Classification of papaya crispiness based on mechanical properties

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Abstract: This research investigated an objective technique for the classification of papaya varieties based on crispiness. Five varieties of papaya were sampled with variation in crispiness. The papaya samples were mechanically tested using texture profile analysis and rectangular blade cutting methods. Discriminant analysis based on the mechanical properties measured using rectangular blade cutting was performed to develop a classification model. The obtained discriminant model was capable of classifying the papaya samples into five different groups with an accuracy of 82.4%.

Keywords: papaya, classification, mechanical properties

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1 Introduction

The physical properties of fruit are important with regard to quality for consumer acceptance. Hardness and crispiness are frequently used to judge fruit quality prior to purchase. Consumers tend to link the hardness and crispiness with the freshness of the produce (Tunick et al., 2013). In extrusion cooking, product crispiness associated with expansion is the primary quality parameter (Sawant et al., 2013). Crispiness is defined as the generated sound when the fruit is bitten and the louder the sound the greater the crispiness of the produce (Bavay et al., 2013). Crispiness is directly associated with the texture of the fruit and can be destructively measured using near infrared spectroscopy or non-destructively measured using a penetration test (Chen and Opara, 2013). The consumption satisfaction of the consumer can be enhanced by crispiness. However, crispiness has not been well defined as it is dependent on the feeling of the consumer. Crispiness is associated with the morphology of the material. Fruits and vegetables are regarded as wet, crisp products with their cellular structure having high turgor pressure. When bitten, the cell wall rapidly ruptures resulting in an immediate out flowing of the internal fluid and a loud crisp sound. The soluble pectin content is another factor that is involved in crispiness (Saeleaw and Schleining, 2011).

Previous research has been conducted to measure crispiness and three main methods have been tested-sensory testing, mechanical testing and acoustic testing (Chen et al., 2005). There are few studies on crispiness testing of fruits and vegetables with most of them involving apple (Ballabio et al., 2012 and Harker et

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al., 2002). Martin-Diana et al. (2006) found that cabbage, following soaking in calcium lactate and heat shock at 50°C, showed prolonged crispiness. The calcium lactate cross-linked with the cell wall and pectin matrix in the cabbage which made cells unshrinkable, preserved the turgor pressure and thus maintained the crispiness. Under compression testing, the sensory crispiness was found to be positively related to the crispiness coefficient which was derived from the maximum force per kilogram of mass of the cabbage. For papaya, the maximum force obtained from the compression test was shown to vary with the firmness of ripe papaya (Alam et al., 2013).

Papaya is one of the important ingredients for papaya salad, the popular dish in Thai restaurant worldwide. However crispy papaya is needed for consumer acceptability. There has been no research on the evaluation of the crispiness of raw papaya. The current research focused on an investigation of the mechanical properties associated with the crispiness of raw papaya used for making salad. In the study, five varieties of papaya were used to represent variation in the crispiness.

2 Materials and methods

2.1 Samples

Five papaya fruits in the raw stage from each of five varieties (KK, KD24, KD25, DN and PL) were selected from a papaya plantation at Kasetsart University, Kamphaeng Saen campus, Thailand. The five varieties were chosen to provide variation in the crispiness of the flesh. Table 1 shows general physical properties and total soluble solids of each variety. KD25 variety is the heaviest fruit with lowest total soluble solids and thickest flesh. The variety with highest total soluble solids and smallest in size is PL.

Table 1 Physical and chemical properties of each variety of papaya

Variety	Average mass, kg	Fruit width, cm	Fruit length, cm	Flesh thickness, cm	Total soluble solids, %
KK	0.86	7.3	43.2	1.90	10.5
DN	1.36	9.4	34.5	2.90	12.9
PL	0.64	8.0	18.1	2.50	14.3
KD25	1.49	11.1	24.2	2.98	10.5
KD24	1.34	9.9	27.2	2.64	11.3

2.2 Measurements

2.2.1 Compression tests

Papaya flesh was prepared into rectangular specimens with dimensions of 1.5 mm×6 mm×1.5 mm and underwent compression testing according to the shear cutting method using a Warner-Bratzler shear blade with a rectangular notch (Figure 1) (Bourne, 2002). In addition, a cylindrical flesh sample with a diameter of 15 mm and length of 15 mm was prepared from the same sample and compressed under plate loading (Figure 2) using the Texture Profile Analysis (TPA) technique. Both tests involved compression at a cross head speed of 1 mm/s of the texture analyzer (LR50; Lloyd; West Sussex, UK). Each fruit was tested in triplicate and the averages were used for further analysis. The change in force with time was recorded and the parameters were calculated from the relationship between the force and deformation and between the force and time for the shear cutting and TPA methods, respectively. Parameters derived from TPA were hardness, cohesiveness, springiness, springiness index, gumminess, chewiness, fracture force, adhesive force, adhesiveness and stiffness (Bourne, 2002). The parameters from the shear cutting method were load at limit, work to limit, maximum load, deflection at maximum load, work to maximum load and stiffness.

