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Isothermal and differential scanning calorimetries to evaluate structural and metabolic alterations of osmo-dehydrated kiwifruit as a function of ripening stage

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ABSTRACT

The effects of osmotic dehydration (OD) on kiwifruit outer pericarp tissue as affected by treatment extent (0–300 min) and raw kiwifruit ripening stage (9 and 14 °Bx) were investigated.
Differential scanning calorimetry (DSC) measurements show decomposition of cell wall components (pectins, cellulose and hemi-celluloses). Changes in decomposition parameters (peak temperature lowered and enthalpy increased) were observed related to kiwifruit ripening degree and OD extent increased. Cell wall pectin network disassembly led to the formation of compounds with lower degradation temperature. Raw unripe fruits showed higher firmness values and lower compressibility compared to ripe and OD treated fruits.
Isothermal calorimetry revealed metabolic heat production of unripe fruits decreasing linearly with the OD extent. Ripe fruit heat production sharply decreased during the first treatment hour, probably as a consequence of membrane integrity loss.
Industrial relevance: OD leads to moisture removal and solute uptake in vegetable tissue, providing minimally processed commodities or ingredients for bakery or ice-cream industry. The industrial relevance is the energy-efficiency, since the process does not require water-phase change. OD provokes still unknown collateral alterations on tissue structure and metabolism. The present work applies a new calorimetric approach to evaluate both structure and metabolism changes on kiwifruit as reliant on process extent and raw fruit ripening stage.

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1. Introduction

Osmotic dehydration treatment or Dewatering–Impregnation–Soaking (DIS) in concentrated solution increases solid concentration in food. Whole fruits or pieces are immersed in hypertonic solution and once contact takes place, three spontaneous fluxes of mass transfer occur. A major flux of water is accompanied by a minor one composed of those solutes capable of crossing the semipermeable membranes of the food into the solution. In a reverse process, some solutes are transferred from the solution into the food as a third flux (Torregiani & Bertolo, 2001).

Raw kiwifruits used in the fresh-cut industry require high firmness and low soluble solids content (Beaulieu, 2010). As a consequence the final fresh-cut product will not present the sufficient ripening level for the consumption. As suggested by Bressa, Dalla Rosa, and Mastrocola (1997), if the unripe fruit slices were subjected to osmotic dehydration (OD) treatment, a new product ready for the consumption could be obtained. Few minutes of OD in 61.5% (w/v) sucrose solution enable unripe kiwifruit slices to reach soluble solids content comparable with ripe fruit (Tylewicz, Rząca, Rocculi, Romani, & Dalla Rosa, 2010). Panarese et al. (2012) showed in an ultrastructural study that cell wall of kiwifruit tissue subjected to OD decreased the reactivity for staining; similar change was also detected on cell wall of ripe kiwifruit tissue and it was related to the highly branched hemicelluloses characterizing the cell wall of ripe fruit (Hallett, Macrae, & Wegrzyn, 1992). Besides both OD and ripening processes can lead to loss of cell wall integrity and modification of tissue textural properties and carbohydrate content, detectable through texture measurements and differential scanning calorimetry (DSC) on different fruits (Falcão-Rodrigues, Moldão-Martins, & Beirão-da-Costa, 2007; Pereira, Carmello-Guerreiro, & Hubinger, 2009; Yashoda, Prabha, & Tharanathan, 2006). Furthermore osmotic dehydration involves alteration on the fruit metabolism (Castelló, Fito, & Chiralt, 2006). Fruit and vegetables are biological active tissues and produce heat as a result of their metabolism. Calorimetric measurements of heat production rate have been used to provide indications of plant tissue metabolic response such as respiration and reaction to wounding stress (Gómez Galindo, Rocculi, Wadsö, & Sjöholm, 2005; Rocculi et al., 2007; Rocculi et al., 2005; Wadsö, Gomez, Sjöholm, & Rocculi, 2004), to quantify the cell damage occurring during thermal treatments (Gomez, Teledo,

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Wadsö, Gekas, & Sjöholm, 2004; Gómez Galindo, Teledo, & Sjöholm, 2005).

The aim of the present work was to evaluate the effect of the ripening stage on the changes of textural and thermal properties and metabolic response promoted by OD on kiwifruit.

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 °Bx were bought on the local market. Kiwifruits were sorted to eliminate damaged or defective fruit and were partially ripened at 4 ± 1 °C and 90–95% of relative humidity (RH) in air. Along the storage time, two kiwifruit groups were selected with refractometric index values of 9 ± 1 (called as LB, low °Brix) and 14.1 ± 0.9 °Bx (called as HB, high °Brix). The osmotic dehydration treatment was applied on fruit hand peeled and cut into 10 mm thick slices with a sharp knife.

