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Laser-based imaging system for non-invasive monitoring of quality changes of papaya during drying

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ABSTRACT

Non-invasive, sensor-based technologies are increasingly considered as preferred methods for evaluating quality attributes of agricultural products. This study investigated the feasibility of a laser light backscattering analysis at three wavelengths (532, 650, 780 nm) for predicting moisture content (*MC*), shrinkage (*S*), lightness (L^*), chroma (C^*) and hue (h^*) changes of papaya during drying. Convective hot air drying was conducted at four temperatures (50, 60, 70, 80 °C), during which time the product was sampled and subjected to non-destructive optical analysis as well as reference measurements. From laser images, the illuminated area (A_I) and light intensity (I_L) were used to assess the backscattering profiles that represent photon migration in the fruit tissue. As expected, drying temperatures significantly affected the quality attributes of dehydrated papayas. Increasing drying temperature resulted in a decrease in *MC*, L^*, and C^* values, whereas h^* and *S* values were increased. The results also revealed that each backscattering factor obtained can potentially be used to describe each quality change, except for C^* value. In addition, multivariate correlations of measured A_I and I_L parameters at 650 nm wavelength were found to precisely yield the best fit for *MC*, L^*, and h^* predictions ($R^2 > 0.92$). Therefore, the study concludes that the use of laser backscattering methods provides a useful tool for quality control as a rapid, consistent, non-intrusive and objective method for in-line measurement of product quality in fruit drying processes.

1. Introduction

Papaya (*Carica papaya* L.) contains various antioxidant compounds and is becoming more promoted as a result of increased interest in functional foods (Oliveira & Vitória, 2011). However, fresh papaya is often processed to other forms for consumption, which can often cause degradation of desirable qualities. Drying is a commonly applied technique which is known to induce adverse effects, such as discolouration and structural changes (Fernandes, Rodrigues, Gaspareto, & Oliveira, 2006; Kurozawa, Hubinger, & Park, 2012; Rodrigues, Cunha, & Hubinger, 2003). Meanwhile, visual appearance is a major quality criterion to be controlled for, as it directly affects consumer acceptance. It is well-documented that different reactions can affect colour of fruit products during drying, namely enzymatic and non-enzymatic browning. In addition, size and shape alterations can occur through shrinkage when water is removed from the fruit tissues (Aguilera, 2003). Visual quality assessment of dried products can be carried out by trained inspectors, however human inspection is tedious, costly and inherently unreliable (Du & Sun, 2004). Other methods require contact measurements, such as a colorimeter for standard determination of colour, yet results are inadequate to describe the overall appearance in heterogeneous samples. For shrinkage determination, sample dimensions are measured and the change in volume is evaluated (Yadollahinia, Latifi, & Mahdavi, 2009).

Recently, non-destructive computer-assisted methods have been applied for monitoring quality and quantity changes of agricultural and food products. Most proposed methods are based on measuring a given property such as optical, vibrational and electrical characteristics. These measurements are subsequently correlated with the physicochemical quality parameters. Application of laser light backscattering is one of the alternative non-destructive methods for evaluating fruit quality, particularly moisture content, colour, firmness and soluble solids content. The scattering of light is a result of photon projection at different angles in a material. Birth (1976) explained that when a light beam hits the

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fruit, a small fraction of photons (~4%) are reflected at the fruit surface, while the rest enters into the fruit tissue and experience absorption, transmission, or diffuse reflection (scattering). The scattering characteristics of photons in the visible wavelength depend on cell structure components. Normally, absorption and scattering profiles can be used to describe the properties of fruits. Absorption is related to the chemical constituents such as soluble solids, moisture, pigments, and coloured compounds. Scattering of light in biological materials not only depends on absorption but also on physical properties such as density, cell size, and extra- and intra-cellular matrices of fruit tissue. Laser backscattering systems have been successfully applied to post-harvest process monitoring, especially sorting and grading machines (Mollazade, Omid, Tab, & Mohtasebi, 2012). Studies also reported that laser diodes are rapid and economical devices operating without spectrograph when compared to near-infrared reflectance (NIR) spectroscopy (Zude, Birlouez-Aragon, Paschold, & Rutledge, 2007).

However, studies on a laser light backscattering for analysing the physical and chemical properties of agricultural products is still limited. Qing, Ji, and Zude (2007) applied a light backscattering imaging for predicting soluble solids content and firmness of fresh apple. Romano, Nagle, Argyropoulos, and Müller (2011) also determined the feasibility of laser diode in the red spectrum for monitoring moisture and hardness changes of apple during drying. Yet only one previous study explored this laser backscattering technique for simultaneous determination of various product characteristics during fruit drying. Therefore, the objectives of this study were (1) to investigate the effects of drying temperatures on physicochemical changes of papaya and (2) to assess the use of laser diodes emitting at three different wavelengths to monitor moisture content, shrinkage, and colour changes of papaya during drying.

