Postharvest Biology and Technology 128 (2017) 18–23

Contents lists available at ScienceDirect

Postharvest Biology and Technology

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

# Positioning in spectral measurement dominates estimation performance of internal rot in onion bulbs

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ARTICLE INFO

*Article history:*
Received 29 September 2016
Received in revised form 6 February 2017
Accepted 6 February 2017
Available online xxx

*Keywords:*
Basal plate
Multivariate analysis
Transmittance spectra
Visible and near infrared spectroscopy
Visual criteria for rot level

ABSTRACT

The feasibility of visible and near infrared (VIS/NIR) transmittance spectroscopy for nondestructive discrimination of healthy and diseased onion bulbs was examined. Rottenness occurring in inner scales that were hard to diagnose by the five human senses was targeted. First, VIS/NIR spectra were acquired for six bulb positions. Subsequently, the degree of rot was measured by visual inspection of vertically cut surface based on our proposed criteria and by weighing of sectioned rotted parts. Our evaluation criteria functioned as an alternative mode of the weighing method. The basal plate of onion bulb had remarkable scattering properties. Therefore, spectral features differed not only by the rot levels but also by positioning the bulb against the sensor setup. The partial least squares regression model developed from the longitudinal position, for which the basal plate did not overlap against the system optical axis, showed the best performance and classified rotted bulbs above level 1 with 98.4% accuracy. Absorbance below 736 nm was the informative region for bulb rottenness detection.



## 1. Introduction

Onion production is increasing steadily, and reached approximately 87 million tons in 2013, making it the 19th ranked commodity in world production (FAOSTAT, 2016). Onions are an important horticultural crop regarding storage characteristics and durability of distribution. However, there is a serious problem in onion trade because shipping onions contain rotten bulbs. Various bacteria and fungi cause internal rot in onion bulbs (Brewster, 2008; Mark et al., 2002; Schwartz and Mohan, 2008). It is not so difficult to detect disorders occurring at outer scales of onion because such rotten bulbs are readily visible and soft to the touch. Healthy inner scales can often be used by removing the affected portions. The detriment to the edible part is slight. In stark contrast, onions with internal rot are usually subject to discard the entire bulb. Moreover, some rotten onions cannot be detected by smelling, visual inspection, and palpation because onions have a multilayered structure with dry scale leaves. Our trial survey using one ton of onions purchased from Japanese domestic markets in a random manner revealed that shipping onions included 4–6% rotten bulbs that were regarded as a subject of complaint from consumers, processors, distributors, and merchants. This present situation engenders lower sales prices, thereby concentrating the production risk on the producer's side. The biased risk can reduce the number of farmers and the amounts of production, creating a latent but substantial risk for all onion users. It is, therefore, necessary to create a sustainable system that achieves appropriate risk allocation at upper, middle, and lower currents of the distribution chain. A strong need exists for technology development to discriminate healthy bulbs from diseased ones.

Some reports have described nondestructive detection of internal quality attributes in onion bulbs (X-ray (Shahin et al., 2002; Tollner et al., 2005); GC/MS (Prithiviraj et al., 2004); E-nose (Konduru et al., 2015)). Visible and near infrared (VIS/NIR) spectroscopy is also a promising tool for quality evaluation inside the bulb. The VIS/NIR spectroscopy has been described as being nondestructive, noninvasive, rapid, low cost, low maintenance, and chemical free process. Wang et al. (2012) demonstrated the efficacy of hyperspectral imaging technique (950–1650 nm) for onion sour skin detection. Optical coherence tomography (OCT) with super luminescent diode emission of around 1300 nm has

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http://dx.doi.org/10.1016/j.postharvbio.2017.02.001
0925-5214/

visualized watery skins effectively (Meglinski et al., 2010; Ullah et al., 2015). However, such techniques using higher wavelengths allow observations to depths of only a couple of millimeters because of their light transmission characteristics. Usage of shorter wavelengths is probably more suitable for observation of deeper parts of an onion bulb. Ito and Hattori (2012) reported the applicability of the shorter NIR region (750–1000 nm) for nondestructive detection of disorders at outer scales. Only Ito and Morimoto (2014) examined the potential of shortwave NIR spectroscopy (800–1000 nm) for detection of rotted inner scales. Nevertheless, they measured only local spectra at diagonal sides near the neck (top) part of the bulb, namely shoulder parts, using interactance mode. The effectiveness of transmittance of VIS/NIR range, which acquires information from a whole bulb, has not been addressed to date. Moreover, onions are delivered by conveyor belts in a typical onion packing house. Onions move erratically on the belts during conveying. From a practical viewpoint of developing an automated quality evaluation system, it is necessary to clarify the effects of bulb positioning in measuring the transmittance spectra on detection of internal rot in onion bulbs.