2.2. Osmotic dehydration treatment

Osmotic dehydration (OD) was carried out by dipping the samples in 61.5% (w/v) sucrose solution equilibrated at 25 °C for pre-established contact periods of 0, 30, 60, 180 and 300 min, as reported by Tylewicz et al. (2011). The product/solution ratio was about 1:4 (w/w) and at each OD time, the osmotic solution was changed in order to avoid changes in its concentration. The temperature of the solution was maintained constant by a thermo-controlled water bath (25 °C). Eight OD runs were performed on a total of 240 kiwifruit slices (30 kiwifruit slices for each time–°Brix group condition). Each slice was taken from the central part of each kiwifruit (about 60 g) and was placed in mesh baskets and immersed in osmotic solution. The baskets were constantly stirred at 0.2 g with a propeller. The rotational speed was experimentally determined to assure negligible outer resistance to mass transfer. After that, the slices were taken from the osmotic solution and each slice face was rinsed with distilled water for 3 s and placed on blotting paper for 2 s.

2.3. Analytical determinations

2.3.1. Moisture content and soluble solids content

The moisture content of kiwifruit samples was determined gravimetrically by difference in weight before and after drying in vacuum oven (pressure ≤ 100 mm Hg) at 70 °C. The drying was performed until a constant weight was achieved (AOAC International, 2002). Duplicate measurements were conducted for each kiwifruit slice.

The soluble solids content (SSC) was determined at 20 °C by measuring the refractive index with a digital refractometer (PR1, Atago, Japan) calibrated with distilled water. For each sample, the SSC was determined in triplicate on the juice obtained from each kiwifruit slice, after filtering through Whatman #1 filter paper.

For both moisture content and SSC determinations, average values were obtained for 30 kiwifruit slices for each time–°Brix group condition.

2.3.2. Texture analysis

Firmness (N) was evaluated by performing a penetration test on kiwifruit slices' outer pericarp using a TA-HDi500 texture analyzer (Stable Micro Systems, Surrey, UK) with a 5 kg load cell. Experiment was run with a metal probe of 6 mm diameter, and a rate and depth of penetration of 1 mm s^{-1} and 6 mm, respectively (Beirão da Costa, Steiner, Correia, Empis, & Moldão Martins, 2006). Firmness (N) was evaluated as the first peak force value according to other authors (Beirão da Costa et al., 2006). The mean of two replicates of each kiwifruit slice was averaged for each OD condition (n = 30).

2.3.3. Differential scanning calorimetry (DSC)

DSC analysis was carried out on a Pyris 6 DSC (Perkin-Elmer Corporation, Wellesley, USA). The DSC was equipped with a low-temperature cooling unit Intracooler II (Perkin-Elmer Corporation, Wellesley, USA). Temperature calibration was performed with indium (mp 156.60 °C), tin (mp 231.88 °C), and zinc (mp 419.47 °C); heat flow was calibrated using the heat of fusion of indium ($\Delta H = 28.71$ J g^{-1}). For the calibration, the same heating rate, as used for sample measurements, was applied under a dry nitrogen gas flux of 20 ml min^{-1}. About 10 mg of kiwifruit outer pericarp tissue was sampled and placed in 50 μl punctured aluminum pans prior to measurements. An empty pan was used as a reference. DSC curves were obtained by heating samples from 100 to 390 °C with a heating rate of 10 °C min^{-1}. The chosen range of temperatures enabled to evaluate only decomposition transitions, as kiwifruit T_g has been found in the range of −30 to −50 °C (Li et al., 2008). Three replicates for each treatment condition were performed.

2.3.4. Isothermal microcalorimetry

Six cylinders were sampled using a core borer from the outer pericarp tissue of each kiwifruit slice and placed in sealed 20 ml glass ampoule. Four replicates for each treatment condition were performed. The rate of heat production was continuously measured in a TAM air isothermal calorimeter (Thermometric AB, Järfälla, Sweden), with a sensitivity (precision) of ± 10 μW (Wadsö & Gómez Galindo, 2009). This instrument contains eight twin calorimeters. Each calorimeter had its own reference and the measured signal is the difference between the sample signal and the reference signal. The reference is a sample with thermal properties similar to the sample, except that it does not produce any heat; water was chosen as the reference material. By assuming that the heat capacity of kiwifruit dry matter (C_{ST}) is 1 J g^{-1} K^{-1}, the quantity of water in each reference ampoule (M_W) was determined as:

$$M_w = \frac{C_{ST} \cdot M_{ST} + C_W \cdot M_W}{C_W} \quad (1)$$

where M_{ST} is the dry matter content and M_W is the water content of the kiwifruit sample; C_W is the water heat capacity. The measurements were performed at 20 °C for 24 h. Immediately after the ampoules discharging from the calorimeters, the CO_2 percentage was measured in the ampoule headspaces by a gas analyzer (MFA III S/L gas analyzer, Witt-Gasetechnik, Witten, Germany).

2.3.5. Respiration rate

The respiration rate was evaluated on raw and 60 min treated HB kiwifruit, using a static method. Six cylinders were sampled from the outer pericarp tissue of the slice and sealed in 20 ml glass ampoule. O_2 percentage of triplicate specimens was measured in the ampoule headspace by a gas analyzer (MFA III S/L gas analyzer, Witt-Gasetechnik) after 2, 3, 5, 22 and 24 h at 20 °C from the sampling. The respiration rate (RRO_2) was calculated as:

$$RRO_2 = \frac{mm_{O_2} \cdot V_{head} \cdot \frac{(20.8 - \%O_{2,head})}{100} 101.325}{t \cdot m \cdot R \cdot 293} \quad (2)$$

where mm_{O_2} is the oxygen molar mass (g/mol), V_{head} is the ampoule headspace volume (L), $\%O_{2,\ head}$ is the oxygen percentage in the ampoule headspace at time t (h); m is the sample mass (kg); R is the gas constant (L kPa K^{-1} mol^{-1}).

