X-RAY ASSESSMENT OF TRANSLUCENCY IN PINEAPPLE

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ABSTRACT

A nondestructive method for detection of translucency, a physiological disorder in pineapple, would be beneficial to the industry. Ninety-two pineapples were imaged with X-ray to determine whether translucency could be detected. After imaging, each pineapple was cut open to determine the true level of the disorder and rated on a scale from 1 (no translucency) to 5 (extremely translucent). The X-ray images were inspected by human subjects who evaluated them as either good or bad based on the appearance of translucent and nontranslucent pineapples in training images. The results show a high correlation ($R^2 = 0.96$) between the likelihood of a sample being rated as good and the actual level of translucency observed. Samples with no translucency were correctly identified 95% of the time, while those with extreme translucency were correctly identified 86% of the time. The results indicate that X-ray imaging is a useful method for selecting either pineapples that are most likely to be free of translucency or those that are most likely to be extremely translucent.

INTRODUCTION

Pineapple (*Ananas comosus* L.) is an important domestic crop for the State of Hawaii with production exceeding 200,000 tons in 2005 at a market value of 79.3 million dollars (NASS 2006). It is also a major international crop, with a

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2005 annual worldwide production of approximately 16 million tons (FAO 2006). Internal pineapple quality has an impact on both prices and consumer acceptance. United States Department of Agriculture (USDA) quality standards are based on the amount of defects present within 25 count samples, with the two categories of defects defined as decay and damage. Damage includes a number of defects including discoloration of the crown leaves, crown slips, mechanical injury, bruising, sunburn, cracks, insect damage and internal breakdown. Internal breakdown is defined as "a physical deterioration which results in a watersoaked or black or brownish discoloration" (USDA 1990). For U.S. Fancy, the standards require that no more than four pineapples out of any 25 count samples reveal any of these types of damage. The number of required samples depends on the number of containers in the lot. Damage is assessed by cutting open the pineapple and observing the internal condition of the fruit.

While not specifically mentioned, the water-soaked appearance of the flesh described as part of the definition of internal breakdown in the USDA quality standards is a symptom of a physiological disorder known as translucency. The water-soaked appearance is a consequence of the intercellular spaces within the pineapple filling with liquid (Sideris and Krauss 1933). Enhanced sucrose levels associated with translucency make the pineapple sweeter, and fruits that exhibit mild levels are favored by many customers over normal fruit. However, as the disorder progresses to more severe levels, the result is increased senescence eventually leading to decay, off flavors, and increased susceptibility to sunburn and mechanical damage (Chen and Paull 2000).

Research to nondestructively detect pineapple fruit quality has been very limited, and specifically to detect translucency even more so. Acoustics have been used to evaluate pineapple quality (Chyung 2000), but no specific mention of translucency was made. A device using light transmission has been developed (Takao and Ohmori 1996), and X-ray computer tomography (CT) has been shown to be effective (Sornsrivichai *et al.* 1998), but to date neither method has been extensively used by pineapple producers. While CT is used for some kinds of industrial testing (Kropus-Hughes and Neel 2006), it is not a practical method for agricultural testing because the equipment is expensive and not suited to rapid inspection. Traditional CT scanners used in medical imaging cost more than one million dollars. Smaller models that are not limited by patient dose constraints are being developed for nondestructive testing but are not yet commercially available. Near Infrared spectroscopy (NIR) has been used to determine soluble solids content of pineapples (Shiina *et al.* 1992; Tanabe *et al.* 1995; Guthrie and Walsh 1997; Walsh *et al.* 2000), but not to detect translucency. Presently, there are no methods being used in the pineapple processing plants to separate out and remove translucent fruit because of the lack of a nondestructive technique to identify them. Consequently, statistics on the actual cost to producers of translucent fruit are not available.

