Computerized recognition of pineapple grades using physicochemical properties and flicking sounds

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Abstract: Fruit is one of the essential sources of human nutrition. Consumers around the world need to be able to purchase fruit of reliable flavor and nutritional quality. Physical appearance and physicochemical properties play a key role in determining desirable quality and flavor. However, for some fruits such as watermelon, durian, pineapple, it is very hard to determine quality and flavor by external appearance. Therefore, a practical method to predict physical and physicochemical properties of fruit needs to be developed. In this study, a computerized technique is investigated to determine pineapple grades and their physical and physicochemical properties, including ripeness, total soluble solids, pH value and water content. The results reveal that by grading using pulp characteristics it is possible to classify pineapples into three distinct groups, which are significantly different in TSS, pH value and water content. In addition, predicting pineapple grades using flicking sounds and signal processing demonstrates that pineapples classified as grade 1 and grade 3 are significantly different in TSS, pH value and water content. This suggests that the estimation of the texture of pineapple pulp and its physicochemical properties can be performed prior to cutting. Therefore, it is feasible to develop an automated grading technique that can be used to determine pineapple quality as accurately as destructive grading to predict pineapple grades, texture and physicochemical properties.

Keywords: *Ananas comosus* L., total soluble solid, pH, physiochemical properties, flicking sounds, computerized pineapple grading, non-destructive grading

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1 Introduction

Pineapple (*Ananas comosus* L.) is one of the most economically significant fruits in the world. Recently, total pineapple production worldwide reached approximately 17.2-18.0 million tons[1]. Smooth Cayenne pineapple is the most widely grown cultivar in a lot of countries including Thailand[2,3].

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Pineapple maturity is estimated on the extent of eye flatness and shell yellowing[4]. For pineapples, sweetness is determined as a total soluble solid (TSS) and the requirement for Smooth Cayenne is at least 12.0 °Brix[5]. During the pineapple ripening process intercellular spaces within the pulp fill with liquid resulting in the water-soaked phenomena. An increase of sucrose levels, which is associated with ripeness, makes the pineapple sweeter. However, enhancing sucrose above levels normally found in fruit results in decay and the pineapple becomes more sensitive to damage[6]. Ripeness in pineapples is related to an increase in fruit weight[7] and it is also associated with fruit maturity. An appearance of basal fruitlets shows the ripe pulp first. This tissue often contains higher sugar content than the tissue at the middle and the top sections of the fruit[2,8].

Pineapple maturity occurs when the intercellular free air spaces inside the pineapples are filled with liquid. This is possibly due to the increased membrane permeability of fruit flesh cells or enhanced water movement in the apoplast caused by a sugar-induced solute potential gradient between the symplast and the apoplast[9]. The TSS is evaluated using refractometry. A pineapple which is soft, sweet, juicy and high in TSS is considered to be of good quality. The TSS has the highest correlation with taste-panel eating preference and is the most suitable year-round index. Conversely, juice pH value and acidity are suggested to be poorly correlated with eating quality[4]. High quality pineapples are suitable for eating fresh and producing naturally sweet premium products. Less-desirable lower-quality pineapples are used for cooking with curry, and making food products such as pineapple jam, sweet pineapple candy, canned pineapple and pineapple wine. Pineapples can be classified into five types[6]. However, these types are inconsistent with the way pineapples are traded in Thailand. High demand ripe pineapples are classified as grade 1 because they are ready to be eaten and served in a restaurant. Ripe pineapples just below the grade 1 standard are in lower demand and are classified as grade 2. Grade 3 pineapples have a long shelf-life and are used for cooking. They are harvested from unripe to almost ripe. Grade 3 pineapples; however, are generally least desired by buyers and not usually eaten fresh due to their sour taste, poor texture and color.

Based on the “green-shell ripe” standard, the shell color of pineapple is classified into seven color levels ranging from No. 0 as all green to No. 6 as all yellow[10,11]. In fact, the classification of the outer appearance such as the peel color does not reveal the pulp flavor. Green pineapples, which can be kept for longer periods, are sometimes sweeter and more flavorful than yellow ones. Fruit quality standards; however, vary with consumer tastes and ethnicity, and may be related to the price paid, making it difficult to apply a standard scale[2]. Typically, growers estimate pineapple ripening subjectively and the pineapple grading process is done in accordance with an agreement between growers, sellers and buyers, which mostly depends on fruit eye flatness, shell yellowing, and striking and flicking sounds. Normally, pineapples in fresh markets are classified into three grades by vendors. This often results in a disappointment to consumers because traders grade inconsistently use this technique. Internal qualities, *i.e.*, sweetness, texture, marbling disease, and pink disease, however, are required to be determined by a specialist.

