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Optical techniques for rapid quality monitoring along minimally processed fruit and vegetable chain

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ABSTRACT

Product quality must be maintained at each step of product handling, processing, and preservation, and therefore rapid methods should be available to provide useful information in process management. The aim of this review was to give an overview of optical techniques for measuring quality of fruit and vegetables along minimally processed chain. A brief description of spectroscopic and imaging techniques currently used in the fruit and vegetable sector and a selection of applications are presented, paying particular attention to those along pre-, post-harvest and post-packaging phases. Future perspectives about the simplification of these non-destructive techniques were finally explored.

1. Introduction

Minimally processed fruit and vegetables, including fresh-cut products, are today particularly appreciated by consumers, due to their nutritive properties, convenience and ease of use. The production of ready-to-eat fruits and vegetables has in fact increased worldwide in recent years, and a further growth is expected. Economic indicators show the great interest of the farming community towards this sector, given the high added value of the minimally processed products in comparison with the fresh one (5–6 times higher). The commercial feasibility of ready-to-eat commodities is closely connected with their ability to keep quality attributes. The shelf life of these products is affected by a number of factors, such as growing techniques, harvesting operations, processing and storage conditions (Gorny, Gil, & Kader, 1996). Among these factors, the stage of ripeness at the time of harvest is one of the most important, as it affects both the shelf life and the eating quality of fresh-cut fruits and vegetables. In particular, fresh-cut fruits are more difficult to preserve than other minimally processed products because some of them have to be completely ripe before processing (Gorny, Cifuentes, Hess-Pierce, & Kader, 2000). Sorting harvested products according to their maturity stage in the packinghouse can eliminate immature-green ones and separate partially-matures from fully-matures, in order to improve the uniformity of ripening in lots at destination. Thus, for determining the optimal postharvest strategy for product handling and marketing the knowledge of vegetable ripeness stage is of great importance (Slaughter, 2009). This can be evaluated by means of analysis of biological (respiration rate), physical (color, texture), physico chemical (pH), microbiological and nutritional parameters (Aguayo & Silveira, 2009; Kader, 2008; Rico, Martín-Diana, Barat, & Barry-Ryan, 2007; Soliva-Fortuny & Martín-Belloso, 2003). However, these conventional analytical methods are generally expensive, slow, require considerable analytical skill and are not suited for automation. Thus, rapid and non-destructive methods may allow the fruit and vegetable ripeness stage and quality parameters to be evaluated before harvesting. These methods could be also used to investigate the freshness decay of minimally processed products also in the post-packaging phase, along the distribution chain. Non-destructive optical techniques have been developed considerably over the last 20 years (Guidetti, Beghi, & Giovenzana, 2012; Nicolaï et al., 2007) and their applicability for the evaluation of agro-food products has widely been proven. Spectral-optical techniques in fact fulfill all the requirements for continuous monitoring of compounds that can be related to the taste and nutritional value of

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horticultural products. Nevertheless, these technologies are currently adopted mainly by research centers or big companies equipped with laboratories and trained personnel, due to their cost and complexity of use. A simplification of these technologies is necessary to make them accessible also to operative staff in small and medium enterprises. The sector is therefore interested in new simplified systems for rapid analysis, that can be adopted along every step of the chain and directly at the point of sale with a double objective: to use the information from sensors to better manage the product, and to preserve the consumers' expectations by providing additional selection criteria. The future availability of simpler and low-cost compact tools will allow a big impact at different levels of the supply chain, with a real possibility of wide diffusion of these technologies from the manufacturing process up to the point of sale and the consumer. For a simplification and a greater diffusion of these non-destructive techniques, in recent years, interest has shifted towards the development of portable systems that could be used in pre- and post-harvest (Temma, Hanamatsu, & Shinoki, 2002; Walsh, Guthrie, & Burney, 2000; Zude, Herold, Roger, Bellon-Maurel, & Landahl, 2006). Chemometrics can be used for the selection of a small number of relevant variables, which represent the most useful information contained in the full spectra (Sun, 2010; Xiaobo, Jiewen, Povey, Holmes, & Hanpin, 2010). Few examples of commercial non-destructive devices based on a small number of wavelengths are already available on the market (Costa, Bonora, Fiori, & Noferini, 2011). These applications are mainly dedicated to fruits. This type of instruments, simple and portable, can be used directly on fruit on trees and can help operators in taking decisions regarding the best cultivation management practices (such as pruning, thinning, and nutrition). In this way the heterogeneity of the product can be reduced and, therefore, the management of product lots during post-harvest and post-packaging phases can be optimized. The aim of this review is to give an overview of optical techniques for measuring quality indices of fruit and vegetables along minimally processed chain. The description of the most important optical technologies currently used in the chain and a selection of applications are presented.