2.4. Statistical analysis

Significance of the osmotic dehydration effects was evaluated by means of one-way analysis of variance using the software STATISTICA 6.0 (Statsoft Inc., Tulsa, UK). The analysis of the means

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was performed using the Tukey procedure at $P<0.05$. Correlation analysis was performed using GraphPad Prism v.5 (GraphPad Software, Inc., La Jolla, CA, USA) with two-tailed P values <0.05, assuming that data were sampled from Gaussian distribution.

3. Results and discussion

3.1. Soluble solid content of ripe and unripe OD-kiwifruit

It is well known that osmotic treatment leads to a great water loss from kiwifruit and the simultaneous counter-diffusion of solutes from the concentrated solution into the kiwifruit tissues. The soluble solids content (SSC) increase along osmotic dehydration resulted similar for both kiwifruit groups (LB, low and HB, high °Brix degree), as shown in Fig. 1a. However it is possible to observe that the SSC increase of HB group was lower than that of LB group. This result may be due to the higher sugar content of ripe fruit that, in turn, negatively affects the difference between the osmotic potential of the solution and the fruit, which is the driving force of osmotic transport phenomena (Chiralt & Fito, 2003; Shi & Le Maguer, 2003). Furthermore the decrease of the osmotic pressure difference between solution and fruit over time leads to the decrease of the rate of SCC uptake for both LB and HB kiwifruits, as shown in Fig. 1a. The same trend was observed in previously reported data for kiwifruit slices treated in the same osmotic conditions at 25 °C (Santagapita et al., 2012; Tylewicz et al., 2011). Fig. 1b shows the linear regression between soluble solids content and dry matter. Both parameters increased together during OD with very high correlation coefficient ($r>0.96$) for both LB and HB groups.

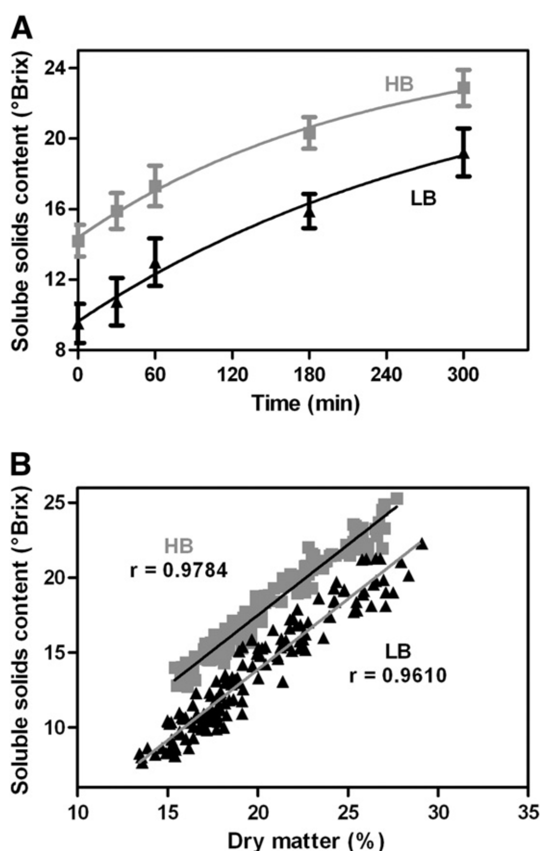

Fig. 1. a) Solid gain expressed as soluble solids content vs. time of dehydration treatment for low (LB) and high (HB) °Brix kiwifruit slices. Each point represents an average of at least 30 kiwifruit slices and bars represent standard deviation values. b) Linear correlation between soluble solids content and dry matter.

3.2. Texture and cell wall integrity of ripe and unripe OD-kiwifruit: texture and DSC measurements

Fig. 2b shows the texture changes of low and high °Brix kiwifruit as a function of osmotic dehydration time. The importance of texture on minimally processed fruits both for technological and qualitative aspects is noteworthy. According to Muntada, Gerschenson, Alzamora, and Castro (1998), firmness is one of the most important parameters since its changes could be related to structural changes. Several structures are affected along OD treatment. Panarese et al. (2012) described that OD induced plasmolysis, shrinkage of the vacuole compartment, changes in size and structure of the cell walls of outer pericarp during OD and dissolution of the middle lamella. The firmness change produced along OD could be partially limited by adding texture-enhancing solutes such as Ca^{2+} and pectinmethylesterase (PME) to the sucrose solution (Van Buggenhout, Grauwet, Van Loey, & Hendrickx, 2008).

