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Nondestructive determination of dry matter and soluble solids content in dehydrator onions and garlic using a handheld visible and near infrared instrument

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ABSTRACT

A non-destructive method based on visible and near- infrared spectroscopy was investigated for determining the dry matter and soluble solids contents of dehydrator onions (485 samples) at the base, equatorial, and shoulder locations and of garlic cloves (270 samples) at the equatorial location. The interactance spectrum (400–1000 nm) of each sample was measured non-destructively within a 5 s period using a handheld spectrometer that employed an optical design of 0° angle between the incident illumination and the detection view. The spectral data were used to develop partial least square regression models to predict the dry matter and soluble solids contents. The results showed that the predictive performance of the onion model with optical measurements taken at the equator and shoulder locations were superior to the performance at the base location. For dry matter and soluble solids contents, the onion model performance had coefficient of determination (R^2) values of 0.96 and 0.97, with RMSECV values of 1.29 and 1.23, respectively. Similarly, for garlic models, the R^2 values were 0.87 and 0.72, with RMSECV values of 1.14 and 1.09, for dry matter and soluble solids contents respectively. These results suggested that the handheld instrument has excellent potential to aid in onion and garlic production processing as a rapid, non-destructive technique to identify the dry matter and soluble solids contents in the field or in an industrial setting.

1. Introduction

Onion and garlic are the most commonly used vegetable crops in the world due to a multitude of cuisines made utilizing their pungent flavor and odor. In 2015, the onion and garlic production in the United States alone were approximately 3.06 and 0.17 million tons, respectively (USDA-NASS, 2015). In the USA, California is the number-one producer of dehydrator onion and garlic. Dehydrator onions include short-day and long-day varieties; short-day varieties are high dry matter content selections derived from the Creole, Creoso, or Primero varieties and long-day varieties with high dry matter content are usually selections or derivation from the Southport White Globe variety. Short-day varieties are small, globe-shaped, and white, and have soluble solids content ranges from 15 to 20%, while the long-day varieties have soluble solids content ranges from approximately 20 to 25% with high pungency (Voss and Mayberry, 1999).

Approximately 65% of the garlic grown in California is used for processing or dehydration, with 20% produced for the fresh market, and 15% produced for seed. Californian garlic can also be categorized into two growing periods California Early and California Late (ERS, 1996). Early garlic, which has a growing period about one month shorter than Late garlic, is primarily grown for the dehydration market while Late garlic is favored by the fresh market.

After harvest, dehydrator onion and garlic are transported to the processing plant by truck. Upon arrival, 20 L samples are randomly selected from each truck and their dry matter (DMC) and soluble solids (SSC) contents are then determined in an inspection laboratory. The current methods used for determining DMC and SSC values are destructive, labor intensive and time consuming. For example, for DMC, the industry uses a method that involves taking a subsample of whole onion or garlic bulbs and determining their change in mass when placing them in a hot-air oven for 48 h at 33 °C to obtain the industry DMC. This method is both very slow, and without the use of a vacuum oven at this low temperature, does not have good agreement with official standard (e.g., AOAC Method 934.06, 1996). For SSC, a subsample of onion or garlic is cut into small pieces and then the SSC is

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determined on a filtered juice sample using a refractometer.

As alternatives to traditional destructive methods, many researchers have attempted to develop different, nondestructive techniques to determine fruit and vegetable quality such as nuclear magnetic resonance (NMR) imaging and hyperspectal imaging. Thybo et al. (2003) used NMR imaging techniques to determine the DMC in potatoes. Chen et al. (1996) determined the DMC in avocados using an NMR technique. Wang et al. (2013)Wang, used reflectance, interactance, and transmittance modes in a hyperspectral imaging technique to determine the internal quality of onions and showed best prediction of the DMC (R^2 = 0.92, SEP = 1.73) and SSC (R^2 = 0.92, SEP = 1.53) using the interactance mode. However, these techniques generally required expensive instrumentation and trained personnel.

