# FACTORIAL DESIGN EXPERIMENT USING TAGUCHI METHOD APPROACH IN PASSION FRUIT CUTTING SLICING MACHINE

## ỨNG DỤNG PHƯƠNG PHÁP TAGUCHI THIẾT KẾ THÍ NGHIỆM NHÂN TỐ CHO CỤM CẮT LÁT CHANH DÂY

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**ABSTRACT**

*In the process of producing drinks with raw materials from passion fruit, the stage of slicing passion fruit is a very important stage. Therefore, when designing the cutting cluster for the passion fruit slicing machine, we need to consider the structural parameters and working parameters of the cutting knife cluster that affect the efficiency and quality of the passion fruit slices after cutting. Parameters that can affect the quality of the product after cutting are: clearance between the knives, knife size, rotation speed of the knife shaft... In this article, the author will focus on researching to find out the structural parameters and working parameters of the passion fruit cutting cluster that greatly affect the efficiency and quality of the passion fruit slicing process. The Taguchi method is also applied in this study.*

**Keywords:** *Passion fruit pulping machine; Passion fruit slicer; Passion fruit cutter; Taguchi method.*

**TÓM TẮT**

*Trong quá trình sản xuất đồ uống có nguyên liệu từ chanh dây, công đoạn thái lát chanh dây là công đoạn rất quan trọng. Do đó, khi thiết kế cụm cắt cho máy thái lát chanh dây, chúng ta cần xem xét các thông số cấu trúc và thông số làm việc của cụm dao cắt ảnh hưởng đến hiệu quả và chất lượng của lát chanh dây sau khi cắt. Các thông số có thể ảnh hưởng đến chất lượng sản phẩm sau khi cắt là: khoảng cách giữa các dao, kích thước dao, tốc độ quay của trục dao... Trong bài viết này, tác giả sẽ tập trung nghiên cứu để tìm ra các thông số cấu trúc và thông số làm việc của cụm dao cắt chanh dây ảnh hưởng lớn đến hiệu quả và chất lượng của quá trình thái lát chanh dây. Nghiên cứu này cũng áp dụng phương pháp Taguchi.*

**Từ khóa:** *Máy nghiền chanh dây; Máy thái lát chanh dây; Máy cắt chanh dây; Phương pháp Taguchi.*

## 1. INTRODUCTION

Numerous species of passion fruit are commercially grown generating jobs and revenue in the cities and country side (Figure 1). Brazil, Colombia and Vietnam are the most traditional countries growing passion fruit (Bernacci et al., 2005) and presenting high economic and social relevance, serving as an alternative crop mainly for family-based agriculture.

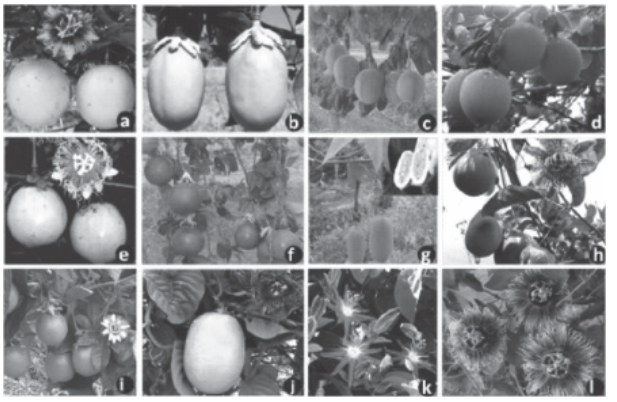

*Figure 1. Main commercial species Passiflora: P. edulis Sims (a); P. alata Curtis (b); P. setacea DC. (c); P. ligularis Juss (d); P. nitida Kunth (e); P. cincinnata Mast. (f); P. tripartita (Juss.) Poir. (g); P. maliformis L. (h); P. edulis Sims f. edulis (i); P. quadrangularis L. (j); P. setacea x P. coccinea cv. BRS Estrela do Cerrado ornamental hybrid (k); P. edulis x P. incarnata cv. BRS Céu do Cerrado – BRS CC ornamental hybrid (l). Photos: Nilton Junqueira, Fábio Faleiro, Ana Maria Costa, Embrapa Cerrados.*