Pineapple producers are in need of a method to nondestructively detect translucency in pineapples, either to assist in their attempts to eliminate the disorder by breeding (NE-179 2000) or to develop an online sorting device that could remove the affected fruit from the product stream. X-ray imaging is a logical and well-established method to detect internal characteristics of many food products, including fruits. X-ray imaging has been used successfully to detect watercore damage in apples (Schatzki *et al.* 1996), a problem very similar in nature to translucency in pineapples. The pineapple's size and skin toughness present challenges for other potential methods such as NIR spectroscopy, light transmission and even acoustics. X-rays, however, are able to penetrate the pineapple and reveal the inner characteristics of the flesh, making it an ideal candidate for a potential method to detect translucency.

The objective of this work is to determine whether X-ray imaging is a suitable method for detecting translucency in pineapples. The method used here (film) would only be suitable for sampling purposes, as in a breeding program. However, it should also demonstrate the feasibility of using X-ray imaging as the basis of a real-time sorting device.

MATERIALS AND METHODS

Samples of "Gold" cultivar pineapples with suspected translucency were obtained from Dole Food Company (Westlake Village, CA) for analysis. In addition, pineapples of the same cultivar without translucency were used as a control group. Each pineapple was x-rayed from the side (30 keV X-ray energy and 3 min of exposure) in an X-ray film cabinet (Faxitron Corp., Buffalo Grove, IL). The pineapples were then cut open to determine the amount of translucency present. The pineapples were scored on a scale of 1 to 5, with 1 indicating no translucency, 2 indicating that less than 25% of the flesh was translucent, 3 between 25 and 50%, 4 between 50 and 75%, and 5 for greater than 75% translucency (Fig. 1). This translucency scale was developed for this study, because a formal definition of extent of translucency was not available in the literature. Out of the total, only 46 pineapples were determined to have some level of translucency. The test group of images therefore consisted of 46 translucent pineapples (levels 2–5) and a control group of an additional 46 good pineapples (level 1).

Ten subjects examined the test group and rated the pineapples in the images as either good or bad, indicating whether they could detect translucency. No attempt was made to evaluate the level of translucency. None of the subjects had previous training or experience evaluating X-ray images of pineapples for translucency. Before evaluating the test group, subjects studied a training group of X-ray images containing some nontranslucent and some

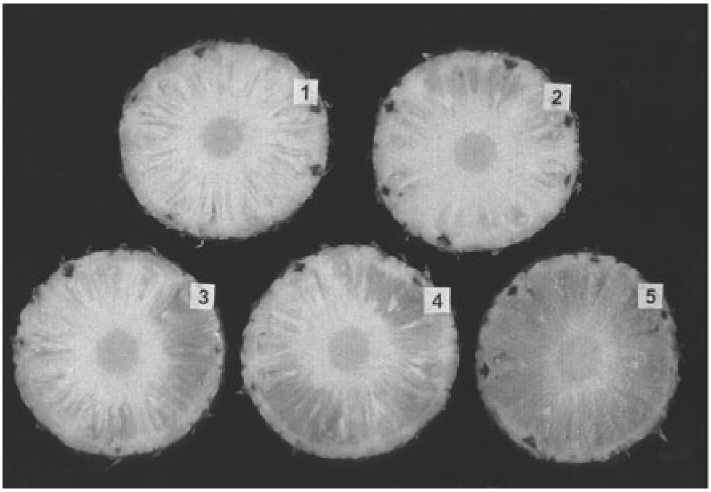

FIG. 1. PHOTOGRAPHS OF CUT PINEAPPLES SHOWING THE FIVE LEVELS OF TRANSLUCENCY DEFINED FOR THIS STUDY

extremely translucent pineapples. X-ray images in the test group were rated based on differences perceived in the training images.

Logistic regression analysis (SAS, General Models Procedure (Proc Genmod) with binary option) was used to determine if the results were significantly different between subjects. The results of all subjects were then averaged and analyzed with regression analysis (after a logit transformation) to determine if a correlation exists between the probability of being rated as good and the actual level of translucency. The logit transformation was required because the relationship of interest was between a binary variable (good or bad), which had been transformed into a percentage, and an approximately continuous variable (translucency levels 1 to 5). Because the percentage variable is bounded by 0 and 100, the distribution is binomial rather than normal and a linear regression is statistically unreliable. The logit transformation compensates for this.

