Scientia Horticulturae 202 (2016) 63–69

Contents lists available at ScienceDirect

Scientia Horticulturae

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

# Changes of backscattering imaging parameter during plum fruit development on the tree and during storage

Yousef Rezaei Kalaj[a,*], Kaveh Mollazade[b], Werner Herppich[a], Christian Regen[a], Martin Geyer[a]

[a] Leibniz Institute for Agricultural Engineering Potsdam Bornim (ATB), Max-Eyth-Allee 100, 14469 Potsdam-Bornim, Germany
[b] Department of Biosystems Engineering, Faculty of Agriculture, University of Kurdistan, Sanandaj, Iran

ARTICLE INFO

*Article history:*
Received 9 October 2015
Received in revised form 14 February 2016
Accepted 18 February 2016
Available online 26 February 2016

*Keywords:*
Fruit flesh firmness
Non-destructive test
Image processing
Normalized anthocyanin index
Full width at half maximum

ABSTRACT

Laser light backscattering imaging (LLBI) as a novel approach appears to be a promising technique for monitoring quality of horticultural products. The aim of this research was to investigate the feasibility of the non-destructive LLBI technique for the evaluation of plums quality indices during fruit development on tree and during storage. Plums of two cultivars were harvested four times during fruit development. At commercial harvest, fruit were stored at $2 \pm 0.5\,^{\circ}$C ($90 \pm 2\%$ RH) for 28 days and 2 days at 20 °C with five measuring dates during storage. Experimental methods involved conventional measurements, i.e. fruit firmness, skin color, soluble solids content, dry matter content, and normalized anthocyanin index (NAI), and non-destructive LLBI at two wavelengths: 532 and 785 nm. The obtained backscattering images were characterized by variation of brightness of the backscattered light. As an objective measure full width at half maximum (FWHM) was calculated from these radial backscattering profiles. The reduction in FWHM532 was strongly correlated with the increase in anthocyanin content as indicated by NAI during fruit development. Furthermore, the increase in FWHM785 was strongly correlated with the decrease in fruit flesh firmness during fruit development on the tree and during storage. In conclusion, results suggest that the LLBI using appropriate wavelengths can be feasible for non-destructive prediction of NAI and firmness in plum fruit.



## 1. Introduction

Plums are generally valuable for human nutrition. Economically they are very important fruit crop of temperate regions of world. Of stone fruits, they rank next to peaches in their economic importance. While China is the world's largest producer of plums with about 53% (6.1 Mt) of total production, 25.5% of word's production belongs to European countries (Anonymous, 2013). However, high demand strongly dependents on the quality of fruit because of increasing awareness of quality and enhanced perspicacity of consumers. Fruit parameters such as fruit flesh firmness, skin color and sugar content are important quality attributes that directly influence consumers on purchasing fresh plum fruit (Abdi et al., 1997; Crisosto and Crisosto, 2005; Usenik et al., 2008). Standard laboratory techniques for evaluation of fruit quality do not allow continuous controls during marketing and processing because they are destructive, costly and introduce contamination (Romano et al., 2010). Many different non-destructive techniques were investigated during the last decade such as methods for analyzing mechanical properties, e.g. acoustic stiffness, impact or ultrasonic analyses. However, they have not been adopted for commercial sorting lines (Lu, 2004). In recent years, the application of non-destructive optical methods has increased for monitoring and controlling quality changes of horticultural products during storage and post-harvest processing. One of the main benefits of non-destructive optical methods is that the measurements can be recorded for a certain time interval in an inexpensive and relatively easy way (Zude and Herold, 2002). These methods are excellent alternatives to destructive techniques.

In this regard, visible (VIS) or near-infrared reflectance spectroscopy (NIRS) and laser light backscattering imaging (LLBI) as computer vision systems are novel promising techniques. NIRS has yet been applied for detection of fruit quality parameters such as soluble solids content (SSC; Lu, 2001) or dry matter content (McGlone and Kawano, 1998). However, this technique would not be able to measure the quality-related anthocyanins. Furthermore, it was shown that NIR spectroscopy is not suitable for analysing the fruit flesh firmness (Zude et al., 2006; Subedi and Walsh, 2009).

* Corresponding author.
*E-mail address:* yousef_rezaeikalaj@yahoo.com (Y. Rezaei Kalaj).