2. Optical techniques

Among the non-destructive techniques, the optical analyses in the region of near infrared (NIR) and visible-near infrared (vis/NIR) have a significant role. In particular, spectroscopy and imaging will be discussed in the next paragraphs.

2.1. Spectroscopy

The NIR and vis/NIR spectroscopy is used to acquire information about the nature of the functional groups present in a molecule, by exploiting the interaction between the light and the structure of a sample. The radiation from the NIR and vis/NIR regions is in fact able to promote transitions at the vibrational level. Visible (400–780 nm) and near-infrared (780–2500 nm) spectra are composed of combination and overtone bands that are related to absorption frequencies in the mid-infrared region (2500–50,000 nm). These combination and overtone bands correspond to the frequencies of vibrations between the bonds of the atoms making up the material. Because each different material is a unique combination of atoms, no two compounds produce the same visible and near-infrared spectra. With suitable algorithms and statistical analysis (chemometrics), NIR and vis/NIR spectroscopy are excellent tools for quantitative analysis. In most case-studies, NIR and vis/NIR techniques do not require sample preparation, offering a practical alternative to time-consuming analytical methods (chemical and physical) and could be capable to analyze samples through glass and packaging materials. Thus, the agro-food sector has demonstrated interest towards NIR and vis/NIR technology for measuring quality parameters along the minimally processed fruit and vegetables chain. One problem in the application of non-invasive spectroscopy for horticultural products analysis is the variation in the scattering characteristics of the tissues. Besides the effect of the absorbing compounds determining the absorption coefficient, the physical properties of the product determining the scattering behavior also affect the intensities of the spectra measured. Light scattering is influenced by the spatial densities and refractive index at the air/liquid boundaries, membranes, vacuoles, and organelles (Cubeddu, Pifferi, Taroni, & Torricelli, 2002; Fukshansky et al., 1993). Since theoretical models on the resulting photon migration in the tissue have only recently been developed for fruit and vegetable tissue (Cubeddu et al., 2002; Fraser, Jordan, Künnemeyer, & McGlone, 2003), empirical, chemometric approaches are still needed to address this problem. In general, instruments for NIR and vis/NIR spectroscopy can be divided in three groups: desk instruments, compact portable instruments and on-line compatible devices. These devices have been recently developed with attention to their simplification, by integrating user friendly software for statistical processing and partial automation of analysis, with the aim to fit less skillful users. Both in the case of portable and stationary instruments, the fundamental components of these systems are: the light source, the light radiation transport system, the sample compartment and measurement zone, the spectrophotometer sensor, and electronic hardware.

Several types of NIR and vis/NIR applications have been developed for non-destructive measurement of the internal composition of fruits and vegetables, with specific acquisition setups. For small translucent fruits (e.g. grape) the optical measurement can be conducted by using the whole fruit light transmission technique (Fig. 1a), that is known as transmittance mode. In this case, the light source and the detector are placed in opposite positions with the sample in the middle. However, for most of the fruits the size and optical density of the sample (e.g. apple) make transmittance measurements not feasible, therefore reflectance (Fig. 1b) and interactance (Fig. 1c) measurement methods are preferred. In both cases, the light source illuminates the sample from the same side where the detector is positioned. Interactance measurements are typically of laboratory conditions, and are made using a fiber optic probe in contact with the sample. The acquisitions in interactance mode require a light barrier to avoid specular reflection. This setup allows light absorbance measurements to be made through a portion of the sample, typically at depths of about 1 cm, depending

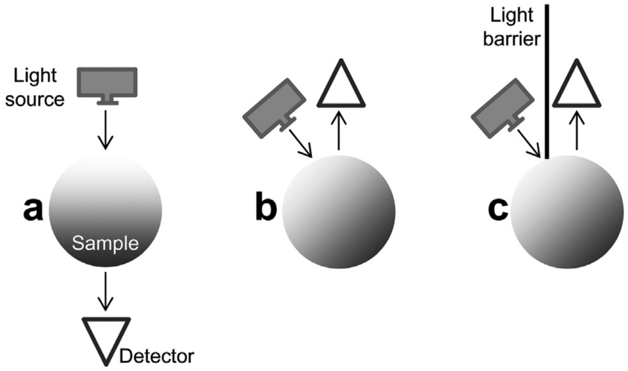

Fig. 1. Setup for the acquisition of a) transmittance, b) reflectance and c) interactance spectra.