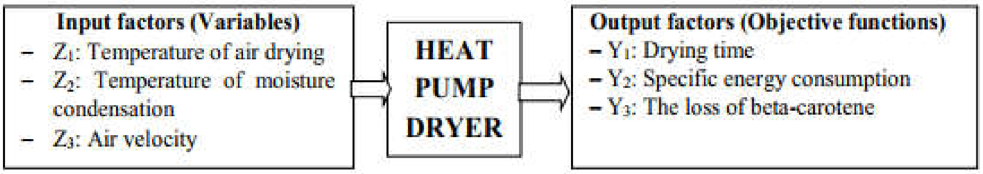


Fig 2. The black box model

II. DESIGN OF EXPERIMENTAL (DOE)

The 2nd empirical regression function of objective functions is defined by the following expression [3]:

$$Y = b_0 + \sum_{j=1}^{k} b_j X_j + \sum_{\substack{j,l=1 \\ j\neq l}}^{k} b_{jl} X_j X_l + \sum_{j=1}^{k} b_{jj} X_j \qquad (1)$$

The number of coefficients in (1) is:

$$m = k + 1 + k + C_k^2$$
$$= 2k + 1 + \frac{k!}{2!(k-2)!} = \frac{(k+1)(k+2)}{2} \qquad (2)$$

Consider the experimental element *Zj*, have:

$$Z_j^0 = \frac{Z_j^{max} + Z_j^{min}}{2}; \qquad j = 1:k \qquad (3)$$

where: Z_j^{max} is high level (Upper level)

Z_j^{min} is low level (Lower level)

Z_j^0 is basic level

Variable range of element Z_j from its center

$$\Delta Z_j = \frac{Z_j^{max} - Z_j^{min}}{2}; \qquad j = 1:k \qquad (4)$$

If elements of matrix *X* belong to [-1,1] then the matrix which are contructed have orgothonal property. However, the value of the variables we study are not in [-1, 1], we need to transform these variables from real value Z_j into new dimensionless variables (coded variables) X_j. Let

$$X_j = \frac{Z_j - Z_j^0}{\Delta Z_j}; \qquad j = 1:k \qquad (5)$$

Where $-1 \le X_j \le 1$ and $X_j^0 = 0$

The experimental number is determined as:

$$N = n_k + n_* + n_0 = 2^k + 2k + n_0 \qquad (6)$$

The value of the star point:

$$\alpha = \sqrt{\sqrt{N.2^{(k-2)}} - 2^{(k-1)}} \qquad (7)$$

For the plan to be orthogonal, the variable X2j is replaced by X'j calculated by the formula:

$$X'_j = X_j^2 - \overline{X}_j^2 = X_j^2 - \frac{\sum_{j=1}^{N} X_j^2}{N} = X_j^2 - \frac{(2^k + 2\alpha^2)}{N} \qquad (8)$$

And conditions of the orthogonal matrix:

$$\lambda = \frac{(2^k + 2\alpha^2)}{N} \qquad (9)$$

Regression coefficients are determined by the formula:

$$b_j = \frac{\sum_{i=1}^{N} X_{ji} Y_i}{\sum_{i=1}^{N} X_{ji}^2}; \quad b_{jl} = \frac{\sum_{i=1}^{N} (X_j X_l) Y_i}{\sum_{i=1}^{N} (X_j X_l)_i^2}; \quad b_{jj} = \frac{\sum_{i=1}^{N} X'_{ji} Y_i}{\sum_{i=1}^{N} (X'_{ji})^2} \qquad (10)$$

Variance of these regression coefficients:

$$s_{b_j}^2 = \frac{s_{th}^2}{\sum_{i=1}^{N} X_{ji}^2}; \quad s_{b_{jl}}^2 = \frac{s_{th}^2}{\sum_{i=1}^{N} (X_j X_l)_i^2}; \quad s_{b_{jj}}^2 = \frac{s_{th}^2}{\sum_{i=1}^{N} (X'_{ji})^2} \qquad (11)$$

After applying the change variables, we have:

$$Y = b'_0 + b_1 X_1 + \dots + b_k X_k + b_{12} X_1 X_2 + \dots + b_{k-1} X_{k-1} X_k$$
$$+ b_{11}\left(X_1^2 - \overline{X}_1^2\right) + \dots + b_{kk}\left(X_k^2 - \overline{X}_k^2\right) \qquad (12)$$