An innovative pineapple classification method, which is consistent and economically viable, is required to improve mass production quality. Techniques developed to grade pineapples without destroying, peeling or cutting fruit have been reported, *i.e.*, the Active Shape Model[12], RGB[10] and the electronic nose[13]. Interestingly, another innovative procedure involves classifying flicking sounds using an automatic detector. The Hidden Markov Model (HMM)[14] is a popular method employed in speech recognition to model signal phenomena[15] and has also been applied efficiently to flicking and striking signal recognition. It has been reported that it is possible to determine fruit quality using fruit flicking and striking sounds, *i.e.*, guava[16], watermelon[17] and durian[18]. However, very limited research has focused on applying signal processing and speech recognition techniques to pineapple grading. In addition, there has been no investigation into the application of signal processing on specific aspects such as pulp texture, colors and physicochemical properties.

Flicking is a short sudden movement of the index or middle finger off the thumb against an object. The flicking of fruits such as watermelon and guava generates variable sounds, which can be used to accurately predict their qualities[16-18]. It would be useful to know the physicochemical properties of fruit in advance without destroying, peeling or cutting. The ripeness of pineapples can probably be determined by flicking, as illustrated in Figure 1.

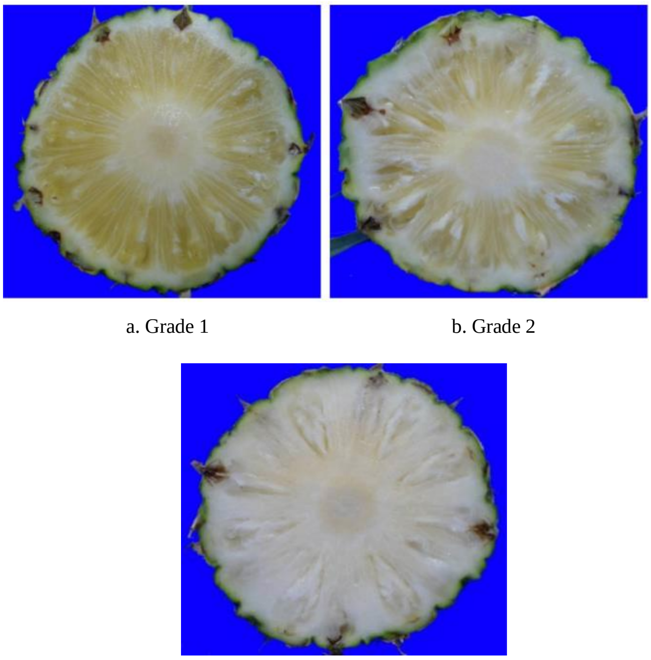
This research aims to evaluate pineapple fruit quality by analyzing criteria relating to flicking sounds. It is hypothesized that some of the physicochemical properties, *i.e.*, TSS, pH value and water content (%, w/w), are specific to grading quality and related to flicking sounds. It is hoped that the method described in this paper will be further developed and applied to automated pineapple selection in the near future.

Figure 1 Flicking a pineapple

2 Materials and methods

2.1 Plant material

Based on the Thai agricultural standards for pineapples (TAS4-2003), Pineapples cv. Smooth Cayenne in Thai markets are classified in three grades. Ninety pineapples consisting of 30 of each grade, determined by vendors using flicking sounds, are randomly collected from several stalls at Si Mum Muang market, one of the biggest fruit markets in Thailand. The quality levels of the pineapples collected from the market are grade 1: highly ripe, soft, very sweet and juicy; grade 2: ripe, rather firm to soft, sweet and juicy; and grade 3: unripe to almost ripe, firm to slightly soft and sour to rather sweet (Figure 2).



a. Grade 1 b. Grade 2

c. Grade 3

Figure 2 Pineapple fruit graded by vendors

2.2 Methods

2.2.1 Determination of pineapple qualities graded by vendors

The quality of whole pineapples is variable and the basal part of the fruit usually shows the most ripeness and is the sweetest. Therefore, to evaluate the physicochemical properties of the whole fruit, 90 pineapples graded by vendors using flicking sounds are cut into three sections: basal, medium and top. Then, based on the grades, the pineapples are weighed and evaluated for physicochemical properties (TSS, pH and water content).

2.2.2 Ripeness determination from cross-sectioned fruit

The cross-section of the basal part is evaluated for percentage of ripe pulp area[19]. The pineapples graded by vendors (the same samples as above) are regrouped according to the percentage of ripe pulp. The percentage of ripe pulp for regrouping depends on the average pineapple quality data in the studied-market, ranging from 0% to 60% for grade 3, 61% to 70% for grade 2 and 71% to 100% for grade 1. The three sections, basal, medium and top are weighed before the juice is extracted and then, TSS, pH value and the water content (%, w/w) are measured and the averages are computed.

2.2.3 TSS

A sample is dropped on a sample well, then a digital refractometer measures the TSS in the pineapple juice. The TSS percentages are derived from direct instrument readings and for each pineapple, average TSS percentages are computed using three times the measurement.

