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Comparison of different modes of visible and near-infrared spectroscopy for detecting internal insect infestation in jujubes

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ABSTRACT

This study compared the abilities of the interactance, reflectance, and transmission modes of visible and near-infrared (Vis/NIR) spectroscopy in detecting internal insect-infested jujubes. Statistical analysis was performed to identify the effective wavelengths that best discriminated the insect-infested jujubes from intact jujubes and to derive a discriminant function in classifying the jujubes showing internal insect infestation and those that were free of infestation. The highest correct classification rates obtained from the above modes were 100%, 90.0%, and 97.0%, respectively. The interactance mode in the long-wave NIR (LWNIR) range is preferable to the transmission mode in the visible and short-wave near-infrared (VSWNIR) ranges. Furthermore, the transmission mode in the VSWNIR range displayed an obvious advantage over the reflectance mode in every range. The results indicate that it is possible to use both the interactance and transmission modes to develop a system in detecting the internal qualities of jujubes.

1. Introduction

The jujube is one of the most popular fruits in China, which is one of the main producers of jujubes. Its popularity has increased since being introduced into Japan for a few decades. The *Ancylis sativa* Liu is a key pest that causes internal damage to jujubes; its larvae bore holes into the interior of the jujube, where they feed until maturity. Therefore, internal insect infestation is difficult to detect quickly or accurately by visible inspection. However, internal insect damage is the main concern in the evaluation of the internal quality of jujube fruits. The presence of a few infested fruits in a shipment may render the whole shipment unmarketable. Therefore, it is important to identify fruits with insect damage before shipping the fruits to market.

Most instrumental techniques used to measure internal properties are destructive and involve a considerable amount of manual work. Spectroscopy has previously been used as a reliable, rapid, and nondestructive method to detect the internal quality of fruits, such as brown heart in pears and apples (Clark et al., 2003; Fu et al., 2007a,b; Han et al., 2006; McGlone et al., 2005; Zerbini et al., 2002), internal disorders (Clark et al., 2004; Teerachaichayut et al., 2007), internal breakdown (Upchurch et al., 1997), and internal infestation (Tigabu et al., 2004; Xing and Guyer, 2008a,b; Xing et al., 2008). The captured radiation spectrum provides information about the physical structure as well as the chemical composition of the product (Nicolaï et al., 2006). Different spectral modes have been used to estimate internal fruit properties and to determine the best mode of studying the quality parameters, based on differences in the nature, type, and characteristics of the fruits (He et al., 2005). Reflectance-mode spectroscopy measures the light that is reflected or scattered from the surface and outer surface layers of a fruit and has gained much attention in fruit-quality research recently (Shao et al., 2007; Veraverbeke et al., 2005; Xing and Guyer, 2008a). The transmission mode can detect both the external and internal properties of a sample (Armstrong, 2006; Clark et al., 2003; Teerachaichayut et al., 2007). Transmission is preferable to reflectance measurement in detecting the internal qualities of some fruits (Fu et al., 2007a; Xing and Guyer, 2008a). However, interactance is a method suited to capture the internal information of fruits when transmission measurement is difficult to obtain (Herold et al., 2005; Kavdir et al., 2007). Some research has also indicated that interactance spectra provide the most accurate results of the three modes when measuring the soluble solid content (SSC) of kiwifruit (Schaare and Fraser, 2000).

If each jujube fruit lacked a hard stone, both reflectance and transmission spectral measurements would be effective at

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revealing the characteristics of the infested jujube tissue, which displays the symptoms of browning, dehydration, and air holes. Transmission spectroscopy cannot ensure that the whole spectrum of light passes through the jujube samples, especially for the long-wavelength near-infrared range (LWNIR). For this reason, the interactance mode is also used to identify the effective wavelengths for sorting infested jujubes from intact fruits.

The objectives of this study were: to (1) compare the abilities of the interactance, reflectance, and transmission modes to detect internal insect infestation in jujubes; (2) identify the effective wavelengths that have the maximum discriminatory capability; and (3) derive a discriminant function using these wavelengths that can identify internal insect infestation.

