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Non-destructive impact test for assessment of tomato maturity

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ABSTRACT

A non-destructive method for assessing the maturity of tomatoes was developed using the mechanical properties of the fruit under the falling impact test. The levels of maturity were classified with cluster and discriminant analyses on the primitive impact measurements and their derivatives. The accuracy of classification was improved with linear discriminant analysis and the number of indices being processed was reduced with stepwise regression analysis. The accuracy of classification is 82.3% by the use of all nine indices and 79.2% by the three most dominant indices. The performance shows that falling impact together with linear discriminant analysis provides a promising non-destructive approach in assessing the maturity of tomatoes. The developed falling impact apparatus could be used in the realization of an on-line quality sorter for tomatoes and the developed methodology can be used to improve the accuracy of classification for a similar problem.

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1. Introduction

Maturity grading of fruits in harvesting before delivery to the market is beneficial for indicating the optimal time for marketing or for optimisation of storage management (Wu and Abbott, 2002; Singh and Reddy, 2006). The maturity of fruit is a qualitative measure, which is difficult to identify. The firmness of a fruit is an index of the mechanical, chemical and rheological properties of the fruit. It is negatively proportional to the maturity of the fruit (Mohsenin, 1986; Lesage and Destain, 1996) and can hence be used as an alternative indicator to maturity in fruit grading and sorting (Jarén and Garczía-Pardo, 2002; De Ketelaere et al., 2006). The compression and the penetration tests are reliable and traditional methods used to estimate fruit firmness. A force–deformation profile is obtained from the test and accordingly, the firmness of the specimen is estimated in reference to the geometrical information of the profile, e.g. the proportional limit, bio-yield strength, and critical strength (ASAE, 1993; Delwiche, 2000; Fidelibus et al., 2002). Several devices related to the classical penetrometer have been developed (Abbott, 1999; Peleg, 1999). While many of these proposed techniques result in reasonably accurate and reproducible estimates, they are of a destructive nature, represent mechanical properties at the point of measurement only, and cannot be used as real-time monitoring for fruit sorting.

There are several non-destructive, fast and objective quality measures that have been proposed and some of them are commercially available (De Ketelaere et al., 2006). Some promising dynamic methods for fruit quality evaluation are based on measurement of fruit response to force vibration or impact (Peleg, 1999; De Ketelaere and de Baerdemaeker, 2001; Jarén and Garczía-Pardo, 2002; García-Ramos et al., 2003; De Ketelaere et al., 2006). The use of mass impact (Delwiche et al., 1987), either by a light rigid mass or fruit falling, has been widely applied in the detection of fruit maturity. The material is either dropped freely onto a force transducer or hammered with an accelerating rigid mass. The impact responses are interpreted in either the frequency or the time domain. The impact indices show a strong correlation with the firmness of vegetables and fruits (Brusewitz et al., 1991; García-Ramos et al., 2003). This method has been used in the detection of the firmness of fruits such as apples (Peleg, 1999; Shmulevich et al., 2003), mangoes (Hahn, 2004), papayas (Reyes et al., 1996), peaches (Delwiche et al., 1987; Wang et al., 2006; Gutierrez et al., 2007), and tomatoes (De Ketelaere and de Baerdemaeker, 2001).

Most of the research in using impact test for estimation of fruit maturity use the impact indices proposed by Delwiche et al. (1987). Estimation based on the parameters does not result in a promising accuracy of classification. A correlation of 0.75 was arrived at for peaches in an off-line study (Delwiche et al., 1987). The method was soon implemented on an automated fruit sorter which gives a classification accuracy of 0.74 (Delwiche et al., 1989). The classification accuracy of the sorter was improved to

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0.84 by replacing falling impact with hammer impact (Delwiche and Sarig, 1991; Delwiche et al., 1996). However, the use of falling impact in detection of fruit firmness is superior to hammer impact because of simpler falling and sensing mechanisms which are more suitable for realisation of on-line sorting.

The indices proposed by Delwiche et al. (1987) are relatively good in practical applications. However, there should be still a space to improve the accuracy of classification when using falling impact based on the proposed indices. Hence, this study investigates the feasibility of falling impact in evaluating tomato maturity via optimisation of the impact indices in the time domain. The study starts from using the original impact indices in the classification and then improves the accuracy through deriving new indices with statistical analyses. Results from destructive penetration and compression tests are used as a calibrator. The maturity derived from firmness is divided into three levels: unripe, half-ripe, and ripe.