The overall shape of the curve obtained by penetration test is shown in Fig. 2a for both HB and LB groups, before and after 300 min of OD. Firmness values showed the expected differences for both LB and HB raw kiwifruits due to the higher ripening on HB samples (Barboni, Cannac, & Chiaramonti, 2010; Beirão da Costa et al., 2006). OD-treated samples of both kiwifruit groups displayed lower firmness and higher compressibility than raw samples. Raw LB revealed the highest firmness values, but the firmness loss along OD was more marked with respect to HB kiwifruit (Fig. 2a). This in turn can be related to the higher capabilities of LB group to increase the SSC (Fig. 1a). The lower firmness values observed after 300 min can be also observed in Fig. 2b, which shows firmness vs. OD time. The major firmness loss occurred during the first hour of OD with different rates for the two kiwifruit groups. LB and HB firmness loss occurring during the first hour of OD resulted respectively four and two times higher than the firmness loss recorded during the following 4 h of treatment.

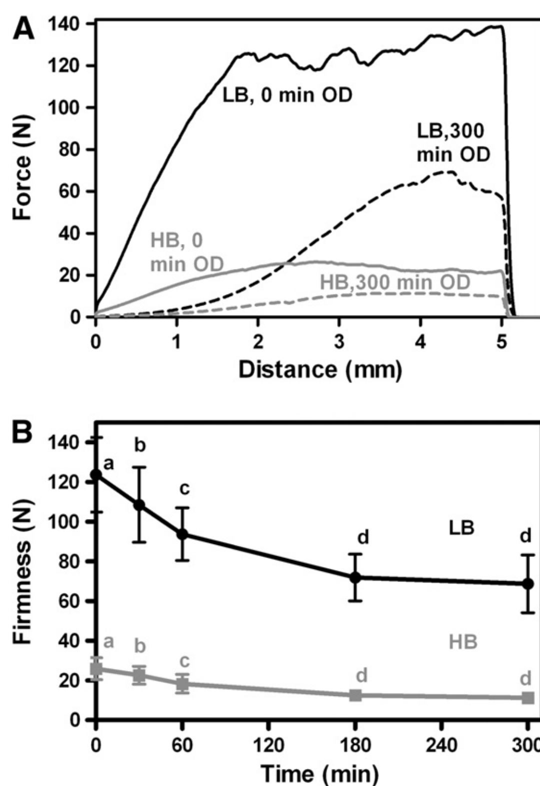

Fig. 2. Overall shape of the penetration curves (a) and firmness (b) of low (LB) and high (HB) °Brix kiwifruit slices as a function of OD duration.

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Fig. 2a depicts for the OD-treated samples two very different slopes prior to arrive to the first peak/maximum force (Fig. 2a). Instead, raw samples (especially LB samples) showed a unique slope prior to the first peak. Since the slope of the force deformation curve (N/s) until the first inflection point indicates the point of non-destructive elastic deformation (Beaulieu, 2010), it could be proposed that the LB raw material did not present the non-destructive elastic deformation, but appears slightly with the ripening increase and especially along OD.

DSC measurements were performed to follow the modification promoted by OD on the principal components of the cell wall, which are: pectins (between 40 and 50%), cellulose (between 23 and 35%), hemi-celluloses (between 15 and 25%) and proteins (between 1 and 7%) (Redgwell, Melton, & Brasch, 1991).

Fig. 3 shows the thermograms obtained for LB and HB kiwifruits before and after 300 min of OD. It is worth noting that characteristic decomposition temperatures of sucrose and cell wall principal components are detected in the range 150–350 °C (Abd-Elrahman & Ahmed, 2009; Einhorn-Stoll, Kunzek, & Dongowski, 2007; Ray, Sarkar, Basak, & Rana, 2004).

Peak 1, highlighted in Fig. 3 by a square shape, can be attributed to sucrose, which decomposition temperature was reported between 206 and 232 °C (Abd-Elrahman & Ahmed, 2009). Peak 1 integration has been carried out from 180 to 235 °C; on average the obtained peak temperature value (209 ± 2 °C) was consistent with the decomposition temperature of sucrose found in previous researches (Abd-Elrahman & Ahmed, 2009).

The peak enthalpy values of peak 1 reported in Table 1 appeared higher for HB than for LB kiwifruit, following the sucrose content increase. Enthalpy values increased slowly for LB along OD whereas enthalpy increased up to 3 times after 3 h for HB kiwifruit.

For higher temperature, a complex peak appears (peak 2, pointed out in Fig. 3 through arrows), ascribable to cell wall component (pectins, hemi-celluloses and cellulose) decomposition (Abd-Elrahman & Ahmed, 2009; Einhorn-Stoll et al., 2007; Ray et al., 2004). For the overall evaluation of cell wall component modification, peak 2 integration has been carried out from 180 to 370 °C. To obtain values, the peak 1 enthalpy has been subtracted in order to reduce the integral overestimation caused by peak overlap.

Peak 2 related to raw LB kiwifruit showed a higher heat flow value than the corresponding peak of raw HB kiwifruit, ascribable to the different physiological state of the cell wall in the LB and the HB raw material (Bennett, 2002). Values of peak 2 associated to HB and LB kiwifruits changed similarly along OD. This analogy can be related to cell wall modifications promoted by both fruit ripening and OD, as pre-established by microstructure analysis by Panarese et al. (2012). Actually, even in terms of calorimetric response, the effect of ripening and OD seems to be comparable; this is confirmed by the very similar shape of LB 300 min and HB 0 min thermograms, in the temperature range corresponding to cell wall component decomposition.