http://dx.doi.org/10.1016/j.scienta.2016.02.029
0304-4238/

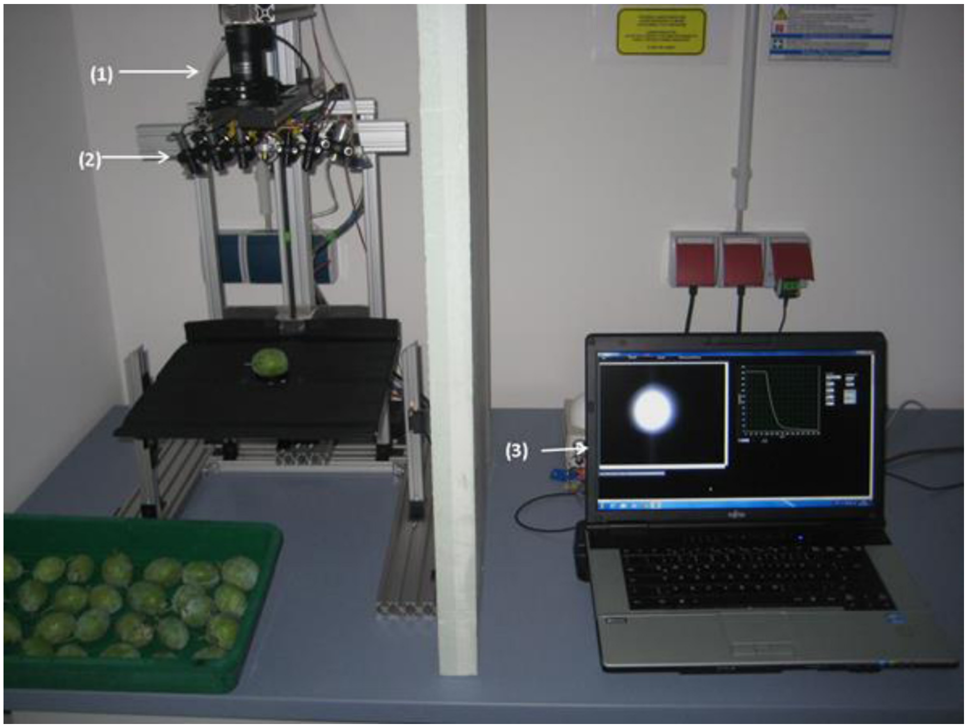


**Fig. 1.** The LLBI system measuring unripe plums, (1) CCD camera with lens; (2) laser sources; and on the other side of the security wall (3) laptop with Backscattering Analyser software.Fig. 1.The LLBI system measuring unripe plums, (1) CCD camera with lens; (2) laser sources; and on the other side of the security wall (3) laptop with Backscattering Analyser software.

Analyses of these fruit properties are potentially possible by quantitative information on light scattering within the sample (Lu, 2004).

LLBI measurements have been increasingly studied for the application in the food industry. LLBI is an inexpensive technique that uses principles of light absorption, scattering, and image processing in visible and near infrared range of electromagnetic spectrum and provides good information on light scattering within the sample (Qing et al., 2007a, 2008). This measurement takes place in a dark chamber where a single light beam is used to illuminate a point on the surface of the fruit (Baranyai and Zude, 2009). In general, when a light beam hits the fruit, most part of light penetrates into the fruit tissue and a small fraction, about 4–5%, is reflected off the surface as external diffuse reflectance (Birth, 1976). One part of the penetrated light is absorbed by the tissue components and the remaining light is scattered toward the exterior tissue (Mollazade et al., 2013). The interaction between light and biological tissue of horticultural produces gives useful information about its structure and component, which later could be used to evaluate the quality of fruit. Light absorption is affected by chemical constituents such as sugar, pigments, water etc. (Udomkun et al., 2014). Scattering, on the other hand, is a physical phenomenon, mainly influenced by cell structure and size, and resulting properties of the tissue matrices (Lu, 2004). Therefore, the degree of scatter detected by an imaging system can provide useful information to predict mechanical and textural properties of fruit (Lu, 2004; Qin and Lu, 2009). As a result, soft fruit tends to have a broader scattering profile than firmer fruit (Peng and Lu, 2005).

Recently, in various studies, laser has been used as the light source to generate scattering images for prediction of fruit quality on several fresh produce such as skin color in apple (De Belie et al., 1999), moisture content in banana slices during drying (Romano et al., 2008, 2010), SSC, firmness or elasticity in apple (Qing et al., 2007a; Qin and Lu, 2009; Mollazade et al., 2013), kiwifruit (Baranyai and Zude, 2009), and plum and tomato (Mollazade et al., 2013, 2015). Each researcher was able to find correlations between the validated methods and the used optical method.

Particularly in plum, the anthocyanin accumulation and the mechanical properties are important, while so far LLBI was not tested on small stone fruit with different characteristics compared to isotropic apple tissue. Therefore, the objective of this study was to evaluate the potential of LLBI for analysing variations in quality-related optical properties during development of plums on the tree and in storage.

## 2. Material and methods

### 2.1. Fruit samples and storage condition

In 2013, 'Jojo' and 'Tophit plus' plums were harvested from an experimental orchard at three dates 95 ($n=60$), 103 ($n=60$), and 117 ($n=60$) days after full bloom (DAFB) for 'Jojo', and 99 ($n=49$), 112 ($n=49$) and 121 ($n=49$) DAFB for 'Tophit plus' before commercial harvest. After sampling, fruit were immediately transferred to the laboratory and subjected to various analyses. Additionally, in commercial harvest, when fruit obtained SSC $\geq 16$ and TA $\leq 1.5$ (137 DAFB and 140 DAFB for 'Jojo'($n=252$) and 'Tophit plus'($n=252$), respectively), fruit free of visual defects were harvested, selected, and subjected to initial analyses and then stored in plastic boxes (3–5 kg) at $2 \pm 0.5\,^{\circ}$C and $90 \pm 2\%$ RH for up to 28 days plus 2 days at $20\,^{\circ}$C. During storage, plums were removed after 7, 14, 21, 28, and 30 days of storage and analysed.

### 2.2. Fruit quality analysis

#### 2.2.1. Fruit skin color and normalized anthocyanin index

Changes in fruit skin color of each plum were determined using a portable colorimeter (CM-2600d, Konica Minolta, Inc., Tokyo, Japan). Assessment of fruit color as well as their changes was based