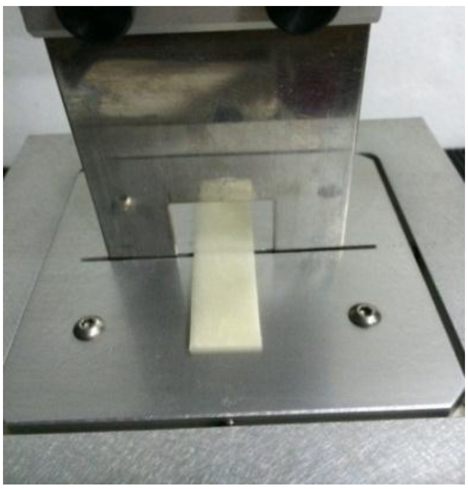


Figure 1 Shear cutting method using a Warner-Bratzler shear blade with a rectangular notch

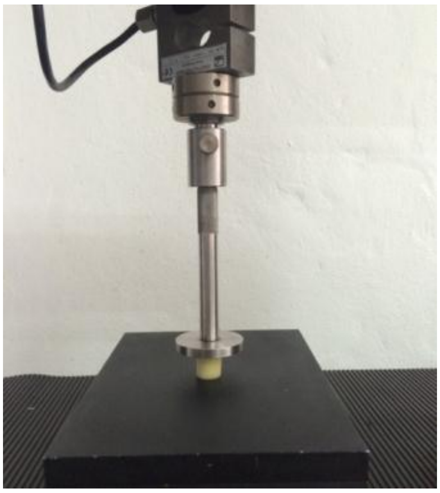


Figure 2 Compression test with Texture Profile Analysis

2.2.2 Sensory test

A sensory panel consisting of 70 people was selected from consumers who liked papaya salad. The papaya flesh was prepared into long shreds as is customary in commercial papaya salad. The shreds were kept in tightly sealed plastic bags each coded with a three digit name. All bags containing papaya salad were immersed in iced water for four hours prior to the sensory test. The testers were assigned to chew the salad and gave a score of crispiness ranging from one to five which was recorded on a score sheet.

2.3 Data analysis

2.3.1 Correlation analysis

Mean values of the mechanical variables derived from the compression tests and the sensory score were correlated to determine the best mechanical property that was related to the crispiness.

Discriminant analysis: the mechanical variables were used as classifying variables to develop the classification models. The variety of papaya was a class variable to be predicted. In each variety, each sample was assigned into a sub-calibration set and a sub-prediction set. The sub-calibration and the sub-prediction sets of each group of one variety were then pooled into the calibration set and the prediction set. The calibration set was used to build a classifying model by discriminant analysis (SPSS version 9.0, Chicago, IL, USA). Discriminant analysis is a multivariate technique used for creating linear functions of multiple variables that promotes the maximum difference between two or more classes and minimizes the variation within each class. The accuracy of the model for classification was evaluated using the samples in the prediction set.

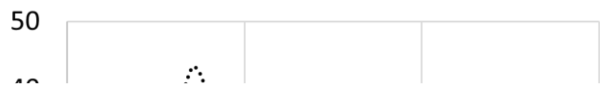
3 Results and discussion

3.1 Mechanical yests

3.1.1 Shear cutting method

A typical change in force against deformation with respect to variety is shown in Figure 3.

The variety KK required the minimum force (y_3 in Table 2) for cutting which agreed with a report by



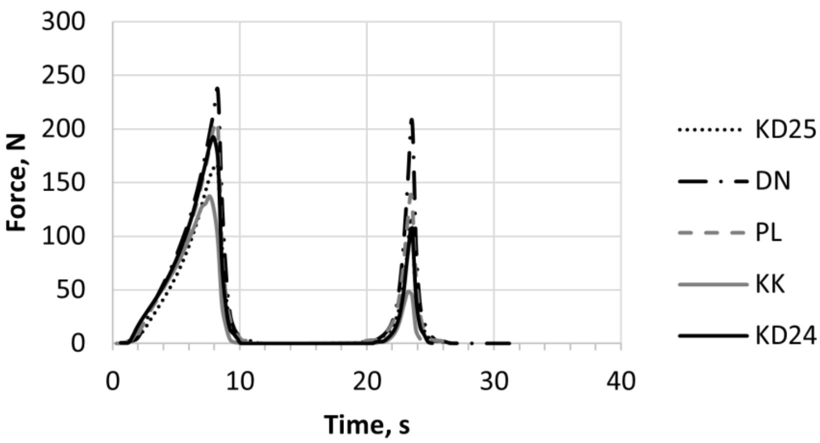


Figure 4 Change in average force against time with variety of papaya flesh

Chareekhot et al. (2014). This result implied that the variety KK was the crispest variety. On the other hand, KD25 required the largest force in cutting which indicated it was the least crisp.