Currently in the world, there are more than 9000 types of drinks, foods and flavors derived from passion fruit (6). Therefore, people are increasingly using passion fruit products because they bring many health benefits. Among them, passion fruit pulp is the most used. Previously, by manual methods, businesses producing passion fruit products removed the passion fruit pulp from the lemon by having workers cut the lemon in half and use a spoon or specialized tool to scoop the pulp out of the peel. This method is simple, the initial investment cost is low, the efficiency of removing the pulp from the peel is very high and almost absolute. However, this method has very low productivity, depending entirely on the skill level of the workers. Currently, businesses producing passion fruit products mostly use machinery and equipment to replace manual labor. Although this has a high initial investment cost, it helps increase productivity, efficiency and stable quality. In the machinery and equipment chain, the passion fruit cutting cluster before screening plays an important role and directly contributes to determining the quality and efficiency of the entire process of separating the passion fruit pulp from the peel. In this article, the author applies the Taguchi method to design experiments with the aim of determining the parameters that most affect the working mode of the passion fruit slicing cluster.

## 2. MATERIALS AND METHODS

### 2.1. Materials

Passion fruit used for research is fresh purple-skinned passion fruit, not wilted, the stem can be removed or the stem is intact. Samples of passion fruit used for research are shown in Figure 1. Survey of passion fruit characteristics: Passion fruit is oval in shape, with an average length (L) of 61.6mm to 67.6mm, average diameter (D) of passion fruit from 49.6mm to 59mm, survey data is shown in Table 1 and survey images are shown in Figure 2.

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*Figure 2. Passion fruit samples used for research*

*Table 1. Geometric parameters of passion fruit*

| No. | L (mm) | D (mm) | No. | L (mm) | D (mm) |
|---|---|---|---|---|---|
| 1 | 67.6 | 59.0 | 11 | 64.0 | 56.0 |
| 2 | 63.0 | 58.3 | 12 | 65.2 | 55.7 |
| 3 | 63.5 | 54.2 | 13 | 62.7 | 53.2 |
| 4 | 64.1 | 56.4 | 14 | 63.3 | 54.9 |
| 5 | 63.8 | 55.0 | 15 | 65.5 | 56.2 |
| 6 | 61.6 | 49.6 | 16 | 63.6 | 55.1 |
| 7 | 62.3 | 50.1 | 17 | 63.7 | 54.7 |
| 8 | 64.5 | 55.5 | 18 | 62.1 | 51.8 |
| 9 | 62.7 | 51.3 | 19 | 63.1 | 54.9 |
| 10 | 66.8 | 57.7 | 20 | 62.0 | 50.3 |

Average weight of lemon: 80g/fruit. Friction angle between passion fruit and metal: using experiments to determine the friction angle between lemon and metal, experimental results are shown in table 2. Average friction angle between passion fruit and metal is 28.80.

*Table 2. Experimental results of friction angle between passion fruit and metal*

| No. | Results (°) | No. | Results (°) |
|---|---|---|---|
| 1 | 27.0 | 6 | 28.5 |
| 2 | 31.5 | 7 | 33.0 |
| 3 | 29.0 | 8 | 28.0 |
| 4 | 27.0 | 9 | 29.5 |
| 5 | 24.0 | 10 | 30.5 |

The structural parameters of the cutter and the working parameters of the cutter assembly that affect the quality of passion fruit slices are the cutter shaft speed n (rpm) and the cutter diameter D (mm). Their maximum and minimum values are given in Table 3.

