STUDY OF PRODUCTION TECHNOLOGY FOR PENNYWORT POWDER PRODUCT BY COLD-DRYING METHOD

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ABSTRACT

The aim of this research was to develop and solve the experimental mathematical model which described the cold-drying process to produce pennywort powder products. Results obtained were to build the multi-objective optimization for cold-drying process of pennywort and the product after drying was good quality, the moisture content met the requirements and the energy cost reached the lowest level. The technological mode of cold-drying process for pennywort was found out by solving multi-objective optimization as follows: the optimal drying temperature was 44.24^oC, the optimal drying time was 14.12 hours and the optimal drying velocity was 12.83 m/s. Corresponding to these optimal factors, the solute concentration reached the minimum value of 11.31%; moisture content reached the minimum value of 3.65%; ΔE of 2.056 while the energy consumption for 1 kg final product reached the minimum value of 1.1 kWh / kg.

Keywords: *cold-drying; heat pump drying; pennywort; pennywort powder.*

1. INTRODUCTION

Pennywort is a herbaceous plant whose scientific name is Centella asiatica. It is widely used in many ways such as raw vegetables, soup vegetables, juices and drinks. The reason why pennywort is so popular, because of its chemical components that are high in nutrition value and have good effects on human's health such as liver refreshing, detoxification, acne treatment, anti-cancer, ect. The chemical components include glucid group, protein, vitamins (C, B1, B2 ...), minerals (Ca, Zn ...), pigments, odors, polyphenols, and especially Saponin [1], [2], [3].

Figure 1. *Pennywort grew up in Cu Chi district, Ho Chi Minh City.*

Pennywort is produced in the form of a tea bag, instant tea to make drinking water which is more convenient and suitable for modern and industrial life.

But the question is precious bioactive substances of pennywort will be decreased or lost after drying? For this reason, it is necessary to study a drying method and drying parameters that are suitable for pennywort products. Therefore, the cold-drying method is chosen in this study because of its outstanding advantages. Cold-drying products have high nutritional value, their chemical ingredients and color are almost not changed, their solubility content is high, their energy cost are low and the final moisture content of pennywort powder products is low which leads to theirs preservation ability is high [4], [5]. As mentioned above there are many valuable ingredients in pennywort but this study only measures the factors that affect to target functions such as color, solute content, energy cost, moisture content because the drying temperature is quite low, which is less than 45ºC so components such as saponin, protein, glucide are not affected in this temperature range [4], [6], [7]. Product color is the first impression that attracts customers or this is the sensory value of the product. The solute represents the product's ability to revert after drying, dissolving the solutes back into water. The product has lower moisture content and can be stored longer. And low energy cost is related to product costs. Due to these reasons, ``Study of production technology for pennywort powder products by cold-drying method' is necessary [10], [11], [12].

2. MATERIAL AND METHODS

2.1 Materials

In this research, pennywort grown in Cu Chi district, Ho Chi Minh City was selected for experiments (Figure 1)

The sample was removed from worm-eaten leaves, crushed leaves and petiole. Then it was washed with water and soaked in 3% saline solution for 3 ÷ 5 minutes. This washing and soaking process completely removed dirt and some microorganisms on the surface. Then let it drain for 10 ÷ 30 minutes to remove water. After that, the sample is placed in a drying tray, spread out evenly into the drying chamber.

2.2 Apparatus

The cold-drying system DSL-v2 (Figure 2) at Faculty of Chemical and Technology, Ho Chi Minh City University of Technology and Education, was used to for experiments which following parameters:

- Productivity 8 ÷ 12 kg / batch, drying time 10 ÷ 24 hours / batch (depending on the type of product).

- Mist condensation temperature: -15⁰C ÷ 25⁰C.

- Drying temperature: 35⁰C ÷ 45⁰C.

- Drying speed: 0 ÷ 12 m / s.

The cold-drying machine DSL-v2 was controlled automatically by computer.

