# Classifying Crispiness of Freeze-dried Durian Using Fuzzy Logic

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**Abstract**- *This paper proposes the classification of freeze-dried durian crispiness using fuzzy logic (FL). In freeze drying process, the durian texture is physically changed. Three features of the freeze-dried durian image are considered to indicate the crispiness. These three features are diameter of pore, ratio between pore and space, and distribution of pore. The classification uses the FL algorithm for decision making. The experiment results show high accuracy of freeze-dried durian crispiness classification comparing with expert opinions*.

**Keywords:** Durian, Crispiness, Freeze drying, Sublimation Rate, Fuzzy Logic.

## 1. Introduction

Durian is a main export fruit of Thailand, which is the first country that exports durians. The income from this export is more than 10,000 million baht per year [1]. Both fresh and processed durians are available in the market. One of popular processed durian products is done by the freeze drying process. Many people like to taste this product, because the freeze-dried durians still keep their flavor and have aroma similar to fresh durians. Moreover, a research [1] has shown that the freeze-dried durians are better than similar products processed by other methods. However, quality control is very important for the exportation of the freeze-dried durians.

In quality control, recent researches [2] [3] [4] [5] [6] have been investigating the quality of the freeze dried products. These researches studied the effects of the freeze drying process to the products. Moreover, image analysis is a tool to support the above investigations [7]. However, the previous work did not address a quality of freeze-dried durian in term of crispiness, which is a key quality parameter for the processed durians.

This paper introduces the crispiness classification of freeze dried durians by considering the physical changes of the durian structure after freeze drying process. We consider 3 physical properties of freeze-dried durian images that indicate the crispiness by using fuzzy logic algorithm to decide the crispiness classification. The paper is organized as follows. The basic concept of our proposal is described in Section 2. Then, the detail method is explained in Section 3. Section 4 describes the experiments and the results. Section 5 and 6 give the discussion and conclusion respectively.

## 2. Basic Concept

In image analysis, freeze-dried durian images are considered. In this analysis, we try to find features of the images that will translate into the crispiness of the freeze-dried durians. In freeze dehydration process [8], the texture of durian has changed. The water molecular flow and damage the texture of durian. Pores are created by this effect. From research studies [8] [9], these pores are mostly the same in size. However, there are some variations of these pores that affect the crispiness.

Firstly, when the diameter of the pore is large, it means the freeze-dried durian is more porous. Therefore, crispiness is also more. This first case is shown in Fig.1 (a) and (b).

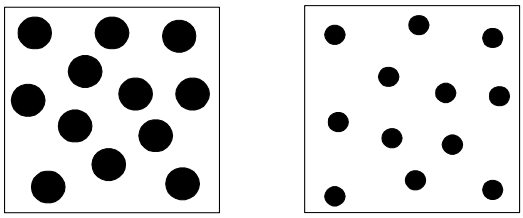
Secondly, observing only the diameter of pores is not enough to consider to crispiness since freeze-dried durians with too few wider pores mean less crispiness than those with a lot of narrower pores. Fig.1 (c) and (d) depict the second case. This case is related to the ratio between the area of the pores and space.

The final consideration is about the distribution of pores. In case of the same size of the pores, freeze-dried durians with a lot of pores are crispier than those with less distribution of the pores. This case is shown in Fig.1 (e) and (f).

These three features of the pores that indicate the crispiness are combined for deciding the level of crispiness of a piece of freeze-dried durian. Since there are no clear indication of how these features affects the crispiness, we choose to use the fuzzy

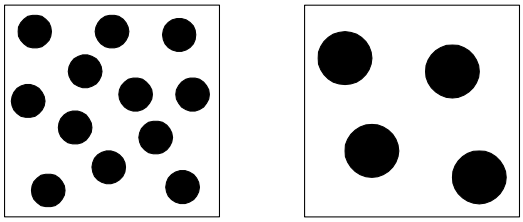
logic to help deciding the level of crispiness based on these features.

Case I Diameter of pore



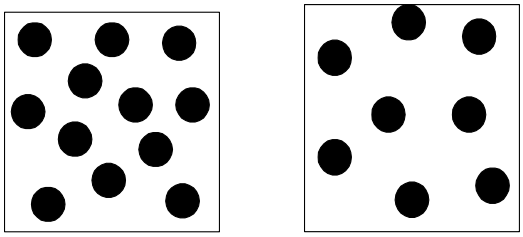
(a) crispy (b) No-crispy

Case II Ratio between pore and space



(c) crispy (d) No-crispy

Case III Distribution of pore



(e) crispy (f) No-crispy

Fig.1 Crispiness based on features of the pores.

## 3. Proposed Method

The proposed freeze-dried durian crispiness classification process is a process that uses 3 features of image for classifying crispiness by Fuzzy Logic Algorithm. Fig. 2 depicts the scheme of the freeze-dried durian crispiness classification and the steps of the proposed method.