2. Materials and methods

2.1. Papaya preparations

Fresh papaya (*Carica papaya* cv. Pluk Mai Lie), procured from a commercial orchard in Nakhon Nayok province, Thailand, was purchased from an import company in Germany. Fruit lots were stored at 10 ± 1 °C and 20–35% relative humidity until preparation for drying. Fruits were selected the day of experiments in order to get samples with uniform elongated club shape, weight (1.0–1.2 kg), ripening stage (70–80% of yellow skin). Fruits were controlled for moisture content (83–85% w.b.), soluble solids content (9.5–10.6 °Brix), titratable acidity (0.12–0.16%, as citric acid) and pH (5.0–5.2).

2.2. Osmotic pretreatment

The samples were treated osmotically according to the procedure described in a previous study (Udomkun, Mahayothee, Nagle, & Müller, 2013). The selected papayas were hand-peeled and cut into a cuboid shape (20 × 30 × 20 mm) using a specially-designed stainless steel cutter. The samples (600–650 g) were rinsed with fresh water and then soaked in 2.5% (w/v) calcium lactate solution. The samples were allowed to soak for 1 h at controlled temperature (20 ± 2 °C) and then blanched at 60 ± 2 °C for 1 min. Subsequently, they were immersed in 30 °Brix osmotic solution at a starting temperature of 60 ± 2 °C and allowed to stand at ambient conditions for 6 h. The osmotic solution was prepared by dissolving 99.9% refined sucrose in water to obtain a required concentration and then pH was adjusted to 4.0 using citric acid. The osmotic solution to fruit samples was maintained at 1:1 (weight basis). After removal from the solution, the samples were rinsed with water, drained, and finally blotted with absorbent paper to remove excess water before drying.

2.3. Drying process

After pretreatment, papaya samples were evenly distributed on a round perforated tray. Convective drying was conducted at four different temperatures (50, 60, 70, 80 °C) and the corresponding air velocity and specific humidity were controlled at 0.5 m/s and 10 g/kg of dry air, respectively, using the through flow chamber of the high precision hot air laboratory dryer at the Institute of Agricultural Engineering, Tropics and Subtropics Group, Universität Hohenheim, Germany. A detailed description of the dryer was provided by Argyropoulos, Heindl, and Müller (2011). Mass reduction was automatically recorded for the determination of the drying curves and estimation of total drying time. During the drying process, six samples were intermittently taken out from the dryer for the laboratory analysis. Papaya samples were dried until the moisture content reached 13.5–14.5% w.b. The final water activity was 0.5 ± 0.05. Experiments were performed in triplicate.

2.4. Moisture content and water activity analyses

Moisture content (*MC*) was determined as percent wet basis (% w.b.) using Karl Fischer titration (758 KFD Titrino, Metrohm GmbH and Co., Switzerland). Water activity (a_w) was measured using a water activity meter (AW-DIO, Rotronic, Switzerland) after 20 min in a thermostatic cell at 25 °C. Results are exhibited as water activity (% ERH/100). All measurements were completed in triplicate by using three samples per treatment.

2.5. Specific volume and shrinkage measurements

Product shrinkage during drying was investigated by observing volume reduction of samples. The toluene displacement method of Yan, Sousa-Gallagher, and Oliveira (2008) was applied to measure the volume of papaya cubes. From this, sample shrinkage was calculated. A flask was calibrated using distilled water and the volume was determined. The density of toluene examined by weighing the flask full with toluene was found to be 0.8686 g/cm^3. One cube of sample was weighed and transferred into a flask half filled with toluene, subsequently the flask was completely filled with toluene. One piece of fruit was used at each time and experiments were performed three times. The results were obtained from the average values. Analyses were made in a triplicate series for each treatment.

The volume of sample (V) was calculated using:

$$V = V_f - \frac{M_{f+s} - M_f - M}{\rho_s} \quad (1)$$

where V_f is the volume of the flask (cm^3), M_{f+s} is the weight of the flask plus the sample and the fluid (g), M_f is the weight of the flask (g), M is the weight of the sample (g), and ρ_s is the density of toluene (g/cm^3). Shrinkage (S) was expressed by the percentage change of the sample volume as compared with its original volume as followed:

$$S = \frac{(V_0 - V)}{V_0} \times 100 \quad (2)$$

where V_0 is the original volume of the sample (cm^3) and V is the volume of the sample during drying (cm^3).