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Research Paper

Non-destructive assessment of kiwifruit physico-chemical parameters to optimise the osmotic dehydration process: A study on FT-NIR spectroscopy

Patricio R. Santagapita [a,b,c,*], *Urszula Tylewicz* [a], *Valentina Panarese* [a], *Pietro Rocculi* [a], *Marco Dalla Rosa* [a]

[a] *Alma Mater Studiorum, University of Bologna, Department of Agricultural and Food Sciences and Interdepartmental Centre for Agri-Food Industrial Research, Piazza Goidanich 60, Cesena, FC, Italy*
[b] *University of Buenos Aires, Faculty of Exact and Natural Sciences, Industry Department, Intendente Güiraldes 2160 – Ciudad Universitaria – C1428EGA (FCEyN-UBA), Ciudad Autónoma de Buenos Aires, Argentina*
[c] *National Council of Scientific and Technical Research (CONICET), Ciudad Autónoma de Buenos Aires, Argentina*

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Non-destructive rapid method based on FT-NIR spectroscopy is assessed to predict the processing response of raw materials at different ripening stages. During osmotic dehydration (61.5% sucrose solution, 5 h) ripe and unripe kiwifruits were analysed with FT-NIR spectroscopy and the most representative physico-chemical parameters to osmotic dehydration (dry matter, soluble solids content, water self-diffusion coefficient and firmness) were assessed by destructive measurements. Predictive models were successfully built by means of partial least square regression (PLSR) analysis ($R^2 > 0.772$, test set validations) for all the four parameters destructively measured. The application of vector normalisation pre-processing was critical to eliminate spectral information that did not relate to the OD process. FT-NIR spectroscopy can successfully predict the evolution of kiwifruit physico-chemical parameters during osmotic dehydration. Thus it can be used as a tool to tune online the process parameters (e.g. time and temperature) to obtain a standardised final product starting from non-homogeneous raw materials.

1. Introduction

Kiwifruit is one of the most suitable fruits to be osmo-dehydrated because its response to the treatment makes it possible to process raw unripe fruits, improving at the same time their firmness and taste (Bressa, Dalla Rosa, & Mastrocola, 1997).

Since the principal function of osmotic dehydration (OD) is tissue dewatering (Chiralt & Fito, 2003), it is important to study

* *Corresponding author*. Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, Departamento de Industrias, Intendente Güiraldes 2160 – Ciudad Universitaria – C1428EGA (FCEyN-UBA), Ciudad Autónoma de Buenos Aires, Argentina. Tel.: +54 11 4576 3366.
E-mail address: prs@di.fcen.uba.ar (P.R. Santagapita).
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and understand its effect on the water state and distribution inside the single cells, as well as in the whole cellular tissue. It is well known that OD promotes water activity reduction (Gianotti, Sacchetti, Guerzoni, & Dalla Rosa, 2001; Silva, Fernandes, & Mauro, 2014) and thus the decrease in freezable water content (Cheng, Zhang, Adhikari, & Islam, 2014; Cornillon, 2000; Tylewicz et al., 2011), that makes it a suitable process for the production of safe products with intermediate water content. However these parameters provide only general information about water in whole samples, in particular the water-solid exchange between the tissue and osmotic medium, without taking into account the water distribution in the different cellular compartments. Time domain nuclear magnetic resonance (TD-NMR) has been found to make up for these deficiencies, giving more detailed information about intensity and relaxation time (T_2) of protons separately for vacuoles, cytoplasm/extracellular spaces and cell wall (Cheng et al., 2014; Marigheto, Venturi, & Hills, 2008; Tylewicz et al., 2011). The OD process causes shrinkage of the vacuole and filling of intracellular spaces with external solution and vacuole content. These phenomena can be translated into the reduction of T_2 in both vacuole and cytoplasm/extracellular spaces compartments, while the intensity of the proton pool located in vacuoles and cytoplasm/extracellular spaces decrease and increase respectively (Panarese et al., 2012; Tylewicz et al., 2011). Recently Santagapita et al. (2013) used TD-NMR techniques to evaluate the water self-diffusion coefficient (D_w) both for whole kiwifruit tissue protons and for each cellular compartment protons. The water self-diffusion coefficient depended on the distinctive cellular structures and solutes in kiwifruit and it decreased during OD due to water loss and sugar gain phenomena. Unfortunately NMR is a destructive method regarding the sampling procedure, since it involves cutting the sample into small cylinders of 7–8 mm of diameter. Moreover, difficulty and high cost of its application has forced researchers and industry to find other techniques, which could be non-destructive and with lower cost and higher availability. Near infrared (NIR) spectroscopy could be a good alternative for studying not only the basic information such as moisture and soluble solids contents but also diffusive phenomena. In order to study the latter, the correlation NIR/NMR response is necessary. Besides, several acquisition accessories are available for NIR spectroscopy, allowing the direct measurement of a desired product, leaving the sample unaffected.