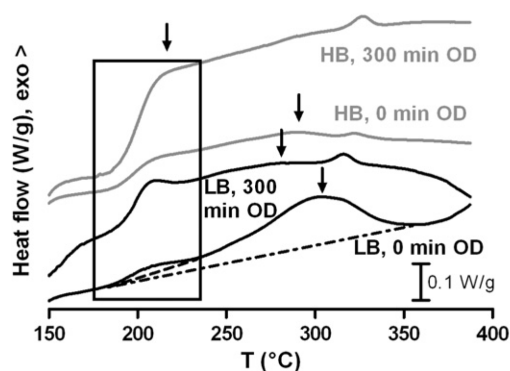

Fig. 3. Thermograms obtained by differential scanning calorimetry (DSC) of low (LB) and high (HB) °Brix kiwifruit slices raw (0 min) and subjected to 300 min of osmotic dehydration. The square indicates the changes that occurred to peak 1 and arrows point out the peak temperature of peak 2. The dashed lines show the two analyzed peaks (values reported in Table 1).

Table 1
Enthalpy values of raw (0 min) and subjected to OD low and high °Brix kiwifruit slices. Peaks 1 and 2 correspond to those evidenced by the dashed lines in Fig. 3.

Kiwifruit ripening (°Brix)	Time (min)	Peak 1	Peak 2
		Area (J/g)*	Area (J/g)*
Low °Brix	0	1.6 ± 0.2^{c}	72 ± 4^{b}
	30	4.5 ± 0.5^{a}	84 ± 11^{b}
	60	4.0 ± 0.4^{a}	79 ± 15^{b}
	180	2.7 ± 0.4^{b}	142 ± 26^{a}
	300	4.1 ± 0.4^{a}	105 ± 27^{ab}
High °Brix	0	10 ± 2^{c}	84 ± 6^{b}
	30	11.9 ± 0.4^{c}	62 ± 3^{b}
	60	11 ± 1^{c}	62 ± 21^{b}
	180	27 ± 2^{b}	101 ± 3^{a}
	300	37 ± 3^{a}	107 ± 17^{a}

* Values in the same column followed by different letters differ significantly at $P<0.05$ levels.

Peak 2 enthalpy values decreased and increased respectively as a consequence of OD for both kiwifruit groups, mainly for HB kiwifruit (Table 1). Bennett (2002) determined that the softening of vegetal tissues during the first stages of ripening is due to depolymerization of hemi-cellulose. Then, the rupture of the pectin network predominates in the last stages of ripening and during fruit over-ripening. Hemi-cellulose depolymerization and pectin network disassembly lead to the formation of more compounds with minor molecular mass (Bennett, 2002; Lloyd & Wyman, 2003). These compounds depicted lower degradation temperature and overall higher enthalpy values.

OD-treated and ripe samples show a little peak between 320 and 327 °C (Fig. 3) with enthalpy values varying between 1.2 and 1.7 J/g and it could be possibly related to cellulose (Godeck, Kunzek, & Kabbert, 2001). In LB raw kiwifruit this peak is hard to read out because of the decomposition enthalpy of those cell wall components that are affected by both ripening and OD.

Raw LB kiwifruit thermograms showed well separated peaks and higher heat flow value than those corresponding to HB. As a consequence of OD peak temperature attributed to cell wall decomposition diminish and enthalpy values increases. These changes are parallel to firmness loss (Fig. 2b) and once again reveal the relation between firmness changes and cell wall integrity loss.

3.3. Metabolic response of ripe and unripe OD-kiwifruit: respiration and isothermal microcalorimetry measurements

Kiwifruit as well as other fruits and vegetables are metabolic active tissues producing heat as a result of respiration. Fig. 4 depicts an example of heat production profiles of cooked, raw and osmo-dehydrated LB kiwifruit samples during 24 h at 20 °C. Thermal treated (100 °C for 10 min) kiwifruit was used as a control as not producing any metabolic heat. Sample ampoule loading into a calorimeter induced a large initial disturbance lasting for at least 20–30 min. The thermograms evidenced a progressive decrease of the specific thermal power P (mW per gram of kiwifruit sample) by increasing the OD time. A similar behavior was obtained for HB kiwifruit.

The aerobic cell respiration produces about 455 kJ of heat per mol of O_2 consumed or mol of CO_2 produced. Therefore calorimetric measurements on tissue metabolism can give similar information as respiration measurements (Wadsö & Gómez Galindo, 2009). In order to verify this relationship in our experimental conditions, and to confirm the capability of TAM-Air isothermal calorimeter to study the metabolic consequences promoted by osmosis, respiration measurements have been performed on HB raw and 60 min treated kiwifruit samples and compared with the heat production results.