2.2.4 pH value

The pH value of the pineapple juice is recorded at room temperature using a pH meter. After standardization with pH 4 and pH 7 buffers, an average pH value derived from three times the measurement is collected.

2.2.5 Water content

To calculate the water percentage, the pineapple juice is removed with a juice extractor and compared to the total weight of the fresh pineapple tissues.

2.2.6 Flicking recognition

During the flicking sound collection process each pineapple is flicked by a human. The flicking force exerted on a pineapple may not be consistent. Flicking sounds can be compared to sounds spoken by humans. Even though speakers utter words of different volume and duration listeners can still understand their meaning. Similarly, in flicking signal recognition, we attempt to distinguish the meaning of the signals. Therefore, this method does not directly evaluate pineapple grades using signal amplitude or a single frequency feature.

Pineapple flicking sounds usually consist of flicking and non-flicking parts, as shown in Figure 3. The flicking part is short; sometimes it is less than 12 milliseconds. The flicking part may contain valuable information related to physicochemical properties and while the non-flicking part is longer, it contains less or no physicochemical information.

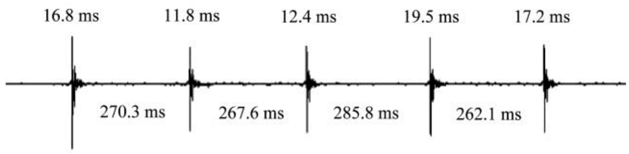


Figure 3 Five flicking signals (The “ms” means millisecond)

To analyze flicking sounds using a computer program, recorded flicking sounds are needed to create HMM acoustic models for grade 1-3 pineapple flicking signals. To recognize the flicking signals, the flicking sound recognition method is applied[16]. However, rather than classifying fruit into two groups, in this study, the pineapples are classified into three groups. To determine the pineapple grades a 3-stage process is employed: 1) to preprocess the signals using non-flicking reduction, 2) to extract acoustic features from the flicking signals and 3) to recognize the acoustic features, as shown in Figure 4.

Prior to the recognition, acoustic models for each pineapple grade and data for pineapple grade recognition consisting of the sequences of acoustic models for each pineapple grade and the defined possible grading recognition results are prepared. At the first stage of the process, long non-flicking parts are reduced. At the second stage, acoustic features, which are Mel Frequency Cepstral Coefficients (MFCCs) and their delta and accelerator coefficients are extracted from the pineapple flicking signals. At the final stage, the pineapple grades are determined using the created acoustic models, and the data prepared for grade recognition. However, when flicking a pineapple several times, such as three times, the first two flicks may be recognized as grade 1 and the last flick may be differently recognized as grade 2. Consequently, the final recognition result can be determined from the majority grade in the recognition results.

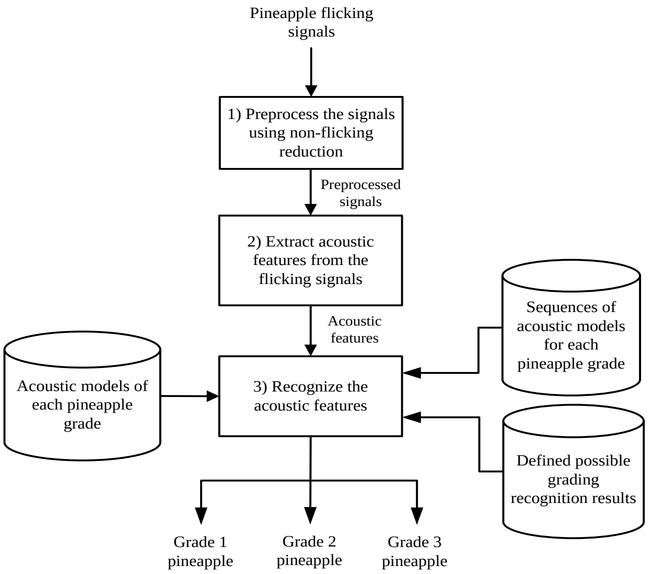


Figure 4 Pineapple grading using flicking sound recognition

Flicking sounds are recorded using the 16-bit PCM format at 11 025 Hz. A 5-millisecond frame size with a 2-millisecond frame shift interval is used in the acoustic feature extraction. Flicking sounds to train HMM acoustic models are collected from 90 pineapples consisting of 30, 30 and 30 pineapples of grades 1, 2 and 3, respectively. Each pineapple in the training set is flicked five times. There are two sets for testing: dependent and independent. The signals for the dependent set are recorded from the 90 pineapples used in training by striking them at different times. The independent test set is recorded from 47 pineapples that are not included in the training set (the physicochemical properties are measured). The test set consists of 14, 17 and 16 pineapples of grades 1, 2 and 3, respectively. Each pineapple in the test set is also flicked five times. The program used to preprocess the signals by reducing the non-flicking part is written using the computer language C and the Hidden Markov Toolkit (HTK) is used to create the HMM acoustic models and recognize the pineapple grades. The acoustic models of the initial and final parts of the flicking sounds including the non-flicking parts are created. Each acoustic model is composed of three emitting states and each state contains two Gaussian mixtures. After the pineapples are classified, they are statistically analyzed to compare ripeness percentage and physiochemical properties among grades.

