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Impact device for measuring the flesh firmness of kiwifruits

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ABSTRACT

The device used in the present study consists of a conveyer belt that throws the fruit onto a flat horizontal plate connected to a load cell. The vertical distance between plate and conveyer belt (drop height) as well as the speed of the belt can be continuously adjusted. Tests were carried out by selecting three different values of drop height and speed. The Magness-Taylor (MTf) index was used as reference, destructive parameter, to describe the flesh firmness and to set-up predictive models. The digitalized time history of the force was analysed to extract some mechanical indices (peak force, impact duration and impulse) used to predict MTf by simple or multiple regression analyses. Moreover, each point of the entire time history was processed by artificial neural network (ANN) software to predict MTf. The goodness of fit, expressed as R^2, was up to 0.823 with the regression models. On the whole, the peak force was the best predictor. The ANNs did not involve a substantial increase in goodness of fit with respect to the best regression models: +8.3%, as mean, 37% as maximum. The speed or position at which the fruit impacts the plate can represent an important parameter influencing the MTf prediction. Free dropping of the fruit instead of throwing onto the plate by the conveyer did not provide a better prediction. The impact device did not cause mechanical damage to the kiwifruits.

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1. Introduction

Non-destructive on-line measurement of the flesh firmness of fruits and vegetables is a difficult as well as a strenuously pursued target. The development of micro electronics, information technology and data analysis methods has provided a great impulse to the progress in this sector during the last decade. Many studies addressed firmness prediction and various techniques were used to do this: ultrasonic (Mizrach et al., 1997, 1999; Mizrach and Flitsanov, 1999; Mizrach 2007; Kim et al., 2009); optical, in the NIR or VIS–NIR range (Lemmertyn et al., 1998; Park et al., 2003; Lu and Bailey, 2005; Peng and Lu 2007; Jha et al., 2006; Liu et al., 2008; Bureau et al., 2009; Pérez-Marín et al., 2009); based on the acoustic impulse response (Duprat et al., 1997; Schotte et al., 1999; De Belie et al., 2000; Pathaveerat et al., 2008), the mechanical impact responses, or other stress of the biological material (Ozer et al., 1998; Peleg, 1999; Jarén and García-Pardo, 2002; Valero et al., 2007; Menesatti et al., 2009; Slaughter et al., 2009). Several studies examined and compared different excitations such as acoustic and mechanical impact (Shmulevich et al., 2003; De Ketelaere et al., 2006); acoustic and optic (Subedi and Walsh, 2009). In other studies two or more systems were used together to improve performances: sound plus impact plus micro-deformation (Steinmetz et al., 1996), microwave plus optical spectroscopy (Lleó et al., 2007); micro-deformation plus optical (Ruiz-Altisent et al., 2006). Some devices used laser systems to measure displacement or deformation induced mechanically by means of a shaker (Terasaki et al., 2001) or by air pressure puffs (McGlone and Jordan, 2000). Finally, a method based on imaging spectrography of laser-induced fluorescence of the chlorophyll should also be considered in the optical domain (Noh and Lu, 2007).

The flesh firmness of several species of fruits has been predicted by the above mentioned systems: apples (Duprat et al., 1997; Lemmertyn et al., 1998; Peleg, 1999; De Belie et al., 2000; Jarén and García-Pardo, 2002; Park et al., 2003; Shmulevich et al., 2003; Lu and Bailey, 2005; De Ketelaere et al., 2006; Noh and Lu, 2007; Peng and Lu, 2007; Kim et al., 2009); peaches or nectarines (Steinmetz et al., 1996; Peleg, 1999; Ruiz-Altisent et al., 2006; Lleó et al., 2007; Valero et al., 2007; Pérez-Marín et al., 2009; Subedi and Walsh, 2009); tomatoes (Duprat et al., 1997; Schotte et al., 1999; De Ketelaere and De Baerdemaeker, 2001; De Ketelaere et al., 2006; Mizrach, 2007); mangoes (Mizrach et al., 1997, 1999; Jha et al., 2006; Subedi and Walsh, 2009); pears (Jarén and García-Pardo, 2002; Liu et al., 2008; Slaughter et al. 2009); apricots (McGlone and Jordan, 2000; Bureau et al., 2009); bananas (Subedi and Walsh, 2009); kiwifruits (McGlone and Kawano, 1998; McGlone and Jordan, 2000; Terasaki et al., 2001); avocados (Mizrach and Flitsanov, 1999); plums (Valero et al., 2007); orange (Menesatti et al., 2009);

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pineapples (Pathaveerat et al., 2008). Models for predicting the flesh firmness parameters (max penetration force, elasticity modulus and stiffness coefficient) were obtained by using different statistical–mathematical techniques, depending on the nature of data. Partial least square and principal component analysis were widely used to process spectral data obtained by optical systems (see, for instance, Lemmertyn et al. 1998; Liu et al., 2008) but also for ultrasonic data (Mizrach et al., 1999). Linear, multiple linear, non linear regressions and discriminant analysis were used for ultrasonic test and based on impact impulse response techniques (see, for instance, Valero et al., 2007; Pathaveerat et al., 2008). Finally, artificial neural network (ANN) was also used for modelling optical data (Fu et al., 2007; Noh and Lu, 2007) or to predict the pear firmness by signals of electronic nose sensors (Zhang et al., 2008) and magnetic resonance imaging technique (Zhou and Li, 2007).

