Postharvest Biology and Technology 133 (2017) 12–19

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Diffuse reflectance characteristic of potato surface for external defects discrimination

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ARTICLE INFO

Keywords:
Spectroscopy
Surface defects
Classification
Optical properties

ABSTRACT

To automate and improve the quality of postharvest potato grading, simultaneous discrimination of various external defects is important; surface optical characteristics may hold the key to this. In this research diffuse reflectance in the UV–vis-NIR region of various potato surface defects were measured in order to characterize the optical properties of undamaged skin and various surface defects or characteristics, i.e. mechanical damage, greening, common scab, and soil deposits on the skin. Genetic algorithm-PLS were used as a variable selection method to identify the most sensitive wavelength set to classify each defect category. The selected wavelengths consist of subsets in the visible and near-infrared range i.e. 577–580; 688–690; 696; 916–918; 1132; and 1651–1654 nm. The most accurate classification results were obtained using a Subspace Discriminant classification model with the accuracy of 99% for calibration and 97.6% for validation. The observed differences in diffuse reflectance spectra were then considered in terms of biophysical parameters. This information can now be used to develop a more advanced system for defect discrimination.

1. Introduction

Current potato production faces significant challenges as the cultivated area decreases and demand for potatoes increases. Improved quality control will play an important role in resolving these issues by maintaining yields and reducing losses (AHDB Potatoes, 2015; FAOSTAT, 2017). Postharvest grading and sorting play a particularly critical role by ensuring consumer quality expectations are met and excluding defected product which can compromise the product further downstream in the supply chain. Commonly, potato is graded based on size, shape, and defects of the tuber. Automated inspection based on some of these criteria are commonly performed with a machine vision integrated into the grading and handling system (Sun, 2016).

External defects are important quality parameters to grade and sort the potato tubers. They are defined as the diseases and defects occurring on the surface of the potato which can be detected externally (Dean, 1994). Various kinds of external defects determine the quality grade and the postharvest handling of the potatoes. Some external defects cause the potato tubers to be inedible and other defects are intolerable for seed tubers. Thus, identification of different kinds of external defects is important and precise identification could reduce losses occurring during the tuber sorting process. However, for some cases, it is difficult for a conventional machine vision system to recognize small defects and to distinguish between each type of defect due to the similar characteristics of these defects. The difficulty in recognizing the types of defects usually comes from the fact that the defects have the same color or optical characteristics in the visible region (Noordam et al., 2000) and common color cameras have a capability only in the visible region. Furthermore, defects with a low severity level are difficult to be recognized since the contrast between the lesion and normal skin is very low.

The possibility to extend the capability of these machine vision systems to optical characteristics beyond the visible wavelength range exists. Al-Mallahi et al. (2010) applied an ultraviolet imaging system to detect potato tubers and remove clods. On the other hand, machine vision in the infrared wavelength range has been used to detect potato external defects, such as common scab (Dacal-Nieto et al., 2011). Hyperspectral imaging in the visible-NIR region also has been reported to be able to recognize various external defects of potato tubers (Su et al., 2013, 2014). The literature suggests that optical properties from UV, Visible, and NIR region could be used for different detection purposes. However, previous approaches focused on general detection of external defects, without performing classification between the types of defects. Nevertheless, to the best of our knowledge, no recent research has focused on classification of potato external defect types. This is important to discriminate or classify the external defect types since the

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http://dx.doi.org/10.1016/j.postharvbio.2017.07.006
Received 21 April 2017; Received in revised form 3 July 2017; Accepted 6 July 2017
0925-5214/

postharvest handling for different kinds of defects or characteristics could be different.

The development of precise machine vision systems requires knowledge and understanding of the optical properties of the objects. Porteous et al. (1981) measured the diffuse reflectance of various kinds of external defects of potato in 11 cultivars. They successfully classified healthy tubers, tubers with common scab/skin spot, green tuber, and inedible tuber using optical spectral reflectance (590–2030 nm). However, they did not include measurements of mechanical damage and soil optical characteristics. Whereas, soil deposits on the potato surface could be falsely identified as defects by the sorting system.

In this research we addressed this issue for the Japanese Makuin (May Queen) cultivar, which is one of the best quality potato cultivars grown in Hokkaido, Japan. We investigated the optical properties over a broad wavelength range (UV–vis-NIR) for discrimination of common external characteristics specific to this potato cultivar, such as common scab, greening, mechanical damage, and soil deposits on the skin. The biophysical reasons behind the differences in each of the defects‘ optical characteristics were examined in terms of moisture content and sample thickness. Exploratory data analysis and variable selection were carried out to find out the most sensitive wavelength set to build classification models of external defects and characteristics.