To convert (11) into (1), b_0 are determined by the formula:

$$b_0 = b'_0 - b_{11}.\overline{X}_1^2 - ... - b_{kk}.\overline{X}_k^2 \qquad (13)$$

And variance of b_0:

$$s_{b_0}^2 = s_{b'_0}^2 + \left(\overline{X}_1^2\right)^2 s_{b_{11}}^2 + ... + \left(\overline{X}_k^2\right)^2 s_{b_{kk}}^2 \qquad (14)$$

▪ **Testing the significance of the coefficients**

Using the reappearance variance [3]

To calculate the reappearance variance, n_0 experiments of center are carried out. Then, the reappearance variance is determined by the formula:

$$s_{re}^2 = \frac{\sum_{u=1}^{n_0}(Y_u^0 - \overline{Y}^0)^2}{n_0 - 1} \qquad (15)$$

The significance of the coefficients in the regression function are tested according to the Student standard:

$$t_j = \frac{|b_j|}{s_{b_j}} \qquad (16)$$

▪ **Test the significance of regression function**

For hypothesis testing “the compatibility of the regression equation with the real data”, the Fisher test is used:

$$F_{1-p}(f_1, f_2) = \frac{s_{rr}^2}{s_{re}^2} \qquad (17)$$

Với: p: significance levels

f1: the first degree of freedom, f1 = N – L

f2: the second degree of freedom, f2 = n0 – 1

L: number of coefficients which are statistically significant

The Residual Variance:

$$s_{rr}^2 = \frac{\sum_{i=1}^{N}(Y_i - Y_i)^2}{N - L} \qquad (18)$$

If $F < F_{1-p}(f_1, f_2)$ then regression function is statistically significant.

III. MATERIALS AND METHODS

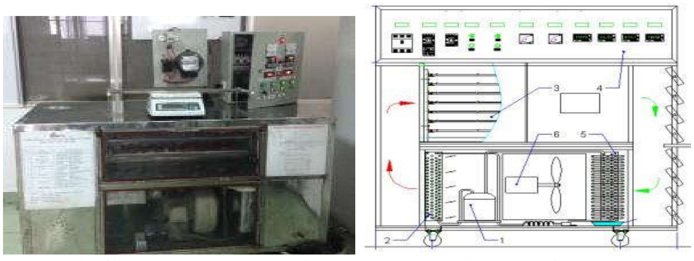
1. Materials

Gac materials used in the experiment were selected in Ho Chi Minh City, selected ripe fruits weighing 1.2-1.3kg, the moisture content of fresh Gac aril was determined by the moisture analyzer Axi AGS100 and result was 75%. The Gac aril was dried to a moisture content of 7.45% [7]

2. Apparatus

The experiments were carried out on S01DHCN heat pump dryer of Industrial University of Ho Chi Minh city (Fig 4). The velocity and temperature of air drying can be adjusted, displayed and monitored in the drying process. The temperature of the air drying can be adjusted from 30 to 50□C by the thermal expansion valve and the flow control valve through the outer condenser.

The weight of samples is determined by Ohaus type PA214 with the range of 0 to 200g and the error of 0.0001g. Temperature and humidity controller Fox-300A-1 were used to determine the temperature of moisture condensation, the temperature and humidity of air drying during the drying process with the range of -40 ÷ 65°C/ 10 ÷ 95% Rh and the error of 0.5°C. Determining velocity of air drying by Extech SDL350 hotwire anemometer datalogger with the error of 0.01m/s. The equipments of High Performance Liquid Chromatography (HPLC) were used to determine the content beta carotene in Gac fruit.