3.1.2 Texture profile analysis

All five varieties gave similar profiles of the change in force over time. The TPA simulated the way people chew food twice using their jaws. The two peaks were clearly separated and a negative force was not apparent. Again, the variety KK presented the lowest force in both peaks which was in agreement with the shear cutting result.

Figure 4 shows a typical change in force against deformation with respect to a variety for the TPA. Average values of 11 mechanical properties derived from Figure 4 (Bourne, 2002) of each variety are presented in Table 2.

The results suggested that the variety KK contained larger cells with thinner walls compared with the other varieties. Therefore, the cells of the variety KK were ruptured more easily with fast flow out of the internal liquid leading to a louder noise or greater crispiness (Saeleaw and Shleining, 2011).

Table 2. Mechanical properties of papaya from different varieties

Variety	x_1[1]	x_2	x_3	x_4	x_5	x_6
KK	11.40±3.79[2]	5.71±4.78	0.06±	2.77±0.80	0.42±0.09	0.85±0.75
DN	18.00±3.19	8.95±6.27	0.07±0.04	3.36±0.67	0.49±0.10	1.26±0.96
PL	18.77±2.19	10.36±6.12	0.08±0.05	3.69±1.46	0.52±0.18	1.57±1.01
KD25	18.42±2.90	11.16±5.05	0.08±0.04	3.59±0.95	0.51±0.12	1.54±0.80
KD24	19.59±1.89	11.0±5.54	0.09±0.04	3.34±0.66	0.47±0.08	1.72±0.96

Variety	x_7	x_8	x_9	x_{10}	x_{11}
KK	3.19±2.70	9.57±4.96	0.14±0.11	0.15±0.14	2.83±0.61
DN	4.63±3.96	14.06±7.90	0.11±0.10	0.12±0.13	4.58±0.86
PL	6.71±5.27	15.09±8.01	0.25±0.43	0.39±0.64	4.85±0.73
KD25	6.10±3.57	13.00±8.44	0.20±0.20	0.18±0.17	4.93±0.84
KD24	6.20±4.15	12.30±10.02	0.12±0.09	0.19±0.33	4.94±0.60

Variety	y_1	y_2	y_3	y_4	y_5	y_6
KK	3.43±1.87	0.055±0.008	22.57±2.63	2.49±0.18	0.013±0.002	34460.07 ±5469.47
DN	0.84±0.49	0.055±0.007	34.06±6.03	1.30±0.11	0.017±0.005	43454.51 ±6600.79
PL	1.37±1.05	0.057±0.007	31.64±3.34	1.35±0.10	0.016±0.002	39127.64 ±3828.03
KD25	1.98±0.79	0.069±0.005	35.20±3.66	1.46±0.06	0.020±0.002	39970.98 ±5198.29
KD24	0.82±0.57	0.059±0.006	35.18±4.57	2.16±0.08	0.018±0.003	43297.58 ±4594.29

Note: [1] x = variables derived from TPA and y = variables extracted from shear cutting method., x_1 = Hardness1 (kgf), x_2 = Hardness2 (kgf), x_3 = Cohesiveness, x_4 = Springiness (mm), x_5 = Springiness Index, x_6 = Gumminess (kgf), x_7 = Chewiness (kgf.mm), x_8 = Fracture Force (kgf), x_9 = Adhesive Force (kgf), x_{10} = Adhesiveness (kgf.mm), x_{11} = Stiffness (kgf/mm), y_1 = Load at Limit (N), y_2 = Work to Limit (J), y_3 = Maximum Load (N), y_4 = Deflection at Maximum Load (mm), y_5 = Work to Maximum Load (J), y_6 = Stiffness (N/m).
[2] Average±Standard deviation
The variety KK has the biggest cell size and thin cell wall compared to other varieties (Chareekhot et al., 2004) which implied that its crispiness was likely to be greater.

3.2 Sensory test

The panel gave the highest score to the variety KK which meant that KK was considered the crispiest variety and thus the most preferred for salad making. KD25 was given the lowest score by the panel which meant it was the least crispy variety and therefore was suitable for fresh consumption in the ripe stage. The results were in agreement with the findings by Chareekhot et al. (2014).

3.3 Correlation between mechanical properties and sensory score

The scores for each level were weighted according to the level of the crispiness and were then combined and averaged to derive the crispiness index for each variety (Table 3). The KK variety had the highest crispiness index (52.4) and KD25 produced the lowest crispiness index (31.4) which corresponded with the previous results of the mechanical properties.