The objectives of this study were, therefore, to assess VIS/NIR transmittance spectroscopy for nondestructive detection of internal rot in onion bulbs and to ascertain the influence of bulb positions against the sensor setup for acquiring transmittance spectrum on the accuracy of internal rot detection of onion bulbs. Furthermore, during the destructive inspection, an overly detailed evaluation of the degrees of rot in the bulb is often onerous. For that reason, it might restrict feasible experiments for developing a nondestructive rottenness estimation model. In this study, the degrees of rot have been evaluated by weighing rot parts and visual inspection. The validity of the proposed visual inspection was discussed.

## 2. Materials and methods

### 2.1. Samples and storage conditions

Onions (*Allium cepa* L., cv. Momiji 3) were harvested in mid-June of 2011 at Awaji Island (Hyogo Prefecture, Japan). After harvest, onion bulbs were hung and stored (ca. 20–25 °C) at an open-air house in the field until early August, which is a classic local style of drying. Samples with dried skin used for the experiments were transported to the laboratory in mid-August. The sizes and weights of samples are presented in Table 1.

### 2.2. Spectral measurements

Transmittance spectra, $I$, of the onion bulbs of 665–955 nm with 1 nm resolution were obtained nondestructively at ca. 30 °C in a dark box using a VIS/NIR spectrometer (Saika Technological Institute Foundation, invented by Inoue et al. (2010)) as presented in Fig. 1. The spectra in six positions against the system optical axis were measured as presented in Fig. 2. A reference spectrum, $I_0$, was measured using a white sphere ($\varphi$ = 100 mm) made of polytetrafluoroethylene. Absorbance was calculated from $I$ and $I_0$. Then it was transformed using standard normal variate (SNV) that is used quite often to remove the scatter and to correct the light path length.

**Table 1**
Descriptive statistics value of samples ($n$ = 89).

| | Mean | SD | Max | Min |
|---|---|---|---|---|
| diameter [mm] | 85.27 | 5.96 | 101.7 | 68.9 |
| weight [g] | 274.70 | 49.00 | 384.5 | 168.0 |

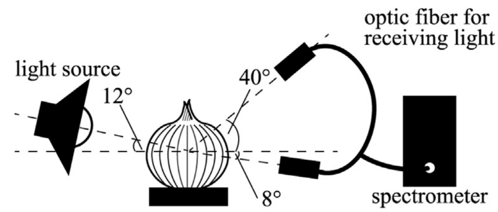


**Fig. 1.** Schematic diagram of spectral measurement.

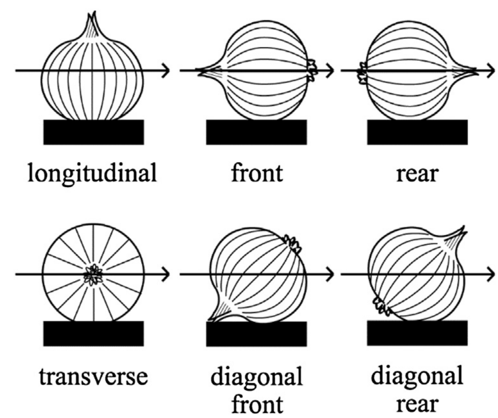


**Fig. 2.** Six positions during spectral measurement. Arrows indicate the traveling direction of irradiating light, i.e., the optical axis of the system.

### 2.3. Quantification of the degree of rot

After optical measurements, each onion bulb was cut vertically (from the neck to the basal plate). Then bulb rot levels were inspected visually and scored based on the following criteria: level 0, sound; level 1, less than a half in one scale; level 2, a half or more in one scale; level 3, less than two scales; level 4, less than three scales; and level 5, more than level 4 (Fig. 3). Subsequently, rotted parts were sectioned carefully using a scalpel. They were then weighed. The share of rotted parts to the whole bulb was calculated using the equation shown below.

$$P = \frac{W_{rot}}{W_{whole}} \times 100 \quad (1)$$

$P$ signifies the rot percentage [%], $W_{\mathrm{rot}}$ stands for the weight of rotted parts [g], and $W_{\mathrm{whole}}$ denotes the weight of a whole bulb [g]. Our target was to detect bulbs with internal rot that was difficult to judge by appearance and palpation. For that reason, rot percentages of onion bulbs were less than or comparable to 50% and were distributed lognormally. The following equation was used to correct the distribution.

$$P_{mod} = \log(P + 1), \quad (2)$$

In that equation, $P_{\mathrm{mod}}$ represents the common logarithmic transformed ratio of the rotted part to a whole bulb plus one. When the bulb is sound, both $P$ and $P_{\mathrm{mod}}$ are zero. Even when the bulb includes rotted parts, all values become positive. Errors by an artificial addition of one percent are negligibly small.

### 2.4. Multivariate analysis

Obtained spectra and corresponding rot levels and the modified rot ratio ($P_{\mathrm{mod}}$) were used, respectively, as explanatory and