1-Compressor; 2-Condenser; 3-Drying chamber; 4-Electrical panel; 5-Evaporator; 6-Fan

Fig4. The heat pump dryerS01DHCN and itsdiagram

3. The method for evaluating the quality of dried Gac aril

Determining time of the drying process (Y_1, minutes) by timer when the final moisture content of product reach 7.45%. Determining the specific energy consumption (Y_2, kWh/kg) for 1 kg vapor by Watt meter,

$$N_e = \frac{N}{W} = \frac{U.I.\cos\varphi.\tau}{G_1 - G_2} \qquad (19)$$

Where:

G_1 – the mass of initial materials, kg

G_2 – the mass of final products, kg

Determining the loss of beta carotene in Gac aril of the finished product (Y_3, %) by HPLC method in TCVN 4715 –90 (Vietnamese standard)

$$Y_3 = \frac{m_s - m_f}{m_s}100\% \qquad (20)$$

Where, msand mf (mg) are the beta carotene in Gac before and after drying respectively. Beta carotene samples were sent to Center of Analytical Services and Experimentation of HCM City (CASE) for testing. Samples were taken from the products of the drying process, stored in vacuum-packed bags with mass in Analyst's request

IV. RESULTS AND DISCUSSION

1. Establishing the constituent objective functions of the multi-objective problem

The experimental number is determined as:N = 2k+ 2k + n0= 19with:k = 3; nk= 2k= 8; n*= 2.k = 2.3 = 6;choose the number of experiment in centern0= 5.The value of the star point:Experimental domains are established through 2ndorthogonal planning as follows[1]:

Table1Multi-objective experiment domains

factor	-α (-1.471)	lower (-1)	central (0)	upper (+1)	+α (+1.471)	Deviation ΔZ_i
Z_1 (°C)	34.64	37	42	47	49.36	5
Z_2 (°C)	12.11	14	18	22	23.88	4
Z_3 (m/s)	1.03	1.5	2.5	3.5	3.97	1.0

Replace X2jbyX'jas formula (8): In this plan, we have:

$$X'_j = X_j^2 - \frac{(2^3 + 2.1,471^2)}{19} = X_j^2 - 0,6488$$

Experimental planning under 2ndorthogonal planning shown in Table 2is completely equivalent to the result obtained using the software Statgraphics Centurion XV version 15.1.02. After carrying out 19 experiments, we obtained the results of the drying time, the specific energy consumption and the loss of beta carotene as shown in Table 2

Table 2: The 2nd orthogonal experimental matrix

N		Real variables			Coded variables				Objective value		
		Z_1	Z_2	Z_3	X_0	X_1	X_2	X_3	Y_1	Y_2	Y_3
2^k	1	47	22	3.5	+1	+1	+1	+1	680	6.56	5.156
	2	47	22	1.5	+1	+1	+1	-1	793	3.49	9.95
	3	47	14	3.5	+1	+1	-1	+1	620	6.31	4.45
	4	47	14	1.5	+1	+1	-1	-1	730	3.97	8.896
	5	37	22	3.5	+1	-1	+1	+1	755	5.1	8.15
	6	37	22	1.5	+1	-1	+1	-1	830	3.15	13.462
	7	37	14	3.5	+1	-1	-1	+1	725	5.32	6.096
	8	37	14	1.5	+1	-1	-1	-1	777	3.61	8.028
2k	9	49.36	18	2.5	+1	+1.471	0	0	660	4.82	5.025
	10	34.64	18	2.5	+1	-1.471	0	0	784	3.55	9.141
	11	42	23.88	2.5	+1	0	+1.471	0	772	3.59	8.004
	12	42	12.11	2.5	+1	0	-1.471	0	680	4.56	5.372
	13	42	18	3.97	+1	0	0	+1.471	690	7.155	3.863
	14	42	18	1.03	+1	0	0	-1.471	815	3.306	10.881
n_0	15	42	18	2.5	+1	0	0	0	740	3.98	4.977
	16	42	18	2.5	+1	0	0	0	715	3.76	4.242
	17	42	18	2.5	+1	0	0	0	731	3.81	4.289
	18	42	18	2.5	+1	0	0	0	710	3.51	4.635
	19	42	18	2.5	+1	0	0	0	721	3.62	4.79

With the results shown in Table 2, the regression coefficients are determined by the formula (10), with 192112.329j ii X==∑; 1921()8jl ii XX==∑; 1921()9.369j ii X='=∑ In this study, five experiments in the center were carried out with the following results:

Table 3. The results of five experiments in the center

n_0	X_1	X_2	X_3	Y_1	Y_2	Y_3
9	0	0	0	740	3.98	4.977
10	0	0	0	715	3.76	4.242
11	0	0	0	731	3.81	4.289
12	0	0	0	710	3.51	4.635
13	0	0	0	721	3.62	4.79