Figure 2. *The cold-drying system DSL – v2*

2.3 Methods

2.3.1 Effect of technological parameters to cold-drying process

- Determining the drying temperature Z_1 (⁰C) by using a temperature sensor.

- Determining the drying speed Z_2 (m / s) by using a speed sensor.

- Determining the drying time Z_3 (h) by computer time system.

Technological parameters were controlled automatically by computer programs.

2.3.2 Determining the product's objective functions

Methods used to identify objective functions or criteria to evaluate product quality such as: color, y_1; solute content, y_2 (%); energy cost, y_3 (kWh / kg) and moisture content y_4, (%), were described as follows:

➢ ***Determining color of pennywort powder***

Colorimeter CR-400 was used to measure a^0, a^*, b^0, b^*, L^0 và L^* value. ΔE was determined by the following:

$$y_1 = \Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} = \quad (1)$$

$$\sqrt{(L_i^* - L_0^*)^2 + (a_i^* - a_0^*)^2 + (b_i^* - b_0^*)^2}$$

$$\sqrt{(L_i^* - L_0^*)^2 + (a_i^* - a_0^*)^2 + (b_i^* - b_0^*)^2} \quad (2)$$

Where:

L_i^*, L_0^*: brightness before and after sample.

a_i^*, a_0^*: value (+): red, value (-): dark green before and after of sample.

b_i^*, b_0^*: value (+): yellow, value (-): green before and after of sample.

➢ ***Determining solute content***

Solute content of the sample was measured by the Gravimetric method [TCVN 6508:2007]. Formula was described as:

$$y_2 = \frac{M + m_1 - m_2 - M.W}{M}.100(\%) \quad (3)$$

Where:

y1 (%): soluble content

m1(g): weight of filter paper after drying.

m2(g): total weight of filter paper and powder after drying

W(%): moisture of sample.

M (g): initial weight of sample.

➢ ***Determining energy consumption***

Energy cost (kWh / kg of) for producing pennywort powder was calculated by following formula:

$$y_3 y_3 = \frac{P.\tau}{G} = \frac{U.I.\tau.cos\varphi \; U.I.\tau.cos\varphi}{G \qquad G}, \text{kWh/kg} \quad (4)$$

Where:

G (kg) – weight of the final product

U (V) – number of Voltmeter

I (A) – number of Ampere meter

$\tau\tau$(s) – cold-drying time

Cos φ φ – powder factor

P(kW) – Watt indicator

➢ ***Determining moisture content***

Moisture content was measured by following TCVN 4326- 2001. Result was calculated by:

$$y_4 = \frac{M_1 - M_2}{M_1 - M_0}.100(\%) \quad (5)$$

Where:

M_0 M0 (g): weight of moisture can after drying

M1 (g): weight of moisture can and sample before drying

M2 (g): weight of moisture can and sample after drying.

2.3.3 Quadratic orthogonal experimental planning

After analyzing the technological objects of the cold-drying process including: product quality, product cost and storage time, they was affected by 3 factors: drying temperature Z_1 (^0C), drying velocity Z_2 (m / s), drying time Z_3 (h). Using quadratic orthogonal experimental planning methods to build the mathematical model about relationships between yj (j = 1÷ 3) and technological factors that affect the drying process (Z_1, Z_2, Z_3). These mathematical models of y_j (j = 1÷ 3) were written as follows [8], [9]:

$$Y_j = b_0 + \sum_{u=1}^{k} b_u x_u + \sum_{u \neq i; u=1}^{k} b_{ui} x_u x_i + \sum_{u=1}^{k} b_{uu}\left(x_u^2 - \lambda\right) \quad (6)$$

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

$$x_i = (Z_i - Z_i^0)/\Delta Z_j; \; Z_i = x_i.\Delta Z_i + Z_i^0 \quad (7)$$

where:

$Z_i^0 = (Z_i^{max} + Z_i^{min})/2$; $\Delta Z_i = (Z_i^{max} - Z_i^{min})/2$; $Z_i^{min} \leq Z_i \leq Z_i^{max}$; i = 1 to 3

$$N = n_k + n_* + n_0 = 2^k + 2k + n_0 \quad (8)$$

$$= 2^3 + 2.3 + 4 = 18$$

With n = 2 (-1 & 1); k = 3; n_0 = 4.

