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Characterising and tracking deterioration patterns of fresh-cut fruit using principal component analysis – Part I

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ABSTRACT

Principal component analysis (PCA) was used to characterise quality deterioration patterns in fresh-cut pineapple, strawberry, kiwifruit and cantaloupe melon during storage. Twenty-seven physiological, biochemical, microbial and sensory attributes, reported as indices of quality, were used to successfully characterise and track deteriorative changes. Freshness for all fruit was characterised by PCA as excellent visual appearance, aroma and firmness. Deterioration was characterised, for the most part, by increased tissue breakdown (exudate and cell permeability levels), firmness loss, increased off-odour development, colour loss (browning and translucency) and high microbial counts. Effects of cultivar and geographic origin were apparent in some fruit. PCA has the potential to track the effects of intrinsic and extrinsic factors of deterioration during storage and could form the basis of future strategies to optimise quality.

1. Introduction

Ensuring quality retention in fresh-cut fruit continues to be a challenge. While storage life and quality are strongly affected by raw materials, severity of processing and storage conditions (Ártés and Gomez, 2006), the precise mechanisms and dynamics of deterioration are incompletely understood. Greater understanding may enable optimised or alternative strategies to be identified and applied. Changes in product appearance and firmness are often first observed, followed by development of off-odours and off-flavours and microbial proliferation. Of particular importance are discolouration (browning, whitening and translucency), loss of firmness (membrane degradation, tissue softening and ion leakage) and decreases in nutritional value (Klein, 1987) coupled with development of off-odours, off-flavours and microbial growth (Brecht, 1995; Varoquaux and Wiley, 1994; Ruiz-Cruz et al., 2010). However these physical, physiological, biochemical and microbial changes occur at different rates and to different extents and are greatly influenced by intrinsic and extrinsic factors, causing significant quality losses between harvest, processing, storage and consumption (Rolle and Chism, 1987; Watada and Qi, 1999; Mahdavian et al., 2007; Safizadeh et al., 2007; Singh et al., 2007; Kazemi et al., 2011; Shirzadeh and Kazemi, 2011).

Significant effects of production locality and/or cultural practices have been noted in many fruit (Blanpied et al., 1987; Rowell, 1988) attributable to the fact that worldwide fruit production has expanded greatly in terms of traditional and new locations of diverse climatic conditions, cultural practices and harvesting techniques. Therefore there is a need for a dynamic overview of the complex continuous quality tests of traditional evaluation systems, where datasets can be simplified to graphical representations for quality interpretation. Such systems are emerging (Rocha et al., 2010; Infante et al., 2011; Hurtado et al., 2012; Chen et al., 2013; Dong et al., 2013; El Kar et al., 2013; Wilson et al., 2013).

In postharvest science, principal component analysis (PCA) is an emerging method for routine data analysis (Reichel et al., 2010; Kienzle et al., 2011). It is regarded as an unsupervised method of multivariate analysis, meaning that the model is not guided in a predetermined direction. Furthermore, PCA is viewed as an iterative measure of 'real world' observation through which a dataset is resolved into a matrix in the form of principal components (PCs) that can be handled by classical statistic methods, visualised and interpreted to extract the particular information required (Wang et al., 2012).

By applying PCA to a range of sensory, physical and chemical data, clearer patterns may emerge that cannot be seen with individual measurements over large data-sets. One way of detecting such patterns is to plot the quality attributes in multidimensional space, the dimensions of which are the new derived variables. In this case, the attributes are ordered along each retained principal

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component (PC) with the distance between each one representing their biological dissimilarity (Holland, 2008).

Typically, only the first two PCs accounts for meaningful variance, hence only PCI and PCII are commonly retained and interpreted in simple structure biplots. Furthermore, because all units of measurement in quality evaluation are different, the data is frequently centred and standardised to unit variance to have equal weight in analysis, with the resulting illustration referred to as a correlation matrix. The loadings produced will show a similar pattern, although their absolute differences will differ, with variables plotted along PCI and PCII displaying different constructs sharing the same conceptual meanings respectively, i.e. good quality and poor quality. In terms of interpretation, a negative loading for an attribute on PCI, for example, means that along PCI, all negative loadings correlate positively with other variables in the same axis plane and negatively with other variables loaded positively.

However, although it is widely used and accepted in postharvest food science and industry, PCA is relatively unpractised when it comes to quality evaluation and factor analysis. The dynamic output from such a system are often visualised as intricate patterns that can neither in detail be predicted nor exactly interpreted by users.

The aim of the present study was to evaluate the effectiveness of PCA in characterising quality changes in a number of fresh-cut fruit. Deterioration patterns due to cultivar and geographic origin differences were also determined with a view of optimising intrinsic factors affecting fresh-cut fruit quality.