2 Establishing the mathematical model of the drying time

The reappearance variance of the experiments in the center:

$$s_{th}^2 = \frac{\sum_{u=1}^{n_0}(Y_u^0 - \overline{Y}^0)^2}{n_0 - 1} = \frac{589.2}{5-1} = 147.3 \text{ and} \qquad \text{the}$$

reappearance error $s_{th} = \sqrt{s_{th}^2} = \sqrt{147.3} = 12.136$

- **Testing the significance of the coefficients**

The values of regression coefficients b_j, t_{bj} s_{bj} are shown in Table 4. Choose the significance levels $p = 0.05$, degree of freedom $f = n_0 - 1 = 4$. Refer the table of critical values for Student's distribution [3], we have $t_{0.05}(4) = 2.78$.
Comparing t_{bj} with $t_p(f)$ if: $t_{bj} = t_p(\ )f$ then the regression coefficient is statistically significant.

Table 4. Calculation results of bj, sbj, tbj for Y1 functio

No	b_j		s_{bj}		t_{bj}	
1	**b'_0 =**	**733.053**	**$s_{b'0}$ =**	**2.784**	**$t_{b'0}$ =**	**263.276**
2	**b_1 =**	**-36.210**	**s_{b1}=**	**3.457**	**t_{b1}=**	**10.476**
3	**b_2=**	**27.687**	**s_{b2}=**	**3.457**	**t_{b2}=**	**8.010**
4	**b_3=**	**-43.305**	**s_{b3}=**	**3.457**	**t_{b3}=**	**12.528**
6	b_{12}=	5.000	s_{b12}=	4.291	t_{b12}=	1.165
7	b_{23}=	-3.250	s_{b23}=	4.291	t_{b23}=	0.757
9	**b_{13}=**	**-12.000**	**s_{b13}=**	**4.291**	**t_{b13}=**	**2.797**
10	b_{11}=	-0.242	s_{b11}=	3.965	t_{b11}=	0.061
11	b_{22}=	1.606	s_{b22}=	3.965	t_{b22}=	0.405
12	**b_{33}=**	**13.850**	**s_{b33} =**	**3.965**	**t_{b33}=**	**3.493**

Thus, the results show the significant coefficients b'_0, b_1, b_2, b_3, b_{13}, and b_{33}, so values b_0, s_{b0} and t_0 are recalculated according to Eqn (13), (14) and (16): $b_0 = 724.066$, $s_{b0} = 7.793$ and $t_0 = 92.91$.
So, the empirical regression model for Y

$$Y_1 = 724.066 - 36.210X_1 + 27.687X_2 - 43.305X_3 - 12X_1X_3 + 13.850X_3^2 \qquad (21)$$

- **Test the significance of regression function:**

The residual variance:

With $N = 19$, $L = 6$ and calculation results of $\sum_{i=1}^{N}(Y_i - \hat{Y}_i)^2$, the residual variance of the model is calculated:

$$s_{re}^2 = \frac{\sum_{i=1}^{19}(Y_i - \hat{Y}_i)^2}{N - L} = \frac{1277.07}{19-6} = 98.236$$

The Fisher value of the model:

$$F = \frac{s_{re}^2}{s_{th}^2} = \frac{98.236}{147.3} = 0.0667$$

The Fisher value of the model:
Refer the table of critical values for Fisher's distribution [3] with $p = 0.05$, $f_1 = 19\text{-}6 = 13$ and $f_2 = 5\text{-}1 = 4$, we have $F_{0.05}(13,5) = 5.89$. Since $F < F_{0.05}(f_1, f_2)$ then regression function is statistically significant.

3. Establishing the mathematical model of the energy consumption

Repeating the steps as the objective function Y_1, the coefficients of the Y_2 regression function are also determined in Table 5. The reappearance variance:

$$s_{th}^2 = \frac{0.01301}{5-1} = 0.0325 \text{ and } s_{th} = \sqrt{0.0325} = 0.1803$$

▪ **Testing the significance of the coefficients**

The values of regression coefficients b_j, t_{bj} s_{bj} are shown in table 5. Comparing t_{bj} with $t_p(f)$ if: $t_{b_j} > t_p(f) = 2.78$ [3] then the regression coefficient is statistically significant.

