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Research Paper

Prediction mapping of physicochemical properties in mango by hyperspectral imaging

Parika Rungpichayapichet [a], *Marcus Nagle* [a,*], *Pasinee Yuwanbun* [b], *Pramote Khuwijitjaru* [b], *Busarakorn Mahayothee* [b], *Joachim Müller* [a]

[a] *Institute of Agricultural Engineering, Tropics and Subtropics Group, Universität Hohenheim, Garbenstrasse 9, Stuttgart, 70599, Germany*

[b] *Department of Food Technology, Faculty of Engineering and Industrial Technology, Silpakorn University, Nakhon Pathom, 73000, Thailand*

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Hyperspectral imaging (HSI) techniques using a newly-developed frame camera were applied to determine internal properties of mango fruits including firmness, total soluble solids (TSS) and titratable acidity (TA). Prediction models were developed using spectral data from relative surface reflectance of 160 fruits in the visible and near infrared (vis/NIR) region of 450–998 nm analysed by PLS regression. For data reduction, MLR analysis showed 16 significant factors for firmness, 17 for TA, and 20 for TSS. The results of MLR did not substantially affect the prediction performance as compared to PLS. An original approach with combined chemometric and HSI data analyses was applied using R programming. Significant correlations were found between HSI data and firmness (R^2 = 0.81 and RMSE = 2.83 N) followed by TA (R^2 = 0.81 and RMSE = 0.24%) and TSS (R^2 = 0.5 and RMSE = 2.0%). Prediction maps of physicochemical qualities were achieved by applying the prediction models to each pixel of HSI to visualise their spatial distribution. The variation of firmness, TSS, and TA within the fruit indicated fruit ripening started from shoulder toward to tip part. From these results, HSI can be used as a non-destructive technique for determining the quality of fruits which could potentially enhance grading capabilities in the industrial handling and processing of mango.

1. Introduction

Mango quality plays an important role on market price and consumer satisfaction. Superior quality induces a customer's willingness to pay premium prices for a product. Overall, physical appearances such as colour and firmness are considered the primary criteria customers use to evaluate fruit quality (Delwiche, Mekwatanakarn, & Wand, 2008). Sivakumar, Jiang, and Yahia (2011) have meanwhile reported that consumer preference and order decisions are more related to fruit taste. However, in commercial operations, heterogeneous fruit quality is encountered due to the variation in degree of ripeness of harvested fruits, which causes non-uniform ripening behaviour and requires different

* *Corresponding author*. Fax: +49 (0)711 459 23298.
E-mail address: info440e@uni-hohenheim.de (M. Nagle).
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postharvest handling (Kienzle et al., 2012). This problem leads to reduced shelf-life and postharvest losses during handling and transport. Therefore, inspection and controlling quality of mango at packing is an imperative process in the mango industry to assure that only superior fruits are distributed to high-value markets.

The potential of non-destructive techniques as tools for sorting and grading have been demonstrated in numerous studies. Near infrared spectroscopy (NIRS) is widely implemented to identify the quality of many fruits, including mango. Studies have shown the potential of NIRS to determine the physicochemical properties of mango such as firmness, total soluble solids content (TSS), titratable acidity (TA) and bioactive compounds (Jha, Narsaiah et al., 2010; Nagle, Mahayothee, Rungpichayapichet, Janjai, & Müller, 2010; Rungpichayapichet, Mahayothee, Khuwijitjaru, Nagle, & Müller, 2015; Rungpichayapichet, Mahayothee, Nagle, Khuwijitjaru, & Müller, 2016; Subedi & Walsh, 2011; Theanjumpol, Self, Rittiton, Pankasemsuk, & Sardsud, 2014; Valente, Leardi, Self, Luciano, & Pain, 2009; Watanawan, Wasusri, Srilaong, Wongs-Aree, & Kanlayanarat, 2014). More recently, hyperspectral imaging (HSI) is being regarded as an effective non-destructive method to determine the quality of agricultural products. The advantages of HSI over NIRS are the simultaneous procurement of spatial and spectral information from the sample and the flexibility of area selection for spectral extraction after data acquisition (Schmilovitch et al., 2014; Zhang, Liu, He, & Gong, 2013). Overall, HSI can provide information on the spatial distribution of physicochemical parameters, enhancing the perception of quality changes within samples (ElMasry, Sun, & Allen, 2013). The ability of HSI to evaluate the quality of fruits was recently reviewed by Magwaza and Opara (2015). For mango, HSI has been applied to detect fruit fly infestation (Haff et al., 2013; Saranwong et al., 2011), mechanical damage (Vélez Rivera et al., 2014), moisture distribution in dried mango slices (Pu & Sun, 2015) and postharvest qualities including colour, firmness and TSS (Makino et al., 2013; Sivakumar, 2006). However, little documentation currently exists describing the variability of physicochemical qualities within mango fruits and studies applying HSI to monitor these spatial quality changes are lacking. Issues also remain with software for HSI analysis, especially with respect to real-time application (ElMasry & Nakauchi, 2016) and high computational requirements for HSI data. Therefore, this study aims to demonstrate the feasibility of HSI as a tool to observe the spatial changes of quality of mango during ripening by (i) testing hyperspectral frame camera technology for rapid image acquisition, (ii) developing reduced-factor HSI prediction models in freely-available, programmable software to quantitatively determine physicochemical qualities of mango, and (iii) establishing prediction maps showing the distribution pattern of quality parameters within fruits for potential grading applications.