The value of the star point:

$$\alpha = \sqrt{\sqrt{N.2^{k-2}} - 2^{k-1}} = \sqrt{2} = 1.414 \quad (9)$$

- The condition of the orthogonal matrix:

$$\lambda = \frac{1}{N}\left(2^k + 2\alpha^2\right)$$

$$= \frac{1}{18}\left(2^3 + 2\left(\sqrt{2}\right)^2\right) = \frac{2}{3}$$

The experimental parameters were established by conditions of technological cold-drying, it was summarized in Table 2.

2.3.4 *Multi-objective optimization method*

- *Single-objective optimization [8]*

For technology object "Cold-drying pennywort", the objective function to be concerned was $y_j = f_j(Z)$ that depended on technological factors Z_1, Z_2, Z_3; these technological factors formed vector of affecting factors or also known as variable vector $Z = \{Z_i\} = (Z_1, Z_2, Z_3)$. These variables vary in the defined domain and values of the objective function $f_j(Z)$ were formed into the value range Ω_Z.

The objective function $y_j = f_j(Z)$ together with the variable vector $Z = \{Z_i\} = (Z_1, Z_2, Z_3) \in \Omega_Z$ ($i = 1 \div 3$) were formed into a multi-objective optimization problem.

Determine the root of $Z_j = \{Z_{ij}^{opt}\} = (Z_{1j}^{opt}, Z_{2j}^{opt}, Z_{3j}^{opt}) \in \Omega_Z$ for:

$$y_j = f_j(Z_{ij}^{opt}) = f_j(Z_{1j}^{opt}, Z_{2j}^{opt}, Z_{3j}^{opt}) = \text{Min(Max)}\{f_j(Z_1, Z_2, Z_3)\} \quad (10)$$

Where: $j = 1 \div 3$

Solve single-objective optimal problems by Solver function in Excel.

- *Multi-objective optimization [8]*

Technical and technological problems often consider an object that not only satisfies one objective but also satisfies many objectives at the same time.

At the same technology object, technological factors $Z = \{Z_i\} = (Z_1, Z_2, Z_3) \in \Omega_Z$ affected on the same time the target functions $f_1(Z)$, $f_2(Z)$, $f_3(Z)$), $f_3(Z)$. Therefore, it was necessary to examine $f_j(Z)$ at the same time on the variable space Z in domain Ω_Z. Thus, the multi-objective optimization problem appeared, which assumed that all single-objective optimization problems were minimal problem so the multi-objective optimization problem could be stated as follows: Determined the common root: $Z = \{Z_i^{opt}\} = (Z_1^{opt}, Z_2^{opt}, Z_3^{optt}) \in \Omega_Z$ for: $y_{jmin} = f_j(Z_i^{opt}) = f_j(Z_1^{opt}, Z_2^{opt}, Z_3^{opt})$

$$= \text{Min} f_j(Z_1, Z_2, Z_3) \quad (11)$$

where: $i = 1 \div n$; $j = 1 \div m$

Because single-objective optimization did not have a common root that satisfied all objectives. Therefore, it was necessary to solve the multi-objective optimization problem to find the optimal root of Pareto. The multi-objective optimization was solved by following utopian method:

An optimal combination of S was defined by following expression:

$$S = \left[\sum_{j=1}^{m} S_j^2(Z)\right]^{0,5} = \left[\sum_{j=1}^{m} (f_j(Z) - f_{j\min})^2\right]^{0,5} \quad (12)$$