2.2.7 Statistical analysis

The total soluble solid (°Brix), pH value and water content (%, w/w) of each pineapple grade is statistically analyzed with three replicates for each treatment. One way ANOVA is performed and equal variances are tested using Levene's method. Where significant differences are found due to treatment, Tukey's B multiple range test is conducted. Correlation between the slope of the line graph from 0 to 5 000 Hz with an interval of 500 Hz and the physicochemical properties (TSS, pH and water content) are estimated and the significance is tested. Differences are considered significant at $P \leq 0.05$. PASW, Statistics 18 is used in the analysis. All data are expressed as mean ± standard error.

3 Results and discussion

3.1 Spectral view obtained from flicking three grades of pineapples

Pineapples sold at fruit markets in Thailand are often roughly classified into three grades. Figure 5 shows a spectral view obtained by flicking grade 1-3 pineapples. The flicking sounds from grade 1 pineapples usually have low magnitude while grade 2 pineapples have higher magnitude and grade 3 pineapples often generate the highest magnitude.

Pineapples are a composite of many flowers whose individual fruitlets fuse together around a central core. An "eye", the rough spiny marking on the pineapple's surface, identifies each fruitlet. Often, the pineapple flesh is not homogeneous. Consequently, there are flicking sound variations and when a pineapple is flicked several times the frequency spectra of each flick sound varies as shown in Figure 6.

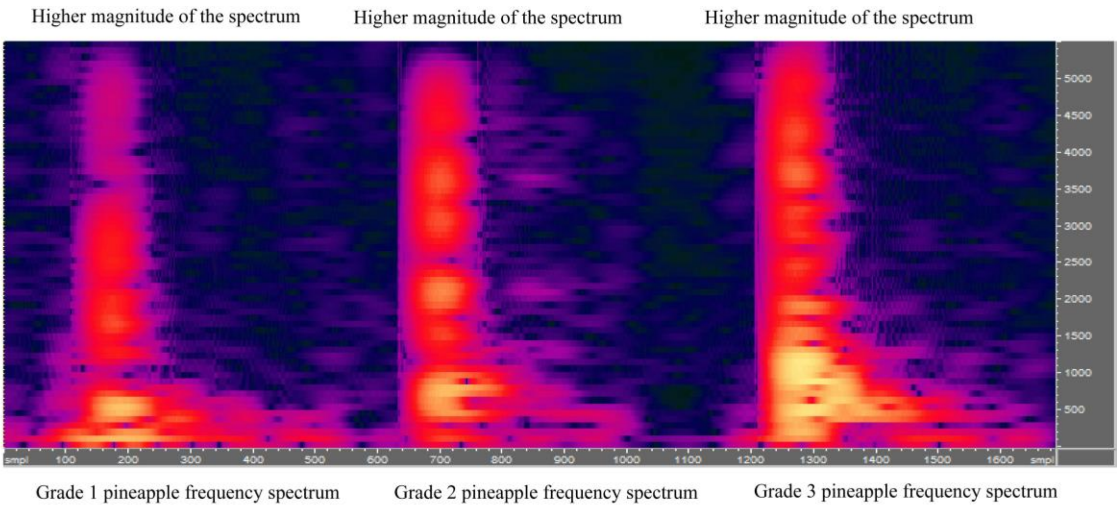


Figure 5 Spectral view obtained by flicking grade 1-3 pineapples

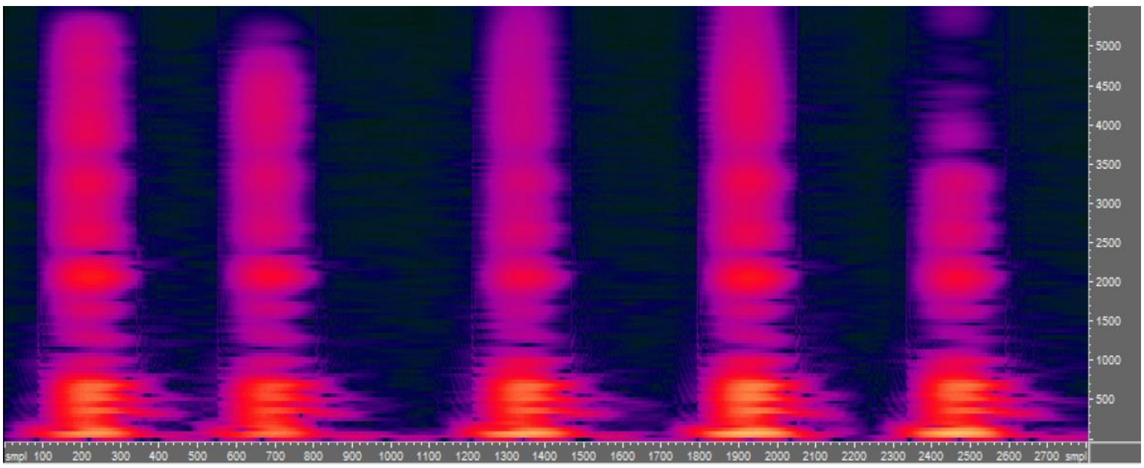
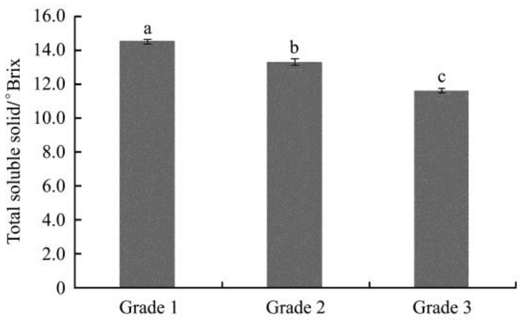