*Table 3. Level of control parameters*

| Symbol | Cutter speed and diameter of shaft | Parameter | |
|---|---|---|---|
| | | Level 1 | Level 2 |
| n ($x_1$) | Cutter shaft speed (rpm) | 180 | 220 |
| D ($x_2$) | Cutter diameter D (mm) | 760 | 800 |

## 2.2. Methods

Cutting knife: The disc knife will cut the passion fruit continuously, making the cut beautiful and not creating any debris. Therefore, the disc knife was chosen for the study.


ISSN 2615 - 9910 (bản in), ISSN 2815 - 5505 (online)
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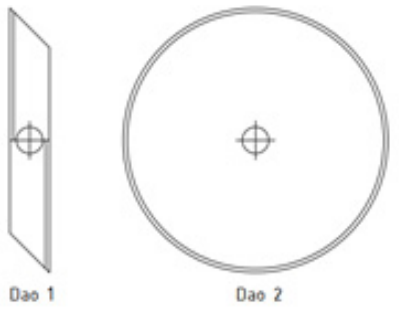


*Figure 3. Cutting knife*

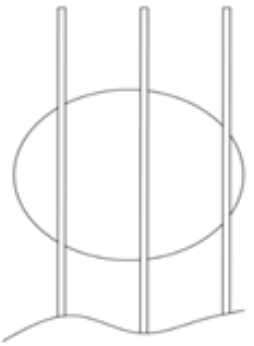

*Figure 4. Passion fruit cutting slicing*

To ensure that the lemon does not slip during the cutting process, the geometric parameters must be ensured, the blade diameter (D) is an important factor determining this issue. Figure 5 shows the forces acting on the lemon during the cutting process, including: the weight of the lemon P, the reaction forces $N_1$, $N_2$, the friction forces $F_{ms1}$, $F_{ms2}$.

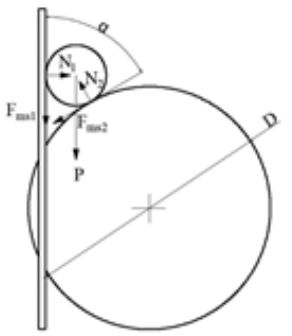


*Figure 5. Analysis of the force acting on passion fruit during slicing*

Considering the balance of passion fruit, we have:

$$\vec{P}+\vec{N}_1+\vec{N}_2+\vec{F}_{ms1}+\vec{F}_{ms2}=0 \quad (1)$$

To ensure that the lemon always goes down regardless of the mass of the lemon itself, the component is removed when projecting equation (1) onto the two directions Ox and Oy.

Projecting the forces acting on the passion fruit onto the ox and oy axes, we have the following equilibrium equations:

$$\sum F_{Ox}=0 \Leftrightarrow N_1-N_2.\cos\alpha-F_{ms2}.\sin\alpha=0 \quad (2)$$

$$\sum F_{Oy}=0 \Leftrightarrow N_2.\sin\alpha-F_{ms2}.\cos\alpha-F_{ms1}=0 \quad (3)$$

Solving equations (2) and (3) we find the condition: α = 2φ with the angle φ being the angle of friction between the passion fruit and the metal (φ = 28.80). When α = 2φ the passion afruit is in equilibrium, it is necessary to take α < 2φ. In addition, when the machine is working, it will generate vibration so the coefficient of friction will decrease. In fact, it is necessary to take 60% of the angle α to ensure the condition of cutting the passion fruit, so the maximum angle α is 34°.

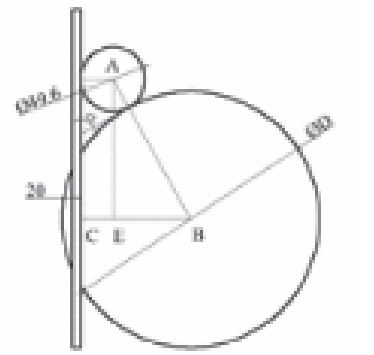


*Figure 6. Geometric parameters determining the diameter D of the disc knife*

Based on figure 6, considering triangle AEB, we have:

$$\sin \hat{EAB} = \frac{EB}{AB}$$

From here find the cutter diameter, D (mm):

$$D = \frac{49.6\cos\alpha + 89.6}{1 - \cos\alpha} \quad (4)$$

### 2.3. Experimental model and Taguchi method

The passion fruit cutting cluster model is designed, manufactured and assembled as shown in Figure 7.