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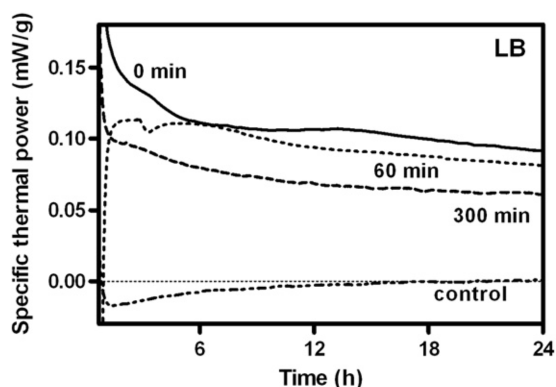

Fig. 4. Specific thermal power profiles of pericarp tissue cylinders of raw, cooked and selected osmo-dehydrated kiwifruits during 24 h of analysis at 20 °C. Each thermogram is an average of four replicates. The initial signal disturbance is a consequence of sample ampoule loading.

The respiration rate RRO_2 ($g\,O_2\,h^{-1}\,kg^{-1}$) was measured using a static method at 2, 3, 5, 22 and 24 h. On the other hand, the thermal power values ($mJ\,s^{-1}\,g^{-1}$) have been integrated at the same measuring time of RRO_2 and expressed as heat of respiration (RRO_2cal) ($g\,O_2\,h^{-1}\,kg^{-1}$). The respiration within the 24 h of analysis was considered aerobic (Iversen, Wilhelmsen, & Criddle, 1989) and the anaerobic metabolism was neglected since the percentage of CO_2 determined by a gas analyzer in the ampoule headspace after 24 h at 20 °C did not exceed the 4–5% for both raw and 60 min treated samples (data not reported). Fig. 5 shows the correlation between RRO_2 values obtained by gas measurement and RRO_2cal values calculated from calorimetric analysis. These parameters appeared strictly and positively correlated for both raw and 60 min treated samples with correlation coefficients higher than 0.98. In order to better understand the effect of OD on the metabolic heat of both LB and HB samples, the thermal power curves have been integrated from 1 to 13 h of analysis. The thermal powers corresponding to the initial disturbance consequent to the sample ampoule loading have been subtracted. Obtained specific heat production (P12h) ($J\,g^{-1}$) results vs. treatment time are reported in Fig. 6. The metabolic heat production of the raw samples was very similar for both the ripening stage investigated and progressively decreased with the increasing of OD time. Gomez et al. (2004) suggested that the decrease in thermal power in carrot tissue is correlated with cell membrane damage as measured by the inactivation of plasma membrane H^+-ATPase. During OD tissue damage progressively occurs. This is induced by osmotic stress and is accompanied by a reduction of the number of viable cells, as reported by Mavroudis, Dejmek, and Sjoholm (2004). The cellular response to osmotic stress depends on the botanical origin of the observed tissue, i.e. Ferrando and Spiess (2001) observed the reduction of viability of strawberries' cortex cells during OD process, while the protoplast of onion epidermis did not suffer any irreversible changes through the process. Metabolic heat production of LB kiwifruit samples showed a linear decrease with the proceeding of OD; instead, the detected heat production for HB samples sharply decreased along the first 60 min of the treatment. These differences can be explained by the different physiological state of the fruit tissue: cells of more ripe kiwifruit seem to be more sensible to osmotic stress because of the increase of membrane permeability due to the loss of membrane integrity during kiwifruit ripening (Song et al., 2009).

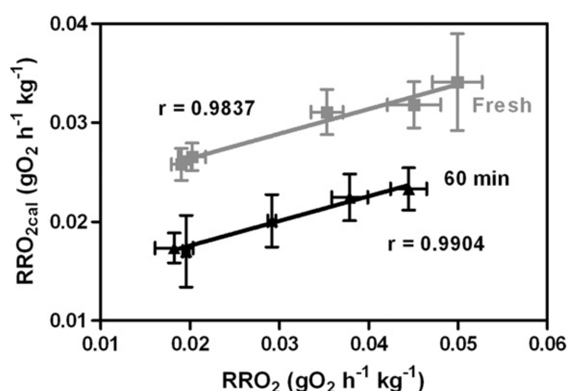

Fig. 5. Linear correlation between respiration rates obtained by O_2 measurement (RRO_2) or calculated from specific thermal power curves (RRO_2cal) for raw and 60 min treated HB samples.

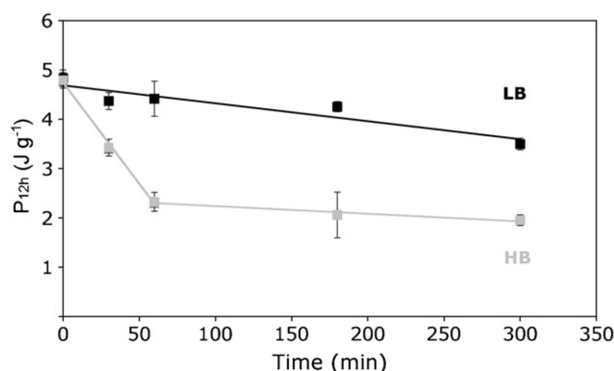

Fig. 6. Specific heat production (P_{12h}) ($J\,g^{-1}$) results vs. osmotic-dehydration treatment time for LB and HB samples.