The average coefficient of determination of the models for predicting the flesh firmness was found to be roughly 0.66 for the ultrasonic, 0.73 for the impact acoustic, 0.75 for the mechanical, and 0.70 for the optical systems. The combination of different methods did not produce a greater average increase of the R^2 values with respect to the best ones mentioned. The reported results refer to a prediction that take into account the data dispersion (in other words, it is based on single fruit determination). A very best fit can be shown if the curves are drawn using average data, of course. So, for example, the R^2 of ultrasonic measurement can reach 0.99.

By using a simple plate impact sensor that receives the fruits from a conveyer belt at different speeds and processing the data by ANNs, aim of the present study is to provide a contribution on the feasibility of on-line sorting based on the firmness of kiwifruits.

2. Materials and methods

The device used in the present research consists of a conveyer belt 485 mm long and 95 mm wide that throws the fruit onto a flat plate made of aluminium connected to a load cell (Fig. 1). The dimensions of the plate are 80 mm in width, 105 mm in length an 8 mm in thickness. It has resonance frequencies at about 540 and 730–740 Hz (Fig. 2). The response of the plate to vibrations was analysed in the range from 30 to 1500 Hz by using an electro-dynamic shaker (Unholtz-Dickie Corporation, S202) driven by an electronic power amplifier (Unholtz-Dickie Corporation, MA240) and controlled by a control console (Data Physics Corporation, DP 350 Win). A constant sinusoidal acceleration at 30 m/s^2 (peak) in linear sweep was used to excite the impact plate. Micro-accelerometers (Brüel & Kjær 4374) were fixed in the middle of the short and long side edges of the plate. The signals coming from the transducers were conditioned and amplified by a B&K Nexus 2692 charge amplifier and digitalized by an acquisition board (National instrument NI4552) installed in a PC.

The speed of the conveyer belt can be adjusted and is controlled by means of an encoder that detects the speed of the electric motor driving the belt. The height from the belt to the plate can also be continuously varied. The output of the load cell (full scale = 200 N) is connected to the NI4552 acquisition board. Acquisition, graphical representation and data storage are carried out by means of a programme written in Labview 5.1. The data acquisition is triggered by the encoder embedded in the motor. Tests were carried out in nine different working conditions by combining three drop heights (10, 15, and 20 mm) with three forward speeds (0.7, 1.0, and 1.3 m/s). To analyse possible differences in prediction power between static and dynamical conditions, a test was also carried out without the conveyer belt, dropping the fruit from a height of 10, 15 and 20 mm. For this test a simple previously set-up device (Ragni and Berardinelli, 2001) was used.

A total of 504 kiwifruits, variety *Hayward*, coming from a 4-month post harvest refrigerating process at 0 °C were placed in a room in controlled temperature condition at 20 °C. The impact and destructive tests were carried out 6 h, one week and two

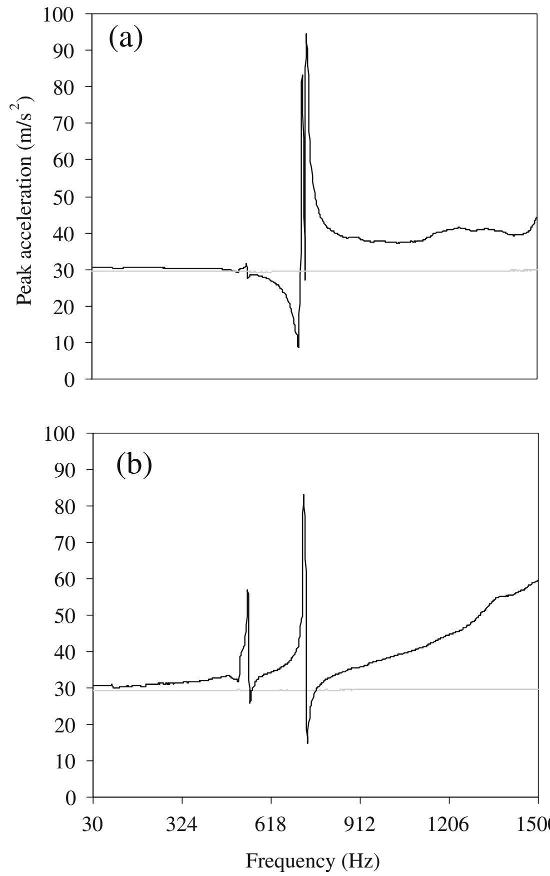

Fig. 2. Response of the impact plate excited by a constant sinusoidal acceleration at 30 m/s^2 (peak) in linear sweep from 30 to 1500 Hz. Vibrations were measured in the middle of the (a) short and (b) long side edges of the plate.

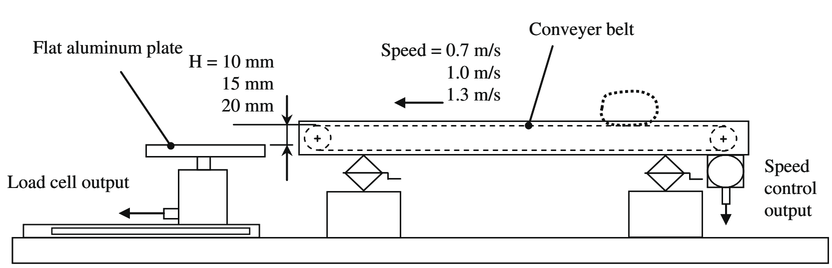

Fig. 1. Experimental set-up (note: the figure is not to scale).

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