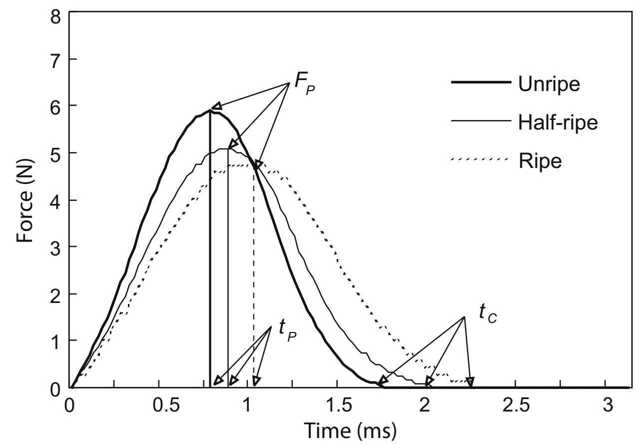

Fig. 2. Three impact responses of tomatoes at different levels of maturity.

2. Measurement of tomato firmness

2.1. Apparatus

Fig. 1 illustrates the experimental system developed in the laboratory for investigation into the impact reaction of fruit falling onto a load cell. The apparatus consists of a pneumatic holding mechanism, a load cell and transmitter, a digital oscilloscope, and a computer. A fruit is held by a manually manipulated vacuum sucker and released to fall freely from an adjustable height onto the load cell. The surface of the load cell that receives the impact of the fruit is stainless steel. The vacuum pressure and the falling height are manually adjustable with the rule of thumb of not incurring bruise damage to the fruit, as inadequate mechanical impact may affect the firmness of the tomato (Van linden et al., 2006, 2007).

The load cell (208C02, PCB Piezotronics, NY, USA) is a piezoelectric transducer that generates an analogical signal proportional to the applied force. Its signal is amplified with a 480A09 transmitter (PCB Piezotronics, NY, USA). A digital oscilloscope (2827-02, Brüel & Kjær, Demark) digitizes and visualizes the amplified analogue signal and then transmits it to the computer through RS-232 serial communication. Data are stored on the computer for subsequent off-line analysis.

2.2. Falling impact and fruit firmness

The fruit falling on the load cell produces a force that causes a deformation on its flesh. To avoid incurring bruise damage to the fruit, the falling height was adjusted to a distance that does not cause inelastic deformation to the fruit. This non-destructive procedure was validated through the compression test which assures that the peak impact force is far below the bio-yield point of the fruit. Fig. 2 demonstrates three impact responses of tomatoes at the same weight but significantly different levels of maturity. The fall on the load cell represents a rheoelastic shock, during which there is a transmission of a certain fraction of the total energy of the fruit onto the surface of the transducer. After the first impact, the fruit suffers a second impact due to the rebound and a new transmission of energy is produced. These energy fractions are directly related with the firmness (Chen and De Baerdemaeker, 1995).

Fig. 2 explicitly reveals that a riper tomato impacting onto the load cell, in comparison with a less ripe one, will take more time (t_P) but achieve a smaller peak force (F_P) at a longer contact time (t_C). These measurements can hence be used as an indicator of the maturity of a tomato, as they provide direct mechanical properties of the fruit (Delwiche et al., 1987). In practice, they are used in combined forms to enhance the significance of the measurements. An intuitive approach to signify the measurement is to use the slopes of force to time (Delwiche et al., 1987), defined as $C_1 = F_P/t_P$, $C_2 = F_P/t_P^2$, $C_3 = F_P/t_C$, and $C_4 = F_P/t_C^2$. The variables $C_1, \ldots, C_4$ do not take account of the weight variation among samples. Hence, the weight of sample (W), a maturity-correlated factor (De Ketelaere et al., 2006), is accounted for in this study by introducing two new variables, $C_5 = C_3/W$ and $C_6 = C_4/W$.

3. Materials and methods

3.1. Fruit materials

Plum tomatoes were hand harvested from the same farm at the same time. Extremely large and small tomatoes were rejected.

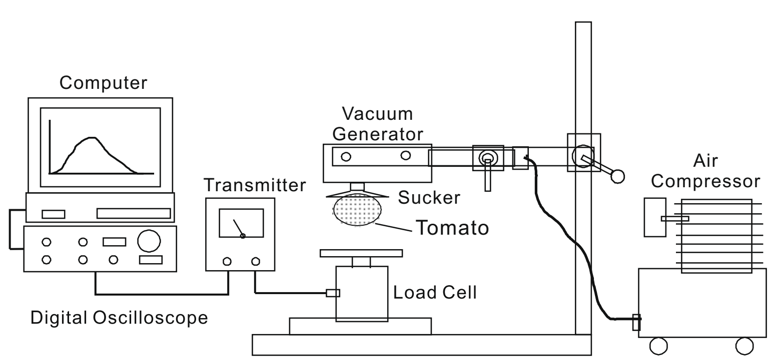

Fig. 1. The impact experimental rig.

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