The possibility to highlight how the response to OD treatment was modulated by fruit ripeness suggests that a combined calorimetric approach can represent a powerful and versatile tool to investigate the behavior of vegetable tissues during minimal processing. Then, by knowing the extent of changes on water and solutes during OD, which in turn modified the textural, structural and viability/respiratory characteristics of the final product, it is possible to exploit both raw unripe and ripe kiwifruits from a technological point of view.

4. Conclusions

OD promoted critical changes in the kiwifruit, as pointed out with good agreement by both texture profiles and thermal degradation thermograms. The magnitude of those changes depended on the maturity degree of raw kiwifruits.

DSC revealed hemicellulose degradation and pectin network rupture of kiwifruit cell wall. The measurements showed that the decrease of peak temperature and the increase of enthalpy were both associated with kiwifruit maturity degree and OD extent. These changes seemed to be responsible for the lower force necessary to achieve penetration in the HB kiwifruit.

Isothermal calorimetry confirmed its high potentiality for calo-respirometric measurement on fresh vegetable tissues. Metabolic heat production of kiwifruit samples showed a linear decrease with the proceeding of OD, confirming the damage progression on tissue induced by osmotic stress, accompanied by the reduction of the number of viable cells. Ripe kiwifruit metabolic heat reduction was more pronounced, probably as a consequence of the membrane integrity loss occurring within the kiwifruit ripening.

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References

Abd-Elrahman, M. I., & Ahmed, S. M. (2009). Thermal degradation kinetics and geometrical stability of D-sucrose. *International Journal of Polymeric Materials*, *58*, 322–335.

AOAC International (2002). *Official methods of analysis (OMA) of AOAC International, 17th Edition, USA. Method number: 920.15.* Available at http://www.eoma.aoac.org/

Barboni, T., Cannac, M., & Chiaramonti, N. (2010). Effect of cold storage and ozone treatment on physicochemical parameters, soluble sugars and organic acids in *Actinidia deliciosa*. *Food Chemistry*, *121*, 946–951.

Beaulieu, J. (2010). Factors affecting sensory quality of fresh-cut produce. In O. Martin-Belloso, & R. Soliva-Fortuny (Eds.), *Advances in fresh-cut fruits and vegetables processing* (pp. 115–143). Boca Raton: CRC Press.

Beirão da Costa, S., Steiner, A., Correia, L., Empis, J., & Moldão Martins, M. (2006). Effects of maturity stage and mild heat treatments on quality of minimally processed kiwifruit. *Journal of Food Engineering*, *76*, 616–625.

Bennett, A. B. (2002). Biochemical and genetical determinants of cell wall disassembly in ripening fruit: a general model. *HortScience*, *37*, 3–6.

Bressa, F., Dalla Rosa, M., & Mastrocola, D. (1997). Use of a direct osmosis treatment to produce minimally processed kiwifruit slices in a continuous pilot plant. *Acta Horticulturae (ISHS)*, *444*, 649–654.

Castelló, M. L., Fito, P. J., & Chiralt, A. (2006). Effect of osmotic dehydration and vacuum impregnation on respiration rate of cut strawberries. *Lewensmittel Food Science and Technology*, *39*, 1171–1179.

Chiralt, A., & Fito, P. (2003). Transport mechanisms in osmotic dehydration: The role of the structure. *Food Science and Technology International*, *9*, 179–186.

Einhorn-Stoll, U., Kunzek, H., & Dongowski, G. (2007). Thermal analysis of chemically and mechanically modified pectins. *Food Hydrocolloids*, *21*, 1101–1112.

Falcão-Rodrigues, M. M., Moldão-Martins, M., & Beirão-da-Costa, M. L. (2007). DSC as a tool to assess physiological evolution of apples preserved by edibles coatings. *Food Chemistry*, *102*, 475–480.

Ferrando, M., & Spiess, W. E. L. (2001). Cellular response of plant tissue during the osmotic treatment with sucrose, maltose and trehalose solutions. *Journal of Food Engineering*, *49*, 115–127.

Godeck, R., Kunzek, H., & Kabbert, R. (2001). Thermal analysis of plant cell wall materials depending on the chemical structure and pre-treatment prior to drying. *European Food Research and Technology*, *213*, 395–404.

Gomez, F., Teledo, R., Wadsö, L., Gekas, V., & Sjöholm, I. (2004). Isothermal calorimetry approach to evaluate tissue damage in carrot slices upon thermal processing. *Journal of Food Engineering*, *65*, 165–173.

Gómez Galindo, F., Rocculi, P., Wadsö, L., & Sjöholm, I. (2005). The potential of isothermal calorimetry in monitoring and predicting quality changes during processing and storage of minimally processed fruits and vegetables. *Trends in Food Science & Technology*, *16*, 325–331.

Gómez Galindo, F., Teledo, R., & Sjöholm, I. (2005). Tissue damage in heated carrot slices. Comparing mild hot water blanching and infrared heating. *Journal of Food Engineering*, *67*, 381–385.

Hallett, I. C., Macrae, E. A., & Wegrzyn, T. F. (1992). Changes in kiwifruit cell wall ultrastructure and cell packing during postharvest ripening. *International Journal of Plant Science*, *154*, 49–60.

