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Time-resolved reflectance spectroscopy nondestructively reveals structural changes in 'Pink Lady®' apples during storage

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Abstract

With the aim of studying the optical properties of 'Pink Lady®' apples measured by TRS during storage in normal atmosphere and of relating them to fruit maturity and structural characteristics, 60 apples, measured at harvest by TRS at 670 nm and in the spectral range 740−1100 nm, were ranked on the basis of decreasing μ_a670 (increasing maturity) and randomized into 6 batches corresponding to 6 times of analysis: at harvest and after 7, 15, 29, 66 and 91 days of storage at 1°C. At each storage time, apples were measured by TRS in the same spectral range as at harvest, and firmness, intercellular space volume (RISV), soluble solid content (SSC) and starch hydrolysis were measured; Streif Index and weight loss were computed. Overall, the μ_a spectra showed a maximum at 670 nm (chlorophyll-a) and at 980 nm (water), while the μ'_s spectra had a decreasing trend with the wavelength increase. The μ_a670 and μ_a980 decreased with storage time as a consequence of a decrease in chlorophyll and water contents, respectively. The size and the density of the scattering centers were affected by the interplay of various phenomena: starch hydrolysis, flesh softening, water loss and RISV increase. High correlation coefficients were found between μ_a in the spectral region 920−1100 nm and firmness, Streif Index and RISV, while low correlation coefficients were observed between μ_a and SSC, and between μ'_s and all the quality parameters. Using PLS analysis, good prediction for firmness, RISV and Streif Index were obtained using μ_a spectra; models' performance improved when μ_a and μ'_s are combined.

Keywords: apple structure, TRS, absorption coefficient, scattering coefficient, fruit maturity

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1. Introduction

Apple fruit is mainly composed of the fleshy tissue of parenchyma cells permeated with vascular tissue and intercellular air spaces enclosed by the epidermis. Each tissue has a different microstructure composition which determines the fruit mechanical properties affecting texture and gas (O_2 and CO_2) diffusivity determinant of fruit respiration. Cell size and shape, presence of an adhesive middle lamella between individual cells, turgor pressure, mechanical properties of the cell wall, the amount of intercellular spaces and subcellular features (plasma membrane and plasmodesmata) determine the macroscopic properties of fruit. The knowledge of all microstructural characteristic is important for the understanding of fruit quality at harvest and after storage, as well as the susceptibility to physiological disorders. The shape and size of these components show considerable variability according to cultivar, fruit development, harvest date and storage conditions [1-3].

A fruit can be modelled as a diffusive media, where light distribution is determined by the interplay between scattering phenomena (due to fruit microstructure) and light absorption (due to the presence of chromophores and other chemical compounds). Time-resolved reflectance spectroscopy (TRS) provides a complete optical characterization of diffusive media with the simultaneous non-invasive measurement of the optical properties of absorption and scattering. TRS is based on the measurement of the temporal delay and the broadening experienced by a short laser pulse (pulse duration in the order of 100 ps) while travelling through a turbid medium [4]. By using an appropriate theoretical model of light penetration for the analysis of photon time distribution, it is possible to simultaneously estimate the absorption coefficient (μ_a) and the reduced scattering coefficient (μ'_s). Light penetration achieved by TRS in most fruit and vegetables can be as great as 1-2 cm, depending on the optical properties [5]. Hence, TRS provides information on the internal properties of the medium and is not significantly affected by surface features [6].

Previous studies on apples have shown that μ_a measured at 630 nm (μ_a630) is related to fruit maturity: more mature apples (low μ_a630 values) had lower titratable acidity at harvest and higher soluble solids after storage compared to less mature fruit (high μ_a630 values) and were perceived sweeter, more aromatic and were more appreciated by panellist at sensory analysis [7]. On the other hand, the reduced scattering coefficient gave an insight into the textural properties of apple fruit: μ'_s measured at 750 and 780 nm were linked to pectin composition showing a high and positive correlation with galacturonic acid content in water soluble pectin fraction, and a negative correlation with residue insoluble pectin and protopectin index [8]. The μ'_s measured in the range between 750 and 790 nm were also related to mechanical properties of fruit (firmness, stiffness, intercellular spaces) and to sensory attributed related to structure (firm, crispy, mealy and juicy) [9, 10].

The aim of this work was to study the optical properties of 'Pink Lady®' apples measured by TRS in the near infrared spectral range during storage in normal atmosphere, and to relate these optical properties to fruit maturity and structural characteristics.

2. Materials and Methods

Sixty apples, picked in Laimburg (Bolzano, Italy), at harvest were individually weighed and measured by TRS at 670 nm and in the spectral range 740−1100 nm on two opposite positions around the equator region. Apples were ranked on the basis of decreasing μ_a670, averaged on the two fruit sides (increasing maturity), and randomized into 6 batches corresponding to 6 times of analysis: at harvest (0) and after 7, 15, 29, 66 and 91 days of storage at 1°C in normal atmosphere. At each storage time, apples were measured by TRS in the same spectral range as at harvest. In parallel, flesh firmness (11 mm diameter plunger mounted on an Instron UTM, crosshead speed 200 mm/min), intercellular space volume (RISV, [11]), soluble solid content (SSC) and starch hydrolysis (EUROFRU scale from 1=minimum to