Figure 6 Spectral view obtained from flicking a pineapple

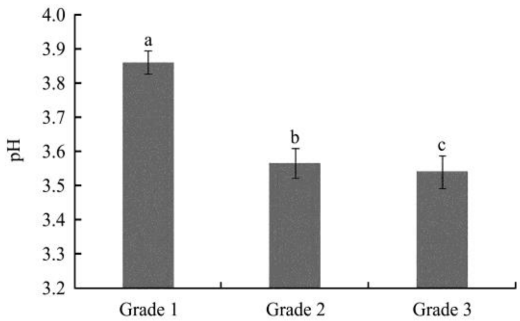
3.2 Grading by ripeness percentage from the cross-section

Ninety pineapples of three grades evaluated by vendors were randomly collected from the market. They were cut to evaluate the ripeness. Then, they were graded into three groups according to the percentage of ripe pulp that was soft, juicy and yellow in color.

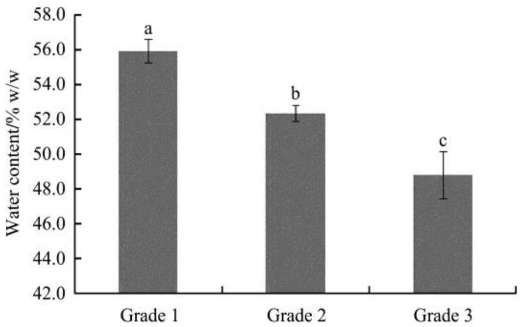
Based on grading by ripeness percentage, the TSS, pH value and water content of each grade were evaluated. The results showed a significant physicochemical difference among grades, grade 1 had the highest percentages while grade 3 had the lowest percentages in all categories (Figure 7).



a. Total soluble solid



b. pH



c. Water content

Figure 7 Physicochemical properties of pineapple graded by percentage of ripe pulp. Error bars indicate standard error; $n = 30$, the letters above bars indicate significant differences ($P \leq 0.05$)

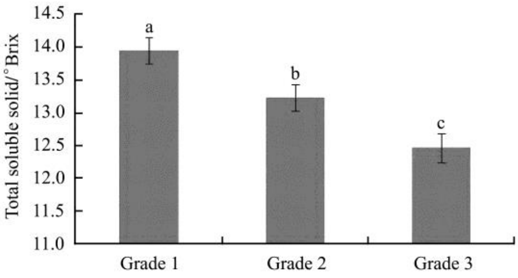
The results show that there are relationships between ripeness, TSS, pH and water content. Higher percentage of ripe pulp is related to higher TSS, pH value and water content. Grading by percentage ripeness of pulp, that is soft, juicy and yellow in color, results in the division of the pineapples into three distinct groups. Each group contained significant differences in TSS, pH value and water content. This may demonstrate that pineapple grading should be concerned with percentage of ripe pulp.

Percentage of ripeness determined from cross-sectioned fruit results in more accurate classification than grading done by vendors. Although ripeness percentage plays an important role and is a good indicator for pineapples, the fruit needs to be cut. Besides, grading by vendors is subjective and depends on skills, which take time to acquire. For the results of regrouping using percentage ripe pulp, the pineapple grades showed no consistency with grading done by vendors at the market. Even experienced vendors inaccurately grade pineapples as grade 2 when they are actually grade 1 and grade 3 according to percent of ripe pulp with an error of 40.0% and 20.0%, respectively. This may be because the physical and physicochemical properties of grade 2 pineapples are ambiguous when compared to grade 1 and grade 3 pineapples, making it difficult to distinguish grade 2 pineapples from the other two grades.