Table 5. Calculation results of b j, s bj, t bj f or Y 2 f unction

TT	b_j		s_{bj}		t_{bj}	
1	**b'_0 =**	**4.377**	**$s_{b'o}$ =**	**0.041**	**$t_{b'o}$ =**	**105.784**
2	**b_1 =**	**0.407**	**s_{b1}=**	**0.051**	**t_{b1}=**	**7.924**
3	**b_2=**	**-0.190**	**s_{b2}=**	**0.051**	**t_{b2}=**	**3.690**
4	**b_3=**	**1.195**	**s_{b3}=**	**0.051**	**t_{b3}=**	**23.262**
6	b_{12}=	0.056	s_{b12}=	0.064	t_{b12}=	0.882
7	b_{23}=	0.121	s_{b23}=	0.064	t_{b23}=	1.901
9	**b_{13}=**	**0.219**	**s_{b13}=**	**0.064**	**t_{b13}=**	**3.430**
10	**b_{11}=**	**0.177**	**s_{b11}=**	**0.059**	**t_{b11}=**	**3.002**
11	b_{22}=	0.126	s_{b22}=	0.059	t_{b22}=	2.140
12	**b_{33}=**	**0.660**	**s_{b33} =**	**0.059**	**t_{b33}=**	**11.200**

Thus, the results show the significant coefficients b'_0, b_1, b_2, b_3, b_{13}, b_{11} and b_{33}, so values b_0, s_{b0} and t_0 are recalculated according to Eqn (13), (14) and (16): b_0 = 3.834, s_{b0} = 7.793 and t_0 = 92.91. So, the empirical regression model for Y_2 is:

$$Y_2 = 3.834 + 0.407X_1 - 0.190X_2 + 1.195X_3 + 0.219X_1X_3 + 0.177X_1^2 + 0.660X_3^2 \quad (22)$$

▪ **Test the significance of regression function**

The residual variance:

$$s_{re}^2 = \frac{\sum_{i=1}^{19}(Y_i - \hat{Y}_i)^2}{N-L} = \frac{0.694}{19-7} = 0.058$$

With $N = 19$, $L = 6$

The Fisher value of the model:

$$F = \frac{s_{re}^2}{s_{th}^2} = \frac{0.058}{0.0325} = 1.778$$

Refer the table of critical values for Fisher's distribution [3] with p = 0.05, f_1 = 19-7 = 12 and f_2 = 5-1 =4: $F_{0.05}(12, 4)$ = 5.91. Since $F < F_{0.05}(f_1, f_2)$ then regression function is statistically significant.

4. Establishing the mathematical model of the loss of beta carotene in final product

Repeating the steps as the objective function $Y_1$and Y_2, the coefficients of the Y_3 regression function are also determined in Table 6.The reappearance variance:

$$s_{th}^2 = \frac{0.404}{5-1} = 0.101 \text{ and } s_{th} = \sqrt{0.101} = 0.317$$

Testing the significance of the coefficients:

The values of regression coefficients b_j, *tbj sbj* are shown in Table 6. Comparing *tbj* with *tp* (f) if: $t_{b_j} > t_p(f) = 2.78$ [3] then the regression coefficientis statistically significant.

Table 6. Calculation results of *bj*, *sbj*, *tbj* for Y3 function

TT	b_j		s_{bj}		t_{bj}	
1	**b'_0=**	**6.811**	**$s_{b'o}$ =**	**0.073**	**$t_{b'o}$ =**	**93.481**
2	**b_1 =**	**-1.082**	**s_{b1}=**	**0.090**	**t_{b1}=**	**11.962**
3	**b_2=**	**1.064**	**s_{b2}=**	**0.090**	**t_{b2}=**	**11.766**
4	**b_3=**	**-2.174**	**s_{b3}=**	**0.090**	**t_{b3}=**	**24.041**
6	**b_{12}=**	**-0.716**	**s_{b12}=**	**0.112**	**t_{b12}=**	**6.377**
7	**b_{23}=**	**-0.466**	**s_{b23}=**	**0.112**	**t_{b23}=**	**4.150**
9	b_{13}=	-0.250	s_{b13}=	0.112	t_{b13}=	2.222
10	**b_{11}=**	**1.161**	**s_{b11}=**	**0.104**	**t_{b11}=**	**11.191**
11	**b_{22}=**	**0.979**	**s_{b22}=**	**0.104**	**t_{b22}=**	**9.432**
12	**b_{33}=**	**1.295**	**s_{b33} =**	**0.059**	**t_{b33}=**	**11.200**