S(Z) was the distance from point f(Z) to the utopia point f^{UT}. Choosing the optimal combination of S(Z) as the objective function, the multi-objective optimization problem was stated as follows: Find the root of $Z^S = (Z_1^S, Z_2^S, Z_3^S) \in \Omega_Z$ such that the objective function S(Z) reached the minimum value.

$$s_{\min} = s(z^s) = \min S(z) = \min\left[\sum_{j=1}^{m} (f_j(z) - f_{j\min})^2\right]^{0,5}$$

Where: $Z = \{Z_i\} = (Z_1, Z_2, Z_3) \in \Omega_Z$ (13)

From the S_{min} equation, using the same solution to solve an single-objective optimization problem to find the corresponding Z_i values. Then changing new roots of an equation Z_i into each initial single-objective optimization equation to find new y_{min} value.

3. RESULTS AND DISCUSSION

3.1 Determination of raw pennyworth's chemical composition and its powder after drying

The experiments were carried out by all the methods discussed above to determine the chemical components of pennywort and its powder including: the water content, vitamin C, saponin, protein, soluble fiber, minerals, tanin, calci and other components. The results were summarized in Table 1.

From Table 1, it is obvious that the relative humidity of the material was relatively high (89,8%), however, using the cold drying method with appropriate parameters could create a low relative humidity of pennywort's powder (3,65%) so that it can enhance the quality of postharvest products. The content of other components such as protein, soluble fiber, minerals, tanin, calci, vitamin C, saponin etc. was fairly differential between raw material and cold drying products due to errors occurring during experiments (weighing, handling…). On the other hand, the condition of cultivars, harvesting process, the various soil and types of pennywort also contribute to the changes of content in each chemical compound. Therefore, it can be stated that the components of pennywort are insignificantly affected by the cold drying process. Apart from these constituents, the others listed as follows: glucid, lipid, polyphenol, pigments, volatile compounds, minerals and vitamins were not involved in this study due to the experimental time deficiency. These results of raw material's chemical composition were highly correlated to the range of values mentioned in previous studies [3-4].

Table 1. *The chemical composition of pennywort material and its powder*

Substance	Raw material (%dry weight)	Pennywort's powder after drying (% dry weight)
Protein (%)	19.608	19.606
Saponin (%)	1.017	1.021
Soluble fiber (%)	10.196	10.194
Minerals (Ash) (%)	12.353	12.348
Tanin (%)	0.814	0.823
Calci (%)	0.008	0.079
Vitamin C (%)	0.199	0.200
Others (%)	55.805	55.729
	Relative humidity of material	Relative humidity of products
Water (%)	89.8	3.65

3.2 Develop the mathematical models of pennywort's cold drying process

According to the analysis of technological objects, the pennywort's cold drying process was affected by parameters, including: temperature of moisture condensation Z_1 (^oC), velocity drying agents Z_2(m/s) and time of cold drying process Z_3(h). All objective functions of the drying process of material such as the product colour y_1; solute content y_2 (%); the energy consumption per weight y_3 (kWh / kg) and residual water content y_4 (%). These functions always depended on technological factors as mentioned above. The experiments were conducted along with individual factors and resulted in the changes of critical domain y_j ($j = 1 \div 4$) in the identified domain Z_i ($i = 1 \div 3$) as shown in Table 2.

Table 2. *Technological factors levels design*

Parameters	Z_1 (^0C)	Z_2 (m/s)	Z_3 (h)
-α	35.76	7.17	4.34
-1	37	8	6
0	40	10	10
+1	43	12	14
+α	44.24	12.82	15.66
ΔZ_i	3	2	4

From Table 2, the orthogonal experimental matrix level 2 was built, as stated in Table 3a and Table 3b [13 -14].