RESULTS AND DISCUSSION

Table 1 shows the number of pineapples in the test group by stage of translucency as determined by cutting open each fruit. Figure 2 shows digitized versions of sample training X-rays. The pineapple in Fig. 2a was free of translucency (score = 1) and that in Fig. 2b was highly translucent (score = 5). The difference in the radiographs between the translucent and nontranslucent

TABLE 1.
DISTRIBUTION OF TRANSLUCENCY WITHIN THE TEST GROUP OF IMAGES

Score	Number of pineapples
1	46
2	9
3	14
4	13
5	10
Total	92

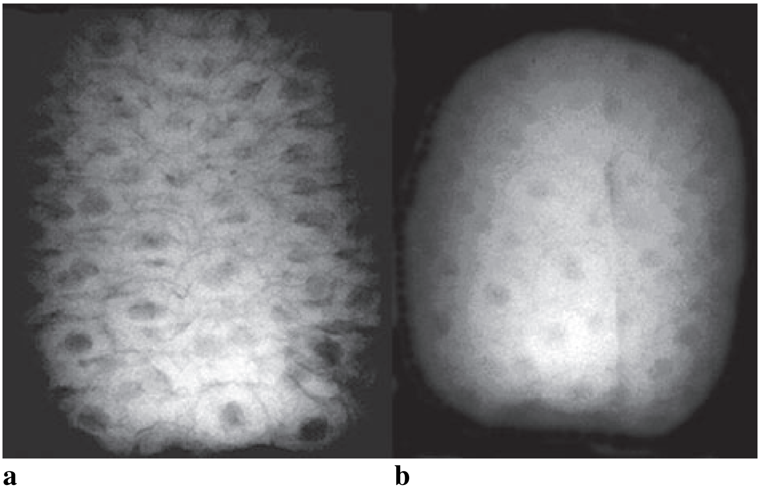

FIG. 2. TRAINING IMAGES OF PINEAPPLE (a) WITHOUT AND (b) WITH TRANSLUCENCY

fruit appears in the patterns of radial streaks visible in the former that do not appear in the later case. It can be speculated that this is a consequence of water flooding into the intercellular spaces.

The results of the human recognition tests are reported in Table 2, including logit transformation values for the average scores (fraction rated as "good" for each level on the translucency scale). Regression analysis of the transformed data showed a strong correlation between the fraction classified non-translucent and the actual amount of translucency present ($R^2 = 0.96$). Results of the logistic regression also indicated that the subjects were not significantly different from one another in their results.

TABLE 2.
AVERAGE SCORING RESULTS FOR 10 SUBJECTS

Score	Number of samples	Number rated as good	Fraction	Logit transform
1	46	43.6	0.948	2.9
2	9	6.3	0.7	0.847
3	14	6.6	0.61	0.447
4	13	2.7	0.207	−1.34
5	10	1.4	0.14	−1.815

As an approximation, if visual scores of 1 and 2 are grouped as good, and 3, 4 and 5 are grouped as bad, then the classification error rate from the data in Table 2 was 181 wrong out of 920, or 19.7%. The best pineapples (translucency score = 1) were correctly rated 95% of the time and the worst (translucency score = 5) were correctly rated 86% of the time. If the goal were to select appropriate pineapples for a breeding program, then the ability to detect the pineapples with no translucency would be the objective. Alternatively, for real-time sorting the goal is to remove the pineapples that show extreme translucency, because they will exhibit off flavors. This group of pineapple was correctly identified 86% of the time.

CONCLUSIONS

The results indicate that X-ray is a potential method for selecting both pineapples that are most likely to be free of translucency (95% accurate) as well as those most likely to suffer from extreme translucency (86% accurate). For intermediate levels of translucency the X-ray method was less accurate. For rapid inspection, radiographs are not a suitable medium, and some type of real-time digital imaging system would be needed. Possibilities include a linescan X-ray machine for a mass inspection system, or CCD-based detectors that can be used in traditional X-ray cabinets for slower image capture without the need for film. The linescan machine is well suited for real-time sorting devices, but costs up to $100,000 per unit. The CCD arrangement would be too slow for a sorting device, but may still be appropriate for breeding research at considerably less cost than a linescan machine.

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