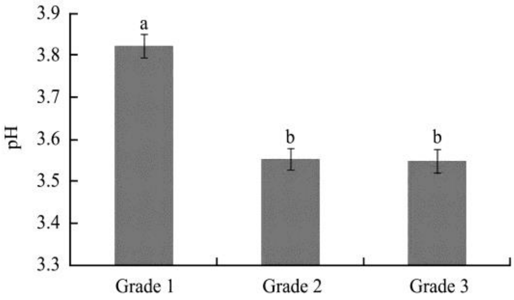
Prediction of fruit physicochemical properties without destruction is practical for the pineapple grading process. Flicking sounds may be applied to determine the physicochemical properties in advance. Therefore, the relationship between physicochemical properties and flicking sounds should be analyzed to develop an automated grading technique.

3.3 Grading by vendors

The three grades of pineapple classified by vendors showed no significant difference in their weight (288-315 g). Interestingly, the results reveal that grade 1 contained the highest TSS while grade 3 had the lowest TSS (Figure 8a). Grade 1 also had the highest pH value, nevertheless, grade 2 and grade 3 contained similar values (Figure 8b). Water content showed a slight difference among the three grades, which were 54.5%, 52.6% and 53.1%, respectively. Ripening pineapple fruit shows high TSS, pH value and water content[4]. Each grade could have had different physicochemical properties; however, the only apparent difference was in TSS. This may be because the human grading technique is subjective and dependent on the graders' senses.



a. Total soluble solid



b. pH

Figure 8 Physicochemical properties of pineapple graded by vendors. Error bars indicate standard error; n = 19, the letters above bars indicate significant differences ($P \leq 0.05$)

3.4 Relationship between physicochemical properties and flicking sounds

From the preliminary investigation, the magnitude of the frequencies extracted ranged from 0-5 000 Hz with an interval of 500 Hz. Although no single frequency features or information could be precisely used to classify pineapples into three grades, as done by the vendors, the results show a relationship between pineapple ripeness and flicking sounds. The ripe pulp percentage was significantly related to frequencies at 0, 500, 4 000, 4 500, 5 000 Hz and the slope of the line graph between 500 and 1 000 Hz, 2 000 and 2 500 Hz, and 3 500 and 4 000 Hz. For example, based on the one-way ANOVA analysis in Figure 9, the slope of the line graph between 2 000 and 2 500 Hz from grade 1 is significantly different from grade 3. However, since the slope cannot clearly distinguish grade 1 from grade 2 and grade 2 from grade 3, a single frequency feature including the slope of the line graph between two frequencies extracted from flicking sounds cannot be used to accurately classify pineapples into three grades.

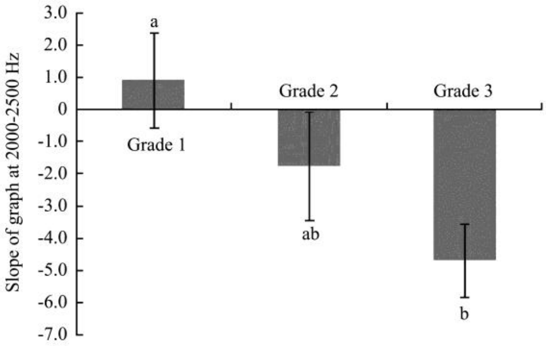


Figure 9 Pineapples graded by the slope of the line graph between 2 000 Hz and 2 500 Hz

The results show that applying a single feature with a threshold to classify pineapples into three groups is somewhat difficult and this may be the reason vendors often wrongly classify grade 2 pineapples. Hence, a combination of various frequency features together with efficient computerized flicking sound recognition are examined for pineapple grading, predicting the percentage of ripe pulp and physicochemical properties.

3.5 Grading by computerized flicking sound recognition

Pineapples were graded by computerized flicking sound recognition using the HMM and then compared with the actual ripe pulp grades, which were determined from cut pineapples. The results from the computerized pineapple grading from the dependent set are reported in Table 1.

Table 1 Computerized pineapple grading results from the dependent set

Actual grades classified by percent ripe pulp	Classified grades from flicking sounds		
	Grade 1	Grade 2	Grade 3
Grade 1	86.67%	6.67%	6.67%
Grade 2	10.00%	83.33%	6.67%
Grade 3	0.00%	10.00%	90.00%

Pineapple grading rates of 86.67%, 83.33% and 90.00% were obtained from 30, 30 and 30 grade 1, 2 and 3 pineapples in the dependent test set, respectively. For the grade 1 pineapples, 6.67% of the pineapples were classified as grade 2 pineapples and 6.67% of the pineapples were classified as grade 3 pineapples. For the grade 2 pineapples, 10.00% of the pineapples were classified as grade 1 pineapples and 6.67% of the pineapples were classified as grade 3 pineapples. For the grade 3 pineapples, 0.00% of the pineapples were classified as grade 1 pineapples and 10.00% were classified as grade 2 pineapples.