Table 3a. *The orthogonal experimental matrix level 2*

N		x_0	x_1	x_2	x_3	x_1x_2
K^2	1	1	1	1	1	1
	2	1	-1	1	1	-1
	3	1	1	-1	1	-1
	4	1	-1	-1	1	1
	5	1	1	1	-1	1
	6	1	-1	1	-1	-1
	7	1	1	-1	-1	-1
	8	1	-1	-1	-1	1

N		x_0	x_1	x_2	x_3	x_1x_2
2k	9	1	1.414	0	0	0
	10	1	-1.414	0	0	0
	11	1	0	1.414	0	0
	12	1	0	-1.414	0	0
	13	1	0	0	1.414	0
	14	1	0	0	-1.414	0
n_0	15	1	0	0	0	0
	16	1	0	0	0	0
	17	1	0	0	0	0
	18	1	0	0	0	0

Table 3b. *The orthogonal experimental matrix level 2*

x_1x_3	x_2x_3	$x_1^2 - \lambda$	$x_2^2 - \lambda$	$x_3^2 - \lambda$
1	1	0.333	0.333	0.333
-1	1	0.333	0.333	0.333
1	-1	0.333	0.333	0.333
-1	-1	0.333	0.333	0.333
-1	-1	0.333	0.333	0.333
1	-1	0.333	0.333	0.333
-1	1	0.333	0.333	0.333
1	1	0.333	0.333	0.333
0	0	1.333	-0.667	-0.667
0	0	1.333	-0.667	-0.667
0	0	-0.667	1.333	-0.667
0	0	-0.667	1.333	-0.667
0	0	-0.667	-0.667	1.333
0	0	-0.667	-0.667	1.333
0	0	-0.667	-0.667	-0.667
0	0	-0.667	-0.667	-0.667
0	0	-0.667	-0.667	-0.667
0	0	-0.667	-0.667	-0.667

Carrying out 18 experiments following the experimental matrix planning in Table 3a and Table 3b. Therefore, the value of objective functions y_1, y_2, y_3 and y_4 was determined and summarized in Table 4.

Table 4. *Value of objective functions*

Number of experiment	Objective function			
	y_1	y_2	y_3	y_4
1	7.32	8.88	1.12	3.74
2	2.35	10.29	1.09	3.79
3	2.37	9.78	1.17	3.78
4	5.21	10.32	1.15	3.91
5	5.7	9.97	0.92	4.04
6	5.68	10.02	0.91	4.09
7	4,71	9.32	0.91	4.20
8	4.21	9.76	0.9	4.22
9	4.66	9.71	1.03	4.06
10	4.19	9.85	0.97	4.13
11	6.33	9.82	0,96	4,01
12	2.16	9.86	1.1	4.09
13	2,3	9.64	1.31	3.68
14	3.47	11.05	0.85	4.36
15	3.31	9.49	1	4.06
16	5.62	9.63	1.01	4.09
17	3.72	9.67	1.03	4.03
18	2.54	9.32	1.01	4.10

From Table 4, resolving the experimental data by Excel Microsoft 2018 software in order to find out the coefficients of regression equations, testing the significance of the coefficients by the Student criterion and checking the fitness between mathematical model data and experimental results by Fisher criterion. Results received were the mathematical models as follows:

- ***The product colour after cold drying process*:**

$y_1 = 4.214 + 0.276\ x_1 + 0.871\ x_2 + 0.916\ x_1x_2 – 0.046\ x_2x_3 + 0.585(x_1^2-2/3)$ (14)

- ***The product solute content after cold drying process*:**

$y_2 = 9.799 – 0.220x_1 – 0.149x_3 – 0.183x_1x_3 – 0.230\ x_2x_3 + 0.265(x_3^2 – 2/3)$ (15)

- ***The energy consumption per weight of product after cold drying process :***

$y_3 = 1.024+ 0.013x_1 – 0.024x_2 +0.128x_3 – 0.016x_2x_3 – 0.016(x_1^2 – 2/3) + 0.024\ (x_3-2/3)$ (16)

- ***The residual water content of product after cold drying process:***

$y_4 = 4.021 - 0.031x_1 - 0.047x_2 - 0.191x_3 - 0.036(x_2^2 - 2/3) - 0.051(x_3^2 - 2/3)$ (17)

By testing Fisher criterion, it can be observed that these experimental regression equations fitted the experimental figures. Hence, these equations can be used to describe the cold drying process of pennywort as well as calculate, design and fabricate the cold drying system.