Thus, the results show the significant coefficients b'_0, b_1, b_2, b_3, $b12$, b_{23}, b_{11}, b_{22}, *and* b_{33} *so* value b_0, sb_o and t_0 are recalculated according to Eqn (13), (14) and (16): $b_0 = 4.582$, $sb_o = 0.204$ and $t0 = 22.472$

The empirical regression model for Y_3 is:

$$Y_3 = 4.582 - 1.082X_1 + 1.064X_2 - 2.174X_3 - 0.716X_1X_2 - 0.466X_2X_3 + 1.161X_1^2 + 0.979X_2^2 + 1.295X_3^2 \quad (23)$$

▪ **Test the significance of regression function**

The residual variance:

$$s_{re}^2 = \frac{\sum_{i=1}^{19}(Y_i - \hat{Y}_i)^2}{N-L} = \frac{3.210}{19-9} = 0.321 \text{ With } N = 19,\ L = 9$$

The Fisher value of the model:

$$F = \frac{s_{re}^2}{s_{th}^2} = \frac{0.321}{0.101} = 3.183$$

Refer the table of critical values for Fisher's distribution [2] with $p= 0.05$ $f_1= 19\text{-}9= 10$ and $f_2= 5\text{-}1 =4$: $F_{0.05}(10, 4) = 5.964$.

Since $F< F_{0.05}$ *(f1, f2)* then regression function is statistically significant.

5. Optimizing the technological parameters

The purpose of the optimization problem is to determine the value of the technological parameters so that the objective functions have the lowest value. For the multi-objective optimization problem during Gac aril drying, the optimal values of variables X_1, X_2, X_3 are calculated so that the values of the objective functions Y_1, Y_2, Y_3 are the smallest in the range $-1.471 \le X_1, X_2, X_3 \le 1{,}471$. Response Surface Method (RSM) is used in this case to determine the optimal technological parameters for the drying process.

The technological parameters (X_1, X_2, X_3) of the cold drying process of Gac had the simultaneous impact on these objective functions (Y_1, Y_2, Y_3) with the identified domain D(X) = {-1.414 ≤ x1, x2, x3, x4 ≤ 1.414}. Thus, the three-objective optimization problem determining the technological drying mode of Gac aril was restated as: Finding in common the test $X = (X_1^{opt}, X_2^{opt}, X_3^{opt}) \in D(X)$ in order that [3]:

$$\begin{cases} Y_1 = f_{1\min}(X_1^{opt}, X_2^{opt}, X_3^{opt}) = \min f_1(X_1, X_2, X_3) \\ Y_2 = f_{2\min}(X_1^{opt}, X_2^{opt}, X_3^{opt}) = \min f_2(X_1, X_2, X_3) \\ Y_3 = f_{3\min}(X_1^{opt}, X_2^{opt}, X_3^{opt}) = \min f_3(X_1, X_2, X_3) \\ \forall X = (X_1, X_2, X_3) \in \{-1.471 \le X_1, X_2, X_3 \le 1.471\} \end{cases} \quad (24)$$

Using Multiple Response Optimization in Statgraphics Centurion XV software version 15.1.02 to perform optimization calculations for technological parameters during Gac aril drying. The results have identified the values of the optimal variables as follows:

$X_1^{opt}= 0.432$; $X_2^{opt} =0.993$; $X_3^{opt} = 0.097$, corresponding to the values of the objective function: $Y_1^{\min} = 676.34$mins; $Y_2^{\min} = 4.363$kWh/kg; $Y_3^{\min} = 4.394$%

Transforming into real variables: $t_g^{opt} = 44.16$oC; $t_o^{pt} = 14.03$oC; $V_g^{opt} = 2.6$m/s