### 3.1. Freeze-dried Durian image

The Freeze-dried Durian crispiness classification uses the image from the SEM. Each image is under the same condition, such as size of image.

### 3.2. Feature detection

This step is for feature detection. The Hough transform is an image tool that is used to detect the circles in the images. After all the circles are detected, a threshold is applied to classify whether a circle is a pore or not. Finally, the diameter of the pores, the ratio between pore and space, and distribution of pore are measured as the input to the fuzzy logic system.

### 3.3. Fuzzy Logic Algorithm

Fuzzy Logic is the step of decision process. The three features of an image are the inputs for if-then rule of the FL. The AND operator is used for making the decision.

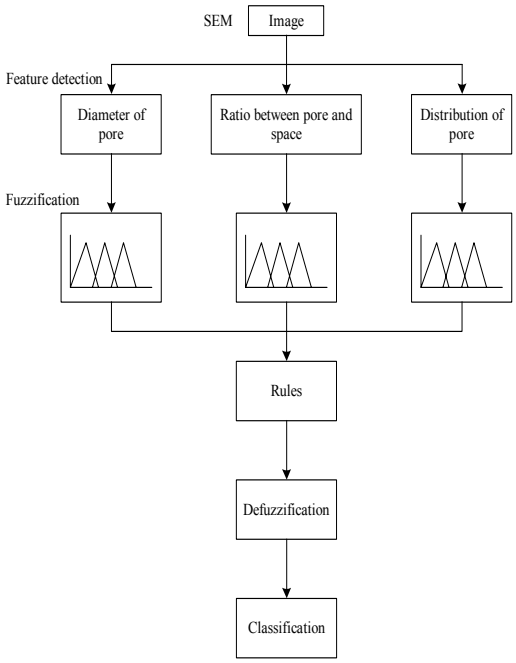



Fig.2 The system of classification using Fuzzy Logic Algorithm (FL)

**3.3.1. Membership function.** In fact, the freeze drying process depends on 3 factors as temperature, pressure, and time. The optimal point of sublimation rate [8] is Vs = $f$ (Ps). It is the optimal point of freeze drying process. In our experiment, we use this formula to find the optimal diameter of the pores, and each input is compared with this diameter and converted to the percentage using the optimal diameter as the reference.

Fuzzy membership function is in the range of [0 – 1], which corresponds to the degree of how the input belongs to a linguistic class. Fig.3 shows each membership function, where variable L is the low value, M is the medium value, and H is the high value of each input of the membership function.

**3.3.2. If-then rules.** The fuzzy knowledge base contains IF-THEN rules describing the system behaviors. In an image analysis, each image is in the same condition. The value of each input is not different such as low diameter, high ratio of pore and space or medium distribution of pore. Therefore, when setting rules we consider 3 rules as shown below:

Rule 1:

IF diameter IS low AND ratio_of_area IS low AND distribution IS low THEN output IS low

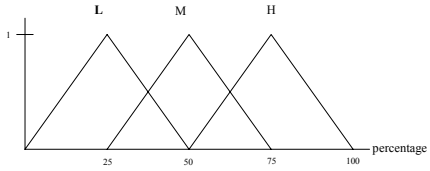
Rule 2:

IF diameter IS medium AND ratio_of_area IS
medium AND distribution IS medium THEN output IS medium

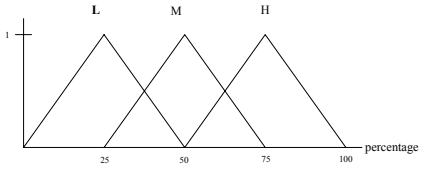
Rule 3:

IF diameter IS high AND ratio_of_area IS high AND distribution IS high THEN output IS high

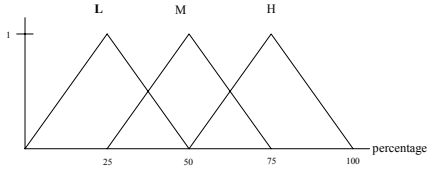
Weights of each input are unity. The degree of each rule is satisfied, and calculated by applying fuzzy "AND" (minimum) operator to the "AND" terms in the rules and the accumulation computed by "OR" (maximum) operator. The result is a fuzzy set that can be defuzzified by computing the centre of the area below the membership function as described.




(a) Diameter of pore




(b) Ratio between pore and space




(c) Distribution of pore

Fig.3 Membership function

## 3.4. Classification

The output of FL is the probability. Therefore, the values are converted to linguistic variables. The classification process divides crispiness into classes. In our case, A, B, C, and No (no crispy) are classified by using the threshold of the probability. In class A, threshold is at 0.626; class B has probability between 0.51 – 0.625; class C is between 0.376 – 0.50, and the probability lower than 0.375 is consider in class "No". When inputs are different such as low diameter, high ratio pore and space or medium distribution of pore, the output of FL is 0.5. Therefore, this image falls into the last class.

# 4. Experimental Results

## 4.1. Fuzzy logic result

The experiment uses 12 images as an input, which each image is under the same condition. The output gotten from the fuzzy logic process shows the class of each image. Outputs of the FL can be found in Table I.