2. Materials and methods

2.1. Potato samples

Potato (*Solanum tuberosum* cv. May Queen) was chosen for the experiment since this cultivar is susceptible to most of the common potato defects, such as common scab, as well as other defects (Fig. 1). Sample potatoes used in the experiment were grown by JA Obihiro Taisho, Hokkaido, Japan and harvested on September 2016. Upon receipt of the samples from Shibuya Seiki Co., they were stored in a dark room at room temperature prior to measurement. Manual inspection to determine the types of defects of each potato tuber was conducted before the experiment. A total of 140 samples of various potato surface types were measured as described in Table 1. Potato sample characteristics were distinguished as follow: undamaged/normal skin; common scab (CS) lesion; mechanical damage (cut/wound/flaky skin); greening; soil (attached to the skin); flesh without skin (peeled).

2.2. Sample preparation and diffuse reflectance measurement

The samples were cut out using a puncher with diameter of 5 mm, then cut using a razor cutter with a thickness of 5 mm and then placed into a PSH-003 sample holder (Fig. 2). For the soil sample, we removed the soil from the potato surface, cut the surface below the soil, and reconstructed it in the sample holder. Note that for the soil sample there was a minimum amount of soil needed to fit the sample holder, we reconstructed the soil with an initial weight of about 15–20 mg.

Table 1
Samples type and total numbers.

No.	Sample categories	Number of samples
1.	Normal skin	33
2.	Common scab	
	- Superficial (CSS)	20
	- Clearly visible (CS)	7
	- Deep (CSD)	7
3.	Greening	16
4.	Mechanical (Mech)	23
5.	Soil	15
6.	Flesh	19
	Total	140

The diffuse reflectance spectra acquisition were taken with a Jasco V-670 spectrometer equipped with ISN-723 Integrating sphere. The reference was measured with a standard white plate (RLH-603). The measurement was made in reflectance mode, with a 5 nm slit bandwidth for the Ultraviolet-Visible (UV–vis) region and a 20 nm slit bandwidth for the Near-infrared (NIR) region. Measurements ranged over 200–2500 nm. We measured at a data interval of 1 nm and scan speed of 1000 nm/min. The measurements were performed 3 times for each sample and the averaged spectra calculated.

2.3. Biophysical parameters measurement

The moisture content of the sample was also measured gravimetrically. This was done by placing the sample on a pre-weighed aluminum foil dish and then weighing the dish with sample before drying. The sample was heated in an oven at 105 °C for 4 h (AOAC, 1995), and then weighted again. Moisture content was calculated using the following equation:

$$Moisture\ \ content\,(\%) = \frac{M1 - M2}{M1 - M}$$

Where: M1 = weight of sample + dish before drying, M2 = weight of sample + dish after drying, M = weight of empty dish

For defects thickness, the top layer of the sample were cut and then measured using Mitutoyo digital caliper. Microscope image was obtained using Keyence VH-Z250R microscope with computer and image acquisition software.

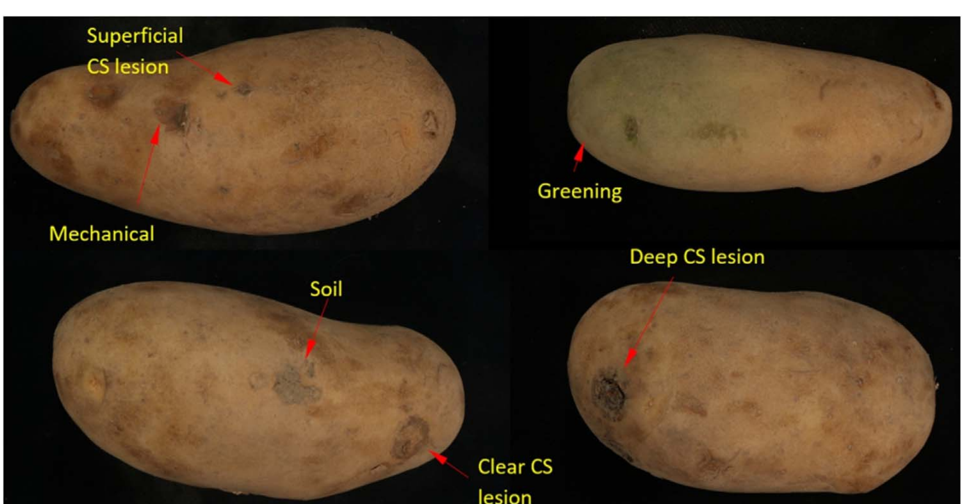

Fig. 1. Representative color image for each defects type.