Near-infrared (NIR) spectroscopy has also been used as a rapid and nondestructive technique for measuring the internal quality of several commodities. It has been particularly successful in estimating the DMC and SSC of fruit and vegetable due to the absorption of sugar and water in the NIR spectral region. For example, research of SSC determination has been done on apples (Lu et al., 2000; McGlone et al., 2003), fresh prunes (Slaughter et al., 2003), Orange (Liu et al., 2010), tomatoes (Ecarnot et al., 2013), apricot (Oliveira et al., 2014) and mango (Rungpichayapichet et al., 2016). The NIR technique has shown promising results in DMC determination in onions (Birth et al., 1985), kiwifruit (Slaughter and Crisosto, 1998), cassava root (Sanchez et al., 2014, pears (Travers et al., 2014), apple (Kumar et al., 2015), durian fruit (Pathaveerat et al., 2015) and avocado (Clark et al., 2003; Olarewaju et al., 2016).

In particular, the NIR method with interactance mode measurement (Conway et al., 1984) has been widely used for non-destructive applications in produce because with this method, light enters the sample and interacts with the tissue inside and some of the unabsorbed light is internally reflected and is measured on the same side as the entrance beam allowing the optical absorption spectrum to be collected from intact, optically dense, biological specimens of irregular size. A handheld NIR instrument should be useful to the produce industry as a management tool for identifying quality in dehydrator onions in real-time and without trained personnel. To address this need, a handheld visible and NIR interactance spectrometer that successfully determined maturity in green tomatoes (Slaughter et al., 2013) was investigated using intact dehydrator onions and garlic cloves. The objectives of the research were to develop visible and NIR-based statistical models for rapid, non-destructive DMC and SSC prediction in onions and garlic cloves using the whole fruit, and to investigate the feasibility of using a handheld spectrometer for DMC and SSC determination in dehydrator onion and garlic samples.

2. Materials and methods

2.1. Sample collection

Samples of 485 dehydrator onions (*Allium cepa*, cv. White Creole) and 270 dehydrator garlic cloves (*Allium sativum*) were provided by GODAB (Garlic and Onion Dehydrator Advisory Board), Livingston, California and a further sample of 100 sweet onions (*Allium cepa*, cv. Savannah Sweet) collected from a fresh market in Sacramento, California were used to provide a wide range of DMC and SSC levels. All onion and garlic samples were stored in a refrigerator (0 °C and 70% relative humidity) until the experiments were conducted. Before spectrum acquisition, the onion and garlic samples were removed from the refrigerator to a laboratory with an ambient temperature of 24 °C and held there for 12 h. All the samples were cleaned to remove surface dirt, dry leaf flakes, and long roots before measurement.

2.2. Handheld spectrometer system

A handheld spectrometer (Model Nirvana-Analytical Spectrometer, Integrated Spectronics, Sydney, NSW, Australia) was used to measure the interactance spectra of the intact sample between wavelengths of 400 nm and 1000 nm at a data resolution of 3 nm and an optical bandwidth ranging from 8 nm to 13 nm (Fig. 1). The instrument used a 0° illumination angle and a 0° detection view angle, where a tungsten light source illuminated the sample through a sampling window of diameter 3 cm. The projected area of the illumination on the sample surface by the optical beam was about 7 cm^2. A small-sized detector acceptance probe was placed at the center of the optical beam, which obscured the optical beam causing a shadow on the sample surface (Greensill and Walsh, 2000). Under this configuration, the detector only received the interactance spectra emerging from the shadowed area. The spectrophotometer was controlled using a built-in, pocket-PC-style computer running the Windows CE operating system. Once a model is developed by the user to determine a desire quality index (e.g., the DMC or SSC of onions or garlic cloves) the user can upload the model coefficients into the instrument. The instrument is then able to predict the desired quality index of future samples based on the uploaded model for real-time use by managers in the produce industry. Unlike many bench-top NIR instruments, this instrument is small and has a low mass (~1 kg), and can be carried easily for the spectral measurements of samples in different locations along the postharvest supply chain.

Fig. 1. Handheld visible-NIR spectrometer being used to measure the interactance spectrum of sample.

To measure the interactance spectrum, each sample was gently held against the outer rim of the sampling window of the spectrometer. Typically, the samples completely covered the sampling window in order to minimize the amount of incoming ambient light which can adversely affect the spectral measurements. In the measurement sequence, an internal gold reference plate was automatically inserted in front of the sample for use as the optical standard just prior to each spectral measurement and after the sample was in the measurement position.

2.3. Onion and garlic spectral measurements

To determine the location that produced the best prediction, onsite