*Figure 7. Passion fruit cutting cluster model*

Taguchi orthogonal array L4 is given in Table 4, where parameters affecting the process and their levels are specified.

*Table 4. Taguchi orthogonal array L4 ($2^2$)*

| No. | $x_1$ (rpm) | $x_2$ (mm) |
|---|---|---|
| 1 | $n_1$ | D1 |
| 2 | $n_1$ | D2 |
| 3 | $n_2$ | D1 |
| 4 | $n_2$ | D2 |

## 3. EXPERIMENT AND RESULTS

The quality of the cut is considered based on the experimental results according to the structural parameter of the cutter diameter and the working parameter of the cutting unit is the rotational speed of the cutter shaft. Let H% be the percentage of the cut achieved by the cutter compared to the quality of the sample cut (the sample cut is made by hand - ideal conditions). The experimental results are presented in Table 5.

*Table 5. Experimental results*

| No. | (n, rpm) | D (mm) | Cut quality (H%) |
|---|---|---|---|
| 1 | 180 | 769 | 89 |
| 2 | 180 | 800 | 92 |
| 3 | 220 | 769 | 94 |
| 4 | 220 | 800 | 98 |

Correspondence to Taguchi orthogonal array L4, standard deviation (S) and signal-to-noise ratio (S/N ratio) were calculated for each cutting quality H% sample (Table 6). S/N ratio was determined following larger-the-better category with help of (5).

$$\frac{S}{N_{ratio}} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (5)$$


ISSN 2615 - 9910 (bản in), ISSN 2815 - 5505 (online)
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*Table 6. Sample statistic according to Taguchi method for cutting quality H% samples*

| No. | Factors affecting slice quality | | Coding factor | | Cutting quality (H%) | $\frac{S}{N_{ratio}}$ |
|---|---|---|---|---|---|---|
| | (n, rpm) | D (mm) | $x_1$ | $x_2$ | | |
| 1 | 180 | 769 | 1 | 1 | 89 | 39.38 |
| 2 | 180 | 800 | 1 | 2 | 92 | 40.76 |
| 3 | 220 | 769 | 2 | 1 | 94 | 42.65 |
| 4 | 220 | 800 | 2 | 2 | 98 | 45.48 |

To determine the factors affecting the productivity of the cutting cluster, we conducted a variance analysis of the variables (ANOVA). The results and variance analysis are presented in Table 7.

*Table 7. The results and variance analysis ANOVA*

| No. | Factor value level | Factor | | Optimal mode |
|---|---|---|---|---|
| | | n | D | |
| 1 | 1 | 40.07 | 41.01 | $n_2D_1$ $n_2 = 220$ $D_1 = 760$ |
| 2 | 2 | 44.06 | 43.12 | |
| 3 | Mean (m) | 42.06 | 42.06 | |
| 4 | Max (1,2) | 44.06 | 43.06 | |
| 5 | Max-m | 2 | 1 | |
| 6 | Percentage (%) of Factor | 66.67 | 0.33 | |
| 7 | Max-min | 3.99 | 2.11 | |
| 8 | Rank | 1 | 2 | |

## 4. CONCLUSION

The research results show that the parameter that most affects the working mode of the cutting cluster in the passion fruit pulping line is the rotation speed of the blade shaft n = 220 (rpm). In addition, the structural parameters of the cutting blade also affect the mode of the cutting cluster with the diameter parameter D = 769mm.

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