Iversen, E., Wilhelmsen, E., & Criddle, R. S. (1989). Calorimetric examination of cut fresh pineapple metabolism. *Journal of Food Science*, *54*, 1246–1249.

Li, S., Zhang, M., Song, X., Duan, X., Zhou, L., & Sun, J. (2008). Effect of pretreatments and storage conditions on the quality of frozen kiwifruit slices. *International Journal of Food Properties*, *11*, 68–78.

Lloyd, T., & Wyman, C. E. (2003). Application of a depolymerization model for predicting thermochemical hydrolysis of hemicellulose. *Applied Biochemistry and Biotechnology*, *105–108*, 53–67.

Mavroudis, N. E., Dejmek, P., & Sjoholm, I. (2004). Osmotic-treatment-induced cell death and osmotic processing kinetics of apples with characterised raw material properties. *Journal of Food Engineering*, *63*, 47–56.

Muntada, V., Gerschenson, L. N., Alzamora, S. M., & Castro, M. A. (1998). Solute infusion effects on texture of minimally processed kiwifruit. *Journal of Food Science*, *63*, 616–620.

Panarese, V., Laghi, L., Pisi, A., Tylewicz, U., Dalla Rosa, M., & Rocculi, P. (2012). Effect of osmotic dehydration on *Actinidia deliciosa* kiwifruit: A combined NMR and ultrastructural study. *Food Chemistry*, *132*, 1706–1712.

Pereira, L. M., Carmello-Guerreiro, S. M., & Hubinger, M. D. (2009). Microscopic features, mechanical and thermal properties of osmotically dehydrated guavas. *LWT — Food Science and Technology*, *42*, 378–384.

Ray, D., Sarkar, B. K., Basak, R. K., & Rana, A. K. (2004). Thermal behavior of vinyl ester resin matrix composites reinforced with alkali-treated jute fibers. *Journal of Applied Polymer Science*, *94*, 123–129.

Redgwell, R. J., Melton, L. D., & Brasch, D. J. (1991). Changes to pectic and hemicellulosic polysaccharides of kiwifruit during ripening. *Acta Horticulturae (ISHS)*, *297*, 627–634.

Rocculi, P., Gómez Galindo, F., Mendoza, F., Wadsö, L., Romani, S., Dalla Rosa, M., et al. (2007). Effect of the application of anti-browning substrates on the metabolic activity and sugar composition of fresh-cut potatoes. *Postharvest Biology and Technology*, *43*, 151–157.

Rocculi, P., Romani, S., Dalla Rosa, M., Gómez Galindo, F., Sjöholm, I., & Wadsö, L. (2005). Use of isothermal calorimetry to monitor and predict quality and shelf-life of minimally processed fruits and vegetables. *Industrie Alimentari*, *44*, 841–846.

Santagapita, P., Laghi, L., Panarese, V., Tylewicz, U., Rocculi, P., & Dalla Rosa, M. (2012). Modification of transverse NMR relaxation times and water diffusion coefficients of kiwifruit pericarp tissue subjected to osmotic dehydration. *Food and Bioprocess Technology*. doi:10.1007/s11947-012-0818-5.

Shi, J., & Le Maguer, M. (2003). Mass transfer flux at solid–liquid contacting interface. *Food Science and Technology International*, *9*, 193–199.

Song, L., Gao, H., Chen, H., Mao, J., Zhou, Y., Chen, W., et al. (2009). Effects of short-term anoxic treatment on antioxidant ability and membrane integrity of postharvest kiwifruit during storage. *Food Chemistry*, *114*, 1216–1221.

Torregiani, D., & Bertolo, G. (2001). Osmotic pre-treatments in fruit processing: Chemical, physical and structural effects. *Journal of Food Engineering*, *49*, 247–253.

Tylewicz, U., Panarese, V., Laghi, L., Rocculi, P., Nowacka, M., Placucci, G., et al. (2011). NMR and DSC water study during osmotic dehydration of *Actinidia deliciosa* and *Actinidia chinensis* kiwifruit. *Food Biophysics*, *6*, 327–333.

Tylewicz, U., Rząca, M., Rocculi, P., Romani, S., & Dalla Rosa, M. (2010). Evolution of quality characteristics of Hayward and Hort16A kiwifruit during osmotic dehydration. *Fruit Processing*, *4*, 150–153.

Van Buggenhout, S., Grauwet, T., Van Loey, A., & Hendrickx, M. (2008). Use of pectinmethylesterase and calcium in osmotic dehydration and osmodehydrofreezing of strawberries. *European Food Research and Technology*, *226*, 1145–1154.

Wadsö, L., Gomez, F., Sjöholm, I., & Rocculi, P. (2004). Effect of tissue wounding on the results from calorimetric measurements of vegetable respiration. *Thermochimica Acta*, *422*, 89–93.

Wadsö, L., & Gómez Galindo, F. (2009). Isothermal calorimetry for biological applications in food science and technology. *Food Control*, *20*, 956–961.

Yashoda, H. M., Prabha, T. N., & Tharanathan, R. N. (2006). Mango ripening: Changes in cell wall constituents in relation to textural softening. *Journal of the Science of Food and Agriculture*, *86*, 713–721.