3.3 Building and solving one-objective optimization problems

All objective functions assessing quality, economic and the preservative time of pennywort's product of cold drying technology including: y_1 - cold drying product's colour; y_2 - solute content; y_3 - the energy consumption per weight and y_4 - the residual water content depended on the technological factors: the drying temperature (x_1), velocity of drying agent (x_2) and drying time (x_3). Problems here are that cold drying products are required to meet the following criteria such as: good standard products, the qualified moisture content in order to prolong the preservative time, the energy consumption minimization together with low cost of products. If every objective function was individually surveyed, the one-objective optimization problems were built and restated as follows: Finding in common the test $x_j^{opt} = (x^j{}_1{}^{opt}, x^j{}_2{}^{opt}, x^j{}_3{}^{opt}) \in \Omega_x = \{-1,414 \le x_1, x_2, x_3 \le 1,414\}$, j = 1 ÷ 4 in order that:

$$\begin{cases} y_1 = minf_1(x_1, x_2, x_3) \\ \quad = f_1\left(x^{1\ opt}_1, x^{1\ opt}_2, x^{1\ opt}_3\right) \\ y_2 = maxf_2(x_1, x_2, x_3) \\ \quad = f_1\left(x^{2\ opt}_1, x^{2\ opt}_2, x^{2\ opt}_3\right) \\ y_3 = minf_3(x_1, x_2, x_3) \\ \quad = f_1\left(x^{3\ opt}_1, x^{3\ opt}_2, x^{3\ opt}_3\right) \\ y_4 = minf_4(x_1, x_2, x_3) \\ \quad = f_1\left(x^{4\ opt}_1, x^{4\ opt}_2, x^{4\ opt}_3\right) \end{cases} \quad (18)$$

Solving the one-objective optimization problems by using Excel Solver software resulted in the roots, as shown in Table 5.

From Table 5, it can be seen that none of the roots were found to satisfy all objective functions y_j (j = 1 ÷ 4) in the one - objective optimization problems (18). Consequently, the utopian roots as well as utopian optimal plan did not exist in this case.

Table 5. *The optimal value of one - objective optimization problems*

x_1	x_2	x_3	y_{min}	y_{max}
0.871	-1.414	-1.414	2.056	/
-1.414	-1.414	1.414	/	11.087
1.414	1.414	-1.414	0.870	/
1.414	1.414	1.414	3.522	/

3.4 Building and solving the multi-objective optimization problems

Instead of having an individual effect to the value y_1, y_2, y_3, y_4, the technological factors of the product's cold drying process x_1, x_2, x_3 affected the above value simultaneously. Thus, the multi-objective optimization problems appeared in this case and it was restated as follows [6]: Finding in common the root: $x^{opt} = (x_1^{opt}, x_2^{opt}, x_3^{opt}) \in \Omega_x = \{-1.414 \le x_1, x_2, x_3 \le 1.41\}$, j = 1 ÷ 4 in order that:

$$\begin{cases} y_1 = minf_1(x_1, x_2, x_3) \\ \quad = f_1\left(x_1^{opt}, x_2^{opt}, x_3^{opt}\right) \\ y_2 = maxf_2(x_1, x_2, x_3) \\ \quad = f_1\left(x_1^{opt}, x_2^{opt}, x_3^{opt}\right) \\ y_3 = minf_3(x_1, x_2, x_3) \\ \quad = f_1\left(x_1^{opt}, x_2^{opt}, x_3^{opt}\right) \\ y_4 = minf_4(x_1, x_2, x_3) \\ \quad = f_1\left(x_1^{opt}, x_2^{opt}, x_3^{opt}\right) \end{cases} \quad (19)$$

Because the utopian roots and utopian optimal plan did not exist, hence in this research, a utopian point method was used to determine the optimal Pareto roots of the multi-objective optimization problems (19).