2. Materials and methods

2.1. Materials

A total of 160 mango fruits (cv. Nam Dokmai, subcv. Si Thong) from two production areas (Phitsanulok and Phetchabun provinces, Thailand) were obtained at commercial export maturity, corresponding to 120 days after full bloom. Eighty fruits from each area were harvested during the peak season in April 2013. Mature fruits were preselected in the field for fruit mass about 310 g and density greater than 1000 kg m^{-3}. Fruits then were transported to Nakhon Pathom province within one day, where the experiments were carried out. Fruits free from visual defects were washed, air-dried, and stored in baskets covered with paper at ambient temperature (32.1 ± 0.6 °C and 73.0 ± 7.9% relative humidity) for up to 8 days of ripening. Ten fruits were randomly selected each day and subjected to HSI analysis and quality reference measurements.

2.2. Reference analyses of quality attributes

Fruits were cut along the sagittal plane from the proximal to distal end into two slabs on either side of the endocarp. Slabs were divided into three positions, i.e. shoulder, cheek, and tip parts (Fig. 1a). Firmness was determined only at the cheek position according to Jha, Kingsly, and Chopra (2006). A puncture test was performed with a needle probe (2 mm diameter) on the peeled mesocarp at a speed of 0.5 mm s^{-1} and a compression depth of 10 mm using a texture analyser (TA-xT2i, Stable Micro Systems, Godalming, UK). Maximum force (N) was used to describe the firmness. For chemical analyses, each mesocarp section was homogenised separately (Ultra-Turrax T25 basic, IKA Labortechnik, Germany). Five grams of the homogenate was squeezed through filter cloth and used to determine TSS by a digital refractometer (PAL-1, Atago, Tokyo, Japan). TA was measured by alkaline titration of 100 mL dilution prepared from 5 g of homogenate with 0.1 N NaOH until a pH of 8.1 and expressed as mass percentage (%) of citric acid (AOAC, 1999). Determinations of TSS and TA were done in duplicate.

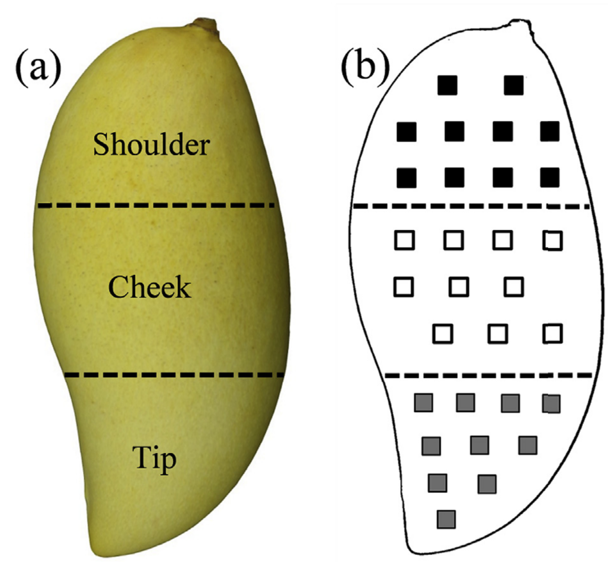

Fig. 1 – Fruit positions for (a) reference quality analyses sampling and (b) region of interest (ROI) selection for hyperspectral measurements; ROIs are not to scale.