Table I: Output of fuzzy logic

| Diameter of pore | Ratio between pore and space | Distribution of pore | Output of FL |
|---|---|---|---|
| 0.20 | 0.21 | 0.30 | 0.250 |
| 0.36 | 0.27 | 0.31 | 0.283 |
| 0.35 | 0.39 | 0.37 | 0.371 |
| 0.40 | 0.37 | 0.41 | 0.391 |
| 0.48 | 0.43 | 0.44 | 0.470 |
| 0.50 | 0.48 | 0.51 | 0.500 |
| 0.54 | 0.51 | 0.54 | 0.516 |
| 0.59 | 0.62 | 0.64 | 0.614 |
| 0.62 | 0.60 | 0.64 | 0.620 |
| 0.67 | 0.70 | 0.68 | 0.686 |
| 0.72 | 0.74 | 0.71 | 0.735 |
| 0.80 | 0.75 | 0.77 | 0.750 |

## 4.2. Classification results

In the quality control, it has no public standards for crispiness classification of freeze-dried durian. Therefore, classify of freeze-dried durian was advised by experiences who are researchers in food engineering department. The porosity of freeze-dried durian sample is considered in classification by the experts [1]. The details of this subjective classification are shown in Table II.

In the experiment, we use the output from FL to consider the crispiness classification of freeze-dried durians. Table III shows the classification result.

Table II: Subjective class.

| Class | Diameter of pore ($\mu$ m) | Ratio between pore and space | Distribution (Number of pore) |
|---|---|---|---|
| No | 245 – 270 | 0.00 - 0.25 | 0 - 4 |
| C | 271 – 295 | 0.26 - 0.50 | 5 - 8 |
| B | 296 – 320 | 0.51 - 0.75 | 9 -12 |
| A | 321 – 345 | 0.76 - 1.00 | 13 -15 |

The results of classification process show high accuracy comparing with the subjective class of the expert using the same images.

Table III: Crispiness classification of freeze-dried durian.

| Output of FL | class |
|---|---|
| 0.250 | No |
| 0.283 | No |
| 0.371 | No |
| 0.391 | C |
| 0.470 | C |
| 0.500 | C |
| 0.516 | B |
| 0.614 | B |
| 0.620 | B |
| 0.686 | A |
| 0.735 | A |
| 0.750 | A |

## 5. Discussion

The experiment result shows that the proposed method can classify crispiness of freeze-dried durian. However, the image used for detecting feature must be set up in the same condition. The freeze-dried durian sample is required to prepare in the same condition in order to obtain high accuracy experiment results. Moreover, the membership of fuzzification input is set to be percentage, because the optimal sublimation rate is Vs and *f*(Ps) [8]. Therefore, our experiment uses the membership of FL input that is presented by percentage of this point.

The experiment result shows that the proposed method is high accuracy crispiness classification of freeze-dried durian comparing with the expert opinion. However, the consumer opinions should be considered.

## 6. Conclusion

The paper introduces the crispiness classification of freeze-dried durians based on the physical changes caused by the freeze-dried process, which results in the changes of the diameter of pores, the rate between pore and space, and the distribution of pores. These features can identify freeze-dried durian crispiness. The experiment result shows the proposed method can classify freeze-dried durian crispiness with high accuracy classification comparing with the expert opinions.

## References

[1] W. Khuaying, "Effect of Processing Conditions on Quality of Freeze-dried Durian," 2003.
[2] C. Hammami, and F. Rene, "Determination of freeze-dried process variables for strawberries," *Journal of food engineering*, vol. 32, pp. 133- 154, 1997.
[3] C. Hammami, and F. Rene, "process-quality optimization of the vacuum freeze-drying of apple slices by the response surface method," *Journal of science and technology*, vol. 34, pp. 145-160, 1999.
[4] D.C. Iwaniw, and G.S. Mittal, "process optimization of freeze-dried strawberries," *Journal of Agricultural*, vol. 32, pp. 133-154, 1990.
[5] A.A. Khan, and Vincent, "Mechanical damage induced by controlled freezing in apple and potato," *Journal of the Texture Studies*, vol. 27, pp. 143-157 1996.
[6] M.K. Krokida, V.T. Karathanos, and Z.B. Maroulis, "Effect of freeze-drying conditions on shrinkage and porosity of dehydrated agricultural products," *Journal of food engineering*, vol. 35, pp. 369-380, 1998.
[7] E.R. Davies, *Image processing for the food industry*, 2000.
[8] S.A. Goldblith, L. Rey, and W.W. Rothmayr, *Freeze Drying and Advanced Food Technology*, 1975.
[9] Olivera, *Processing food: quality optimization*, 1999.
[10] Rafael C. Gonzalez, and Richard E. Woods, *Digital Image Processing*, 1992.
[11] A. Von, Fuzzy Logic & NeuroFuzzy Applications Explainede, 2000.