It is realized that not only did the multi-objective optimization problems (19) had not only the maximum value but also the minimum one. To simplify the solution, these problems were re-established as follows:

$I_1 = y_1$; $I_2 = 1/y_2$; $I_3 = y_3$; $I_4 = y_4$. Thus, the multi-objective optimization problems were restated: Finding in common the root: $x^{opt} = (x_1^{opt}, x_2^{opt}, x_3^{opt}) \in \Omega_x = \{-1.414 \le x_1, x_2, x_3 \le 1.41\}$, j = 1 ÷ 4 in order that:

$$\begin{cases} I_j = \min I_j(x_1, x_2, x_3) \\ \quad = I_j(x_1^{opt}, x_2^{opt}, x_3^{opt}) \\ j = 1 \div 4 \end{cases} \quad (20)$$

From Table 5, the utopian point was figured out $I^{UT} = (I_{1mim}; I_{2mim}; I_{3mim}; I_{4mim})$ = (2.056; 0.09; 0.870; 3.522) and the S-Optimal combination criterion S(x) was constituted below:

$$S(x) = \sqrt{\sum_{j=1}^{4}\left(I_j(x) - I_{jmim}\right)^2} \quad (21)$$

As a result, the multi-objective optimization problems (20) were re-built: Finding in common the root: $x^{opt} = (x_1^{opt}, x_2^{opt}, x_3^{opt}) \in \Omega_x = \{-1.414 \le x_1, x_2, x_3 \le 1.41\}$, j = 1 ÷ 4 in order that:

$$S(x^{opt}) = S_{mim}(x) \quad (22)$$

$$= mim\left\{\sqrt{\sum_{j=1}^{4}\left(I_j(x) - I_{jmim}\right)^2}\right\}$$

The minimum value of S(x) with ($-1.414 \le x_1, x_2, x_3 \le 1.41$) was successfully found by solving problem (22) thanks to the support of Excel Solver Software 2018:

$S_{min} = 0.2640$ (23)

With: $x_1^{opt} = 1.414$

$x_2^{opt} = 1.414$

$x_3^{opt} = 1.0084$

Then, transforming into real variables:

$Z_1 = 44.24^0C$; (24)

$Z_2 = 12.83 m/s$;

$Z_3 = 14.12$ h.

Substituting x_1^{opt}, x_2^{opt}, x_3^{opt} into these equations (14), (15), (16) and (17), the optimal Pareto effect was obtained as:

$y_1 = 2.056$; $y_2 = 11.46$ %;

$y_3 = 1.10$ (kWh/kg); $y_4 = 3.65$ % (25)

It is also observed that the optimal technological parameters are as follows: cold drying temperature is 44.24⁰C; the velocity of drying agent is 12.83 m/s and drying time is 14.12 h correlated with the determination of colorimetric index y_1 = 2.056; solute content y_2 = 11.46 %; energy consumption per weight y_3 = 1.10 (kWh/kg) and residual water content of products after cold drying process y_4 = 3.65 %.

3.5 Experiment to test the results of multi-objective optimization problem

Experiments relating to the cold drying process of material were conducted at the optimal value of technological factors found in (23) and (24), as can be seen in Table 6.

Table 6. *Optimal value of technological factors*

Drying temperature (^{0}C)	Velocity of drying agent (m/s)	Drying time (h)
44.24	12.83	14.12

The pennywort product was analyzed. Therefore, results were summarized in Table 7 and Table 8.