NIR spectroscopy covers the wavelength range from 780 to 2500 nm. When the NIR radiation hits the product, the spectral characteristics change through wavelength dependent scattering and absorption. This change depends on the chemical composition of the product, as well as on its light scattering properties, which are related to the microstructure (Nicolaï et al., 2007).

In the past few years, NIR spectroscopy has been used to determine some physico-chemical parameters such as dry matter (or moisture content) and soluble solid content of several fruits. Particularly, dry matter (Qiang, Mingjie, Jianrong, Huazhu, & Chaitep, 2010; Slaughter & Crisosto, 1998), solid soluble content (Arazuri, Jarén, & Arana, 2005; Chen & Han, 2012; Slaughter & Crisosto, 1998), fructose, glucose and starch contents (Slaughter & Crisosto, 1998), acidity (pH) (Moghimi, Aghkhani, Sazgarnia, & Sarmad, 2010) and firmness (Liu, Guo, & Yue, 2011) have already been successfully predicted by NIR spectroscopy in ripe kiwifruit. Recently, the internal quality of Hayward kiwifruit has been assessed by a non-destructive method such waveguide spectroscopy (Ragni, Cevoli, Berardinelli, & Silaghi, 2012), in which the soluble solid content (SSC) and the Magness–Taylor flesh firmness were adequately predicted.

It is known that OD promotes critical changes in kiwifruit, regarding texture profiles, dry matter and SSC (Panarese et al., 2012; Santagapita et al., 2013). The magnitude of those changes depends on the maturity degree of raw kiwifruits and on the OD process. Thus, if the ripening state of different batches subjected to OD is different, the final product quality will be affected.

The aim of present work was to evaluate the feasibility of a non-destructive and rapid method based on NIR spectroscopy to determine the changes promoted by OD on kiwifruit at different ripening stages. This study could represent a very important tool to make rapid decisions about the optimum OD time, according to the desired product target.

2. Materials and methods

2.1. Raw materials

Kiwifruits (*Actinidia deliciosa* var *deliciosa* cv Hayward) with homogeneous size and refractometric index of 6.9 ± 0.8 °Brix were bought on the local market (a special unripe batch of kiwifruits was requested). Kiwifruits were sorted to eliminate damaged or defective fruit and were partially ripened at 4 ± 1 °C and 90–95% relative humidity (RH) in air. During storage, fruits with refractometric index values of 9 ± 1 and 14.1 ± 0.9 °Brix were selected and defined respectively as LB (low °Brix) and HB (high °Brix) kiwifruits.

2.2. Osmotic dehydration treatment

The kiwifruits were sliced (10 mm thick) transversally to their axis, removing the peel using a scalpel. Three slices from the central part of each kiwifruit were prepared, placed in mesh baskets and immersed in 61.5% (w/v) sucrose solution equilibrated at 25 °C. The OD solution concentration was chosen based on previous studies (Panarese et al., 2012; Santagapita et al., 2013; Tylewicz et al., 2011). The baskets (13 × 3 cm, diameter × height) were continuously stirred with a propeller. The rotational speed (0.2 g-force) was experimentally determined to assure negligible external resistance to mass transfer. Both LB and HB kiwifruits were subjected to OD for pre-established contact period of 0, 30, 60, 180, and 300 min. For each time–temperature condition 30 kiwifruit slices were processed, processing 300 kiwifruit slices in total. The product/solution ratio was about 1:4 (w/w) to avoid changes in the solution concentration during the treatment (Kowalska & Lenart, 2001; Singh, Bawa, & Ahmed, 1998). The temperature and stirring of the solution was maintained constant as reported by Tylewicz et al. (2011). After the OD process, the slices were removed from the osmotic solution, their surface rinsed with distilled water and gently blotted with tissue paper.