Table 2 Computerized pineapple grading results from the independent set

Actual grades classified by percent ripe pulp	Classified grades from flicking sounds		
	Grade 1	Grade 2	Grade 3
Grade 1	78.57%	21.43%	0.00%
Grade 2	23.53%	64.71%	11.76%
Grade 3	6.25%	31.25%	62.50%

Pineapple grading rates of 78.57%, 64.71% and 62.50% were obtained from thirty-nine grade 1, 2 and 3 pineapples in the independent test set, respectively (Table 2). For the grade 1 pineapples, 21.43% of the pineapples were classified as grade 2 pineapples and 0.00% of the pineapples were classified as grade 3 pineapples. For the grade 2 pineapples, 23.53% of the pineapples were classified as grade 1 pineapples and 11.76% of the pineapples were classified as grade 3 pineapples. For the grade 3 pineapples, only 6.25% of the pineapples were classified as grade 3 pineapples and 31.25% were classified as grade 2 pineapples. Tables 1 and 2 show that pineapples tend to be misclassified to adjacent grades. The misclassification rates indicate that the spectrum information from grade 1 is more similar to grade 2 than grade 3. Additionally, the spectrum information from grade 3 is more similar to grade 2 than grade 1.

The relationship between physicochemical properties, ripeness percentage and computerized flicking sound recognition results obtained from the independent set were statistically analyzed. In this experiment, if a grade 1 pineapple was recognized as a grade 2 pineapple, it was considered as grade 2. Similarly, if a grade 2 pineapple was recognized as a grade 3 pineapple, it was considered as grade 3. ANOVA was applied to evaluate the ability of the computerized grading method to determine the physicochemical properties. Thirty-nine grades 1-3 pineapples were used. The results indicate that TSS levels and pH value can be predicted using flicking sounds. The TSS levels found in grade 1 and 2 pineapples were significantly different from grade 3 pineapples. However, there was no significant difference found between grade 1 and 2 pineapples (Figure 10a). With regard to pH value, grade 1 pineapples had a higher pH value than grade 2 and 3 pineapples and there was no significant difference in pH value between grades 2 and 3 (Figure 10b). For water content, there was no difference in grade 1 to 3 pineapples. Water content for grades 1, 2 and 3 was found to be 54.6%, 54.2% and 52.0%, respectively. The percentage of ripe pulp measured from pineapples considered as grade 1 was not significantly different from those fruit considered as grade 2 but it was higher than those considered as grade 3. The percentage of ripe pulp measured from pineapples considered as grade 1 was significantly different from those fruit considered as grade 3, which had the lowest percentage of ripe pulp (Figure 10c).

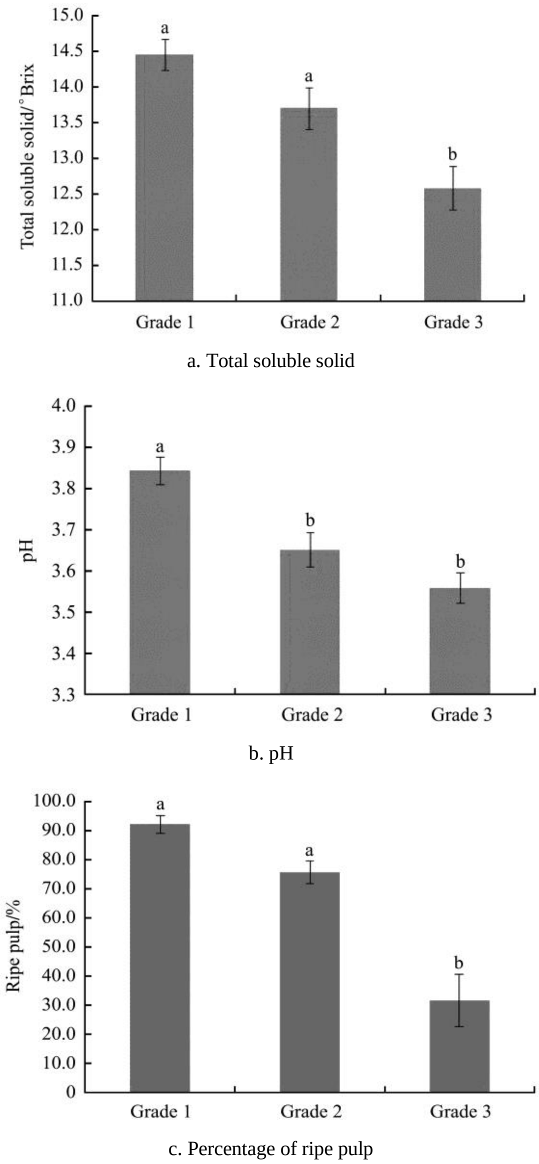


Figure 10 Physicochemical properties of pineapples graded using flicking sounds. Error bars indicate standard error; $n = 13$; the letters above bars indicate significant differences ($P \leq 0.05$)

The results suggest that grade 1 and 3 pineapples can be distinctly classified using flicking sounds and the physicochemical properties can be approximately determined in advance without damaging the pineapples.