Table 7. *Colorimetric index, solute content, the energy consumption per weight and the residual water content of optimal product*

Objective	The 1st	The 2nd	The 3rd	Average
Colorimetric index	2.053	2.059	2.058	2.057 ± 0.004
Solute content	11.01	11.53	11.38	11.31 ± 0.015
The energy consumption	1.11	1.09	1.13	1.11 ± 0.02
Water content	3.43	3.76	3.68	3.62 ± 0.03

Table 8. *The components of pennywort product (g/100g)*

Soluble fiber (%)	Total ash (%)	Tannin (%)	Calci (mg/kg)
4.26	8.89	1.66	7550

Consequently, it is very noticeable that the experimental results in Table 7 and Table 8 showed the optimal value of technological mode: Z_1 = 44.24^{0}C; Z_2 = 12.83m/s; Z_3 = 14.12h correlated with y_1 = 2.056; y_2 = 11,46 %; y_3 = 1.10 (kWh/kg); y_4 = 3.65 % so that this figures were absolutely fitted with laboratory data. Hence, technological parameters could be easily calculated and established in order to successfully design and fabricate the cold drying system via these results.

The value of technological factors obtained in this research was appropriate with the range of results recorded from previous studies about the agricultural cold drying process in Vietnam [15, 16, 17]. Thereby, the scientific and application of this research is further confirmed.

3.6 Cold drying procedure of pennywort

Results obtained from solving the multi-objective optimization problems could be used to calculate and create a technological progress in Figure 3, the final product after drying with optimal parameters as (was) shown in Figure 4.

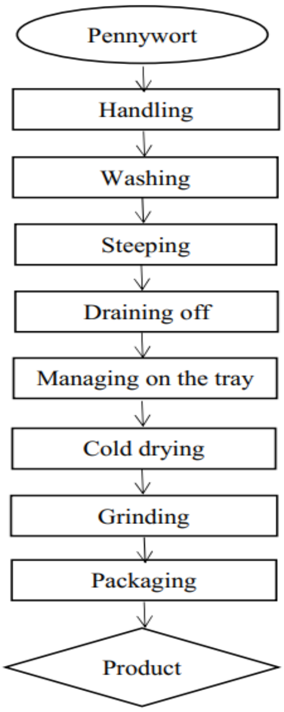

Figure 3. *Cold drying procedure of pennywort*

The interpretation for procedure:

The first step in the progress is handling pennywort before it is washed to remove impurities. Subsequently, raw material is steeped into salty solution (NaCl 3%), 3 ÷ 5 minutes to reject microorganism on its surface.

Figure 4. *The pennywort powder after using cold drying process*

After being steeped, pennywort is drained off and managed on the trays with its material thickness of 1 ÷ 4 cm. The next important step is setting up the optimal mode for the cold drying process with parameters as follows: Z_1 = 44.24^{0}C; Z_2 = 12.83m/s; Z_3 = 14.12h. Before being packaged and vacuum sealed, dried pennywort is grinded into powder with the granule diameter is less than 5 mm, as shown in Figure 4. The procedure finishes with a preservation step in room temperature.

4. CONCLUSIONS

This research has solved some matters including scientific and practical aspects such as:

- Determining pennywort's chemical compositions and building the scientific basis for the cold drying process to preserve all attributes and quality of product.

- Developing the mathematical models (14), (15), (16) and (17) to describe for pennywort's cold drying process.

- Optimizing (solving the multi-objective optimization problems (22) to figure out the optimal technological parameters: cold drying temperature is 44.24^{0}C; the velocity of drying agent is 12.83 m/s and drying time is 14.12 h. As a result, minimum value for the energy consumption per weight is 1.10 (kWh/kg), the qualified residual water content is 3.65%, the maximum solute content is 11.46 % and colorimetric index ΔE is 2.056.

- Developing a complete cold drying procedure for manufacturing commercial pennywort powder.

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