Table 3 Crispiness index derived from the sensory score

Variety	Level of crispiness (5 is crispest and 1 is the least crisp)					Crispiness index
	5	4	3	2	1	
KK	29	19	7	5	10	52.4
DN	15	18	14	16	7	45.6
PL	9	14	21	19	7	41.8
KD25	9	5	10	16	30	31.4
KD24	8	14	18	14	16	38.8

Eleven variables were derived from the force and deformation curves of the shearing cutting method. A further six variables were calculated from the force-time profile in the TPA. In total, 17 mechanical variables and the crispiness index were submitted for correlation analysis to determine the relationship among them.

The results of the correlation analysis are displayed in Table 4.

The variable of work to limit (y_5 in Table 4), which was the energy absorbed with the maximum force by a sample, was the most correlated with the crispiness index (r = 0.91). The work to limit was negatively proportional to the crispiness index. This meant the KK variety absorbed the least energy to reach the maximum force in cutting.

Table 4 Correlation analysis showing the correlation coefficient of each mechanical variable against the crispiness index

Correlation coefficient								
x_1[1]	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
-0.78	-0.91	-0.81	-0.77	-0.69	-0.82	-0.81	-0.34	-0.37
x_{10}	x_{11}	y_1	y_2	y_3	y_4	y_5	y_6	
-0.77	-0.82	0.44	-0.82	-0.80	0.51	-0.91	-0.02	

Note: [1] x = variables derived from TPA and y = variables extracted from shear cutting method., x_1 = Hardness1 (kgf), x_2 = Hardness2 (kgf), x_3 = Cohesiveness, x_4 = Springiness (mm), x_5 = Springiness Index, x_6 = Gumminess (kgf), x_7 = Chewiness (kgf.mm), x_8 = Fracture Force (kgf), x_9 = Adhesive Force (kgf), x_{10} = Adhesiveness (kgf.mm), x_{11} = Stiffness (kgf/mm), y_1 = Load at Limit (N), y_2 = Work to Limit (J), y_3 = Maximum Load (N), y_4 = Deflection at Maximum Load (mm), y_5 = Work to Maximum Load (J), y_6 = Stiffness (N/m).

3.4 Classification model

Three models were built based on: 1) TPA variables, 2) shear cutting variables and 3) a combination of TPA and shear cutting variables, using discriminant analysis. Table 5 shows the performance of the classifying models from the discriminant analysis. The best overall accuracy for the classification of papaya into five varieties was 82.4% using the shear cutting model. KD25 was the variety that was most accurately classified (100%). The accuracy of classification corresponded with the correlation analysis that showed the work-to-limit variable derived from shear cutting.

Table 5 Classification results of discriminant analysis

Variables in the model	Correctly classified papaya, %					
	KD25	DN	PL	KK	KD24	Overall accuracy
TPA variables	28.6	42.9	33.3	100	28.6	47.1
Shear cutting variables	100	85.7	50	85.7	85.7	82.4
Combination of TPA and shear cutting variables	100	71.4	33.3	85.7	100	79.4

The shear cutting model was described by the following five equations which were used for classification.

$$KD25 = -329.1 - 22.7\times y_1 + 3814.5\times y_2 + 6.5\times y_3 + 260.4\times y_4 - 8234.5\times y_5 \quad (1)$$

$$DN = -293.1 - 21.0\times y_1 + 3195.7\times y_2 + 7.0\times y_3 + 242.2\times y_4 - 9914.1\times y_5 \quad (2)$$

$$PL = -287.0 - 21.4\times y_1 + 3392.3\times y_2 + 6.6\times y_3 + 242.7\times y_4 - 9298.9\times y_5 \quad (3)$$

$$KK = -552.3 - 31.0\times y_1 + 4036.0\times y_2 + 6.8\times y_3 + 375.6\times y_4 - 9061.0\times y_5 \quad (4)$$

$$KD25 = -578.2 - 32.3\times y_1 + 4346.3\times y_2 + 8.7\times y_3 + 371.0\times y_4 - 11524.3\times y_5 \quad (5)$$

where y_1 = Load at Limit (N), y_2 = Work to Limit (J), y_3 = Maximum Load (N), y_4 = Deflection at Maximum Load (mm), y_5 = Work to Maximum Load (J).

In the classification of new samples of papaya, the flesh was prepared and measured to determine the shear cutting variables. Then, the five derived variables were used in each equation and the response was computed. The maximum value of response indicated the variety of the new sample. The variety of papaya was represented by the crispiness. For example, if the new sample had the highest value of the KK variety, it meant the new sample had the highest crispiness of flesh or a similar crispiness to the KK variety.

4 Conclusions

Evaluation of the crispiness in papaya was possible based on the mechanical properties. Work to maximum force was measured using the shear cutting method, which showed the best correlation with the sensory index of crispiness. The classifying model created using the mechanical properties measured by the shear cutting method provided an accuracy of 82.4% in sorting papaya into the five different varieties which represented five levels of crispiness.

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