2. Materials and methods

2.1. Jujube samples

Two hundred and forty intact "Lizao" jujubes (*Hovenia acerba* Lindl.) and another 220 jujubes with internal insect infestation (Fig. 1) were used in this study. Both groups were hand-harvested from an orchard in Niigata, Japan, during the harvest period of 2008 and 2009. Every sample was labelled, and the morphological properties (including diameter, height, and transverse area) of each sample were measured and recorded before spectroscopic measurement (Table 1). All jujube samples were measured using interactance, reflectance, and transmission spectroscopy after 3 days of

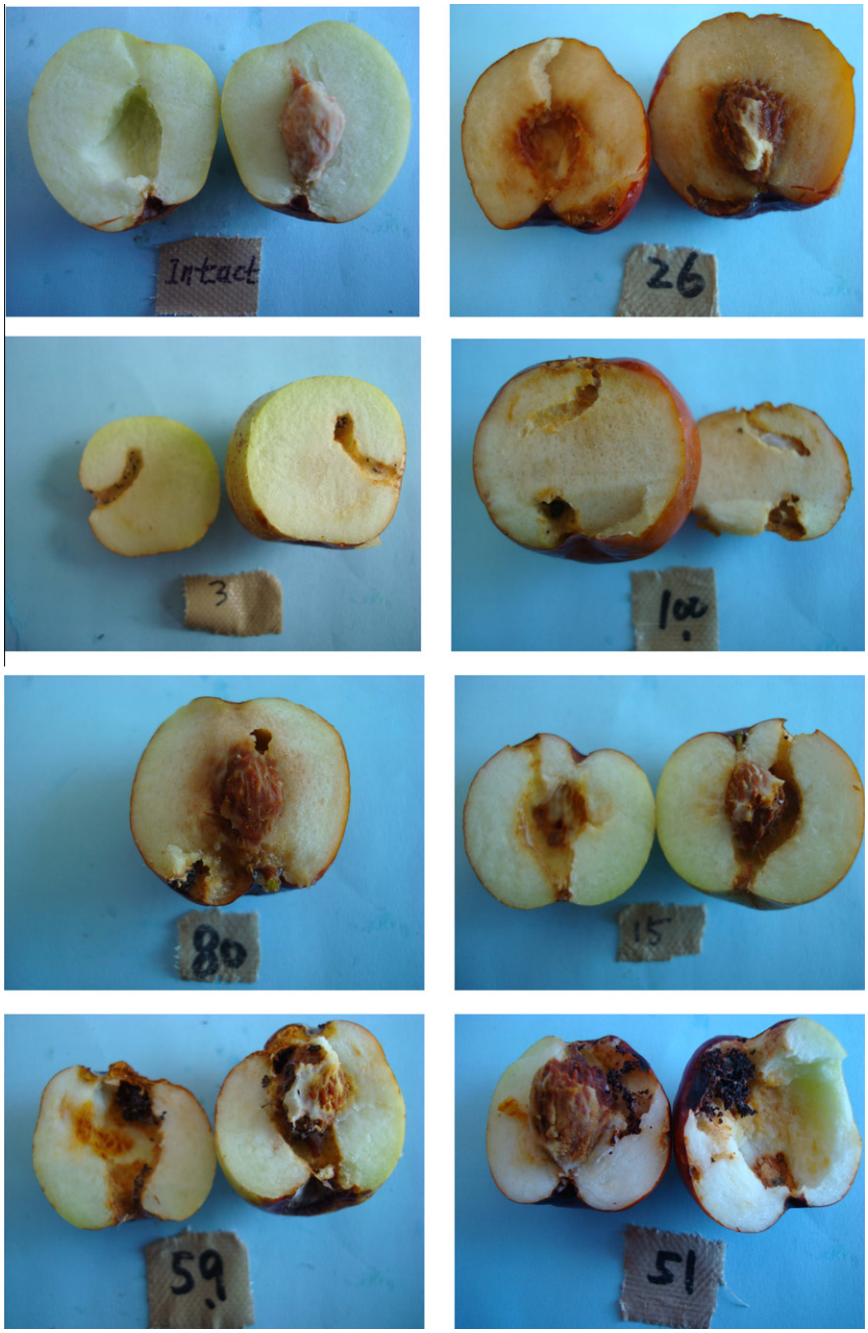

Fig. 1. Example images of jujubes with different internal conditions.