4 Conclusions

Grading based on ripe pulp percentage can be applied to classify pineapples into three grades with significant differences in TSS, pH value and water content. Unfortunately, it requires the destruction of pineapples, which is neither practical at fruit markets nor useful for fruit buyers. Using the method of analyzing flicking sounds described in this study it is possible to classify pineapple grades and determine ripeness and physicochemical properties by computer. However, for more accurate grading, the computerized process needs improvement to match or better the specialists' grading ability. In addition, a machine that grades fruit such as pineapples will be advantageous to the fruit processing industry because it will reduce waste. Buyers who have a mobile device could download an application that records flicking sounds and processes them promptly to determine ripeness, physicochemical properties and pineapple grades. The use of a smart phone or portable computer to determine pineapple quality and taste will lead to more satisfied consumers because there is less chance of an inaccurately graded pineapple being purchased. This technology could also be applied to ascertaining the quality of other fruits prior to purchase.

[References]

[1] Food and Agriculture Organization of the United Nation (FAO). Pineapple. 2010; http://faostat.fao.org. Accessed on [2013-08-15].

[2] Paull R E, Chen C-C. Postharvest physiology, handling and storage of pineapple. In: The Pineapple: Botany, Production and Uses. Bartholomew D P, Paull R E, Rohrbach K G (Eds.), CABI, New York, 2003; 253－278.

[3] Pongjanta J, Nualbunruang A, Panchai L. Effect of location and storage time on physicochemical properties of pineapple fruit. Asian Journal Food and Agro-Industry, 2011; 4(3): 153－160.

[4] Smith L G. Indices of physiological maturity and eating quality in smooth cayenne pineapples 1: Indices of physiological maturity, Queensland. Journal of Agriculture Animal Science, 1988; 45: 213－218.

[5] Kader A A. Pineapple: recommendation for maintaining postharvest quality. Agriculture and natural resources, 2013. http://postharvest.ucdavis.edu/PFfruits/Pineapple/. Accessed on [2013-07-20].

[6] Haff R P, Slaughter D C, Sarig Y, Kader A. X-Ray assessment of translucency in pineapple. Journal of Food Processing and Preservation, 2006; 30: 527－533.

[7] Bowden R P. Further studies on ripeness in pineapple. Food Technology Australia, 1969; 21: 160－163.

[8] Chen C C. Effect of fruit temperature, calcium, crown and sugar metabolizing enzymes on the occurrence of pineapple fruit translucency, PhD dissertation. Hawaii: University of Hawaii, 1999.

[9] Chen C C, Paull R E. Sugar metabolism and pineapple flesh translucency. Journal of the American Society for Horticultural Science, 2000; 125(5): 558－562.

[10] Asnor J I, Rosnah S, Wan Z W H, Badrul H A B. Pineapple maturity recognition using RGB extraction. World Academy of Science, Engineering and Technology, 2013; 78: 147－150.

[11] Dole Fruit Hawii. How to select a fresh pineapple, 2013, www.dolefruithawaii.com/Articles.asp?ID=143. Accessed on [2013-07-12].

[12] Kaewapichai W, Kaewtrakulpong P, Prateepasen A, Khongkraphan K. Fitting a pineapple model for automatic maturity grading. Institute of Electrical and Electronics Engineers, 2007; I-257－260.

[13] Zhu L, Seburg R A, Tsai E, Puech S, Mifsud J. Flavor analysis in a pharmaceutical oral solution formulation using an electronic-nose. Journal of Pharmaceutical and Biomedical Analysis, 2004; 34: 453－461.

[14] Anonymous. The Hidden Markov Model Toolkit (HTK). 2013, http://htk.eng.cam.ac.uk/. Accessed on [2013-07-12].

[15] Tangwongsan S, Po-Aramsri P, Phoophuangpairoj R. Highly efficient and effective techniques for Thai syllable speech recognition. Lecture Notes in Computer Sciences, 2004; 3321: 259－270.

[16] Phoophuangpairoj R. Determining guava freshness by flicking signal recognition using HMM Acoustic Models. International Journal of Computer Theory and Engineering, 2013; 5(6): 877－884.

[17] Phoophuangpairoj R. Automated classification of watermelon quality using non-flicking reduction and HMM sequences derived from flicking sound characteristics. Journal of Information Science and Engineering, 2014; 30(4): 1015－1033.

[18] Phoophuangpairoj R. Computerized unripe and ripe durian striking sound recognition using syllable-based HMMs. Applied Mechanics and Materials, 2014; 446-447: 927－935.

[19] Joomwong A. Impact of cropping season in northern Thailand on the quality of smooth cayenne pineapple. II. Influence on physico-chemical attributes. International Journal of Agriculture and Biology, 2006; 8(6): 330－336.