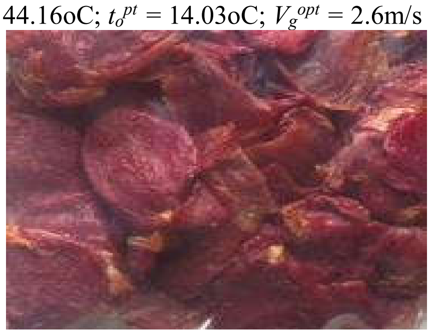


Fig 5. Gac fruit aril was dried by heat pump dryer

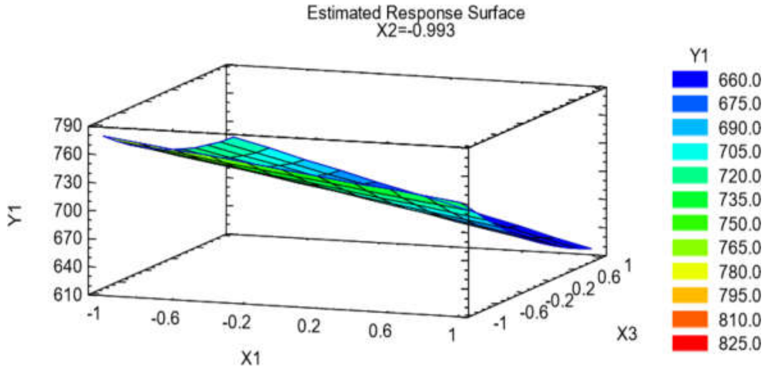


Fig 6. The drying time, X_2 =- 0.993

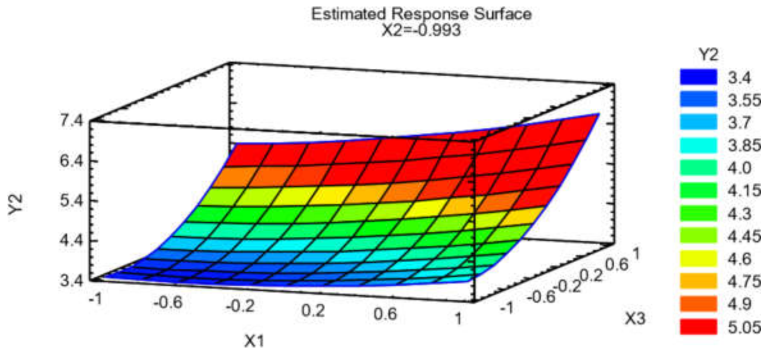


Fig 7. The energy consumption, X_2 =- 0.993

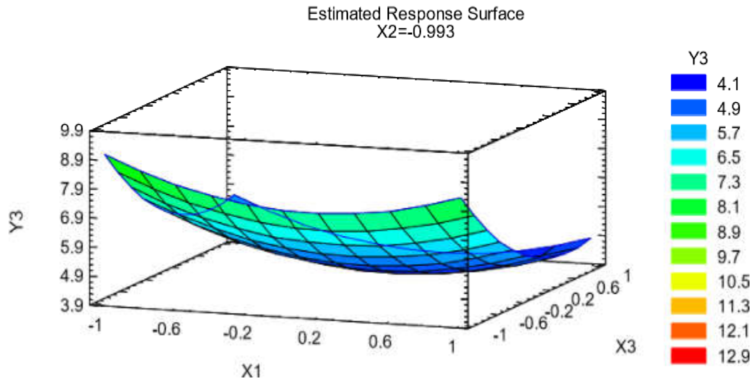


Fig 8. The energy consumption, X_2 =- 0.993

V. CONCLUSION

The multi-objective optimization results of the heat-pump drying method for the Gac aril from the experiment with the temperature of air drying is 44.16°C, the temperature of moisture condensation is 14.03°C and the air velocity of 2.6 m/s are also consistent with the results of Shi. at al (2008)[11]. The drying time is 11.27 hours compared to the result of previous research which is 16.257 hours and the energy consumption 4.363 kWh/kg compared with 66.77 kWh/kg [7], while the beta carotene decease of the final product compared to fresh Gac is still lower. This one ensure that the beta carotene content is not lost. This helps to ensure that the quality of the product meets the quality requirements and required energy cost for production, thus reducing costs which can be applied to industrial production.

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