2. Materials and methods

2.1. Plant materials

Whole fruit were collected from a local wholesaler (Richardson's Fruit and Vegetables, Limerick, Ireland) the day before each trial and stored at 4 °C (for a maximum of 15 h for chilling sensitive commodities) until processed. Intrinsic factors (geographical variation of fruit origin and cultivar) of intact fruit studied are shown in Table 1.

2.2. Fresh-cut processing and packaging

Fresh-cut fruit were processed at room temperature (~22 °C). Peels, husks, stems and hulls were manually removed using a stainless steel knife and the fruit were cut to size as required. All fruits were cut into 25 mm (pineapple and melon) and ¼ (kiwifruit) sizes while strawberries were de-hulled and halved. All samples (150 g) were placed in rigid polylactic acid (PLA) trays within pillow packs (412.9 cm^2) and sealed using an impulse bench-top heat sealer (Relco, UK Ltd., England). A high barrier laminate flexible film (PET12/PE55) with O_2 and CO_2 permeabilities of 62,814 and 212,776 ml μm/m^2 day atm was used to make the pillow packs (Amcor Flexibles, Gloucester, UK). This resulted in product modification of the atmosphere within packs.

2.3. Quality testing

Quality assessments on fresh-cut packaged fruit were performed on day 0, 1, 4 and 7 of storage.

2.3.1. In-pack gas composition

The percent concentration of atmospheric gases within packs was measured at room temperature (~20 °C) using a gas-space analyser (Systech Instruments, UK) fitted with an air-tight syringe. The mean values of duplicate O_2 and CO_2 concentrations were recorded and the experiment repeated twice.

2.3.2. Moisture loss (%)

Percent weight loss was calculated using the method from Moneruzzaman et al. (2008) and expressed as gram loss per 150 g fresh-cut weight using the following equation:

$$\frac{\text{Initial weight of pack} - \text{Weight on day analysis (g)}}{\text{Initial weight of pack (g)}} \times \frac{100}{1}$$

2.3.3. Drip-loss, exudate and cell permeability

The volume of free liquid released during storage (driploss) was recorded as mL/150 g fresh weight. Exudate levels were quantified using the method by Carlin et al. (1990) with slight modifications, and recorded as grams per 100 g fresh weight. Cell permeability was determined by monitoring leakage of UV-absorbing solutes as reported by Picchioni et al. (1994) with slight modifications. The absorbance of the clarified solution was measured at 260 nm against distilled water (UV/Vis Spectrophotometer, Varian Cary 100, Agilent Technologies Ltd., Dublin, Ireland).

2.3.4. Percent soluble solids

Percent soluble solids were measured in clear fruit juice from homogenised fruit pieces using an Atago Digital Pocket Refractometer (Atago Co., Ltd., Tokyo, Japan).

2.3.5. Tissue pH and titratable acidity

Tissue pH was recorded from homogenised fruit pulp. Clear juice (10 mL) was mixed with 10 mL of distilled and deionised water was measured using a Jenway 3510 pH meter. Titratable acidity was calculated as citric acid by titrating juice samples to pH 8.2 using 0.1 N NaOH.

2.3.6. Colour

Surface colour of fresh-cut fruit was determined using a Minolta chromameter 5081, fitted with an 11-mm aperture and a D_{65} illuminant (Konics Minolta, Sensing Inc., Osaka). Three measurements were taken at random locations on each of the fruit samples, and this was replicated three times. CIE L^*, a^* and b^* values were determined and presented herein.

2.3.7. Texture

Firmness was determined using a TA.XT Plus Texture Analyser (Stable Micro Systems, Surrey, UK) fitted with a 6 mm flat tipped cylindrical probe. The force required to penetrate (F) a piece of fruit was recorded as both the maximum and mean force in Newtons (N). The fresh-cut pieces were of uniform shape and size to allow for repeated accuracy of results. Using the Kramer Shear Cell and Extended Craft Knife (pineapple only) attachments, the maximum force, area and mean force required to shear (S) through 150 g of fruit samples, in duplicate, was recorded in Newtons (N) as an index of product firmness.

2.4. Microbial enumeration

The different media used were prepared, plated and stored according to manufacturer's instructions (Oxoid Ltd., Basingstokes, UK). On each sampling day, 10 g of fruit was aseptically removed from each pack and homogenised with 90 mL of 0.1% peptone water at high speed for 120 s. Serial dilutions (10^{-1} to 10^{-4}) were prepared by mixing 1 mL of the homogenate liquid with 9 mL of 0.1% peptone water. Total viable counts (mesophiles and psychrophiles) and yeasts and moulds were prepared in the following way: aliquots (100 μl) of each serial dilution were applied on to the surface of appropriate media and were surface spread in duplicate using an inoculation spreader. For lactic acid bacteria (LAB), media pour plates were prepared whereby 100 μl of sample was added to the media followed by a molten overlay of media (50 °C). Total