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Microstructure analysis and detection of mealiness in 'Forelle' pear (*Pyrus communis* L.) by means of X-ray computed tomography

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ABSTRACT

Mealiness causes fruit to develop a soft and dry texture during ripening. No technique currently exists to detect mealiness non-destructively. Two studies were conducted to i) determine the potential of X-ray macro computed tomography (macro-CT) to detect mealiness in 'Forelle' pear (*Pyrus communis* L.) non-destructively, and to ii) establish histological differences between mealy and non-mealy fruit using X-ray micro computed tomography (micro-CT). Scans were made after 8 and 11 weeks of cold storage at −0.5 °C and at the end of shelf life of 7 days. Total porosity, pore size distribution and connectivity of cells were measured on regions of interest (ROI) cubes excised from the neck and equator of individual fruit. Macro-CT scans showed the presence of structural disorders in the cortex tissue, identified by micro-CT as large pores, in mealy fruit. These pores were already present at the end of cold storage before fruit would become mealy. Statistical differences with fruit which would ripen and become juicy were significant ($P < 0.05$). The disorder appeared more clearly in the neck than in the equator region of the cortex. At the end of shelf life, porosity was significantly higher in mealy than non-mealy fruit. Micro-CT results confirmed that tissues of mealy fruit were more porous than those of non-mealy fruit, with a larger proportion of pores greater than 56.53 μm. Evidence was found of lysigenous pore formation in mealy fruit. Cells of mealy fruit were larger and oval-shaped while non-mealy fruit cells were more spherical. X-ray computed tomography was shown to be a promising technology for the non-destructive determination of mealiness at an early stage.

1. Introduction

Forelle is the second most planted and exported pear cultivar from South Africa (HORTGRO, 2014). The cultivar is mainly favoured for its exceptional blush, crunchy texture combined with sweet flavour when hard and ripe, but also by traditional consumers of pears who like ripened 'Forelle' for its soft, buttery or melting texture. However, like most European pears, 'Forelle' requires cold storage after harvesting in order for fruit to ripen uniformly (Villalobos-Acuna and Mitcham, 2008). When not stored sufficiently long under cold temperatures, 'Forelle' pears may develop mealiness or astringency or both when fruit ripen at ambient temperatures during the shelf life period (Carmichael, 2011; Martin, 2002). Mealiness in 'Forelle' results in a soft, dry texture which is not desired by the majority of pear consumers (Manning, 2009). The standard practice to reduce mealiness therefore involves storing fruit for a minimum of 12 weeks at −0.5 °C before ripening in shelf life. This practice however, does not guarantee that mealiness does not develop.

Around the world, consumers are increasingly becoming conscious of the quality of foods they consume, particularly those from high income societies where the majority of fruit are consumed (Van Dalen et al., 2007). Mealiness is described in some literature as a 'quiet destroyer', as it does not show in the early stages of the supply chain but rather manifests itself in the hand of the consumer (Newman, 2006). No technique currently exists that can detect mealiness non-destructively and before fruit ripen. Techniques that rely on destructive sampling are not very effective in monitoring batch mealiness because the development of mealiness in one fruit in a batch does not mean occurrence in another (Barreiro et al., 2000). Therefore, a technique that can determine the condition of each individual fruit will be the most suitable for determining mealiness in a batch. Because mealiness has been described as an internal quality condition which is

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situated at the histological level (Lammertyn et al., 2002), techniques that examine the microstructure of the tissue may provide new perspectives to our understanding of mealiness.

Techniques that have received attention in the past few decades for determining conditions not detectable from outside such as mealiness include magnetic resonance imaging (MRI) (Barreiro et al., 1999, 2000; Lammertyn et al., 2003a), ultrasound (Bechar et al., 2005) and X-ray computed tomography (Herremans et al., 2014a; Van Dalen et al., 2007; Bechar et al., 2005). X-rays are electromagnetic radiation ranging from 0.01 to 10 nm (Kotwaliwale et al., 2014). Their use in visualising material properties is premised on the material's ability to impede penetration by X-rays. As X-rays traverse an object of heterogeneous material composition, they are attenuated differently by the different components in the material. This difference in the materials ability to attenuate X-rays, also known as a material's radiodensity is reflected in the shadow images produced on the detector (Johansson, 2004; Fonseca et al., 2009). The shadow images produced can then be transformed into 3-dimensional (3-D) images through mathematical operations (reconstruction) with accompanying software (called computed tomography). Tomography reconstructs two-dimensional (2-D) cross-sectional images or slices through a 3-D object. Consecutive two-dimensional slices are then stacked into a volumetric dataset, forming a virtual 3-D image.

The number of applications of X-ray computed tomography (CT) in plant and food science has increased due to its ability to provide microstructural detail without destroying the structure of the material (Mendoza et al., 2007; Herremans et al., 2013a), with little or no sample preparation or chemical fixation required as in techniques such as scanning electron microscopy. Recently, studies have covered a variety of fruits including mango, kiwi, 'Conference' pear, apple and pomegranates (Cantre et al., 2014a,b; Lammertyn et al., 2003b; Herremans et al., 2013a; Magwaza and Opara, 2014). The applicability of X-ray CT on detecting internal browning disorder in 'Braeburn' apples was demonstrated by Herremans et al. (2013b). The researchers also compared the use of X-ray micro-CT and MRI in detecting watercore disorder and established that micro-CT produces superior classification of watercore in apples when compared to MRI.

Currently, the mechanism of mealiness development in 'Forelle' pear is not clearly understood, and can only be investigated destructively after ripening (Crouch, 2011). A first objective of this study was therefore, to determine whether X-ray CT can be used as a non-destructive imaging method to detect the mealy structure of intact 'Forelle' pears before ripening in comparison to the structure after ripening. We therefore performed X-ray CT measurements and analysed the fruit both at the start and end of 7 days shelf life after 8 weeks of cold storage. Mealiness classes were determined after ripening using a sensory panel of three trained judges and confirmed using a confined compression test. A second objective was to describe microstructural differences between mealy and non-mealy fruit. In this second experiment, the tissue microstructure of samples excised from 'Forelle' pears was visualised and analysed with micro-CT.

2. Materials and methods

2.1. Fruit material

Fruit were harvested in March 2013 within the commercial harvest window for 'Forelle' in South Africa, from two farms, namely Koelfontein (lat. 33.00°S, long. 19.33°E) and La Plaisante (lat. 33.41°S, long 19.19°E), located in the Ceres and Wolseley regions in the Western Cape Province. The fruit were harvested at shoulder height from each tree, from either side of the canopy. Fruit were stored in polyethylene bag (37.5 μm) lined commercial cartons to reduce moisture loss and shrivelling and stored for a period of 8 weeks at −0.5 °C before evaluations. Twenty four fruit was scanned at Stellenbosch University using X-ray macro-CT after 8 weeks of cold storage at −0.5 °C before ripening and again after 7 days after ripening at room temperature. After 8 weeks of cold storage, 100 fruit were shipped to KU Leuven, Belgium where micro-CT scanning was performed after a further 3 weeks of storage at −0.5 °C and again after 7 days shelf life. Fig. 1 shows the sample collection, storage and CT scanning done in the study.

2.2. Fruit quality evaluation

As an indication of harvest maturity, a sample of 100 fruit from each farm were destructively evaluated for fruit weight, fruit firmness, total soluble solids (TSS) and titratable acidity (TA) from both farms (Table 2). An additional 100 fruit per farm were evaluated for maturity (Section 2.3) after 8 weeks at −0.5 °C plus 7 days at 20 °C. After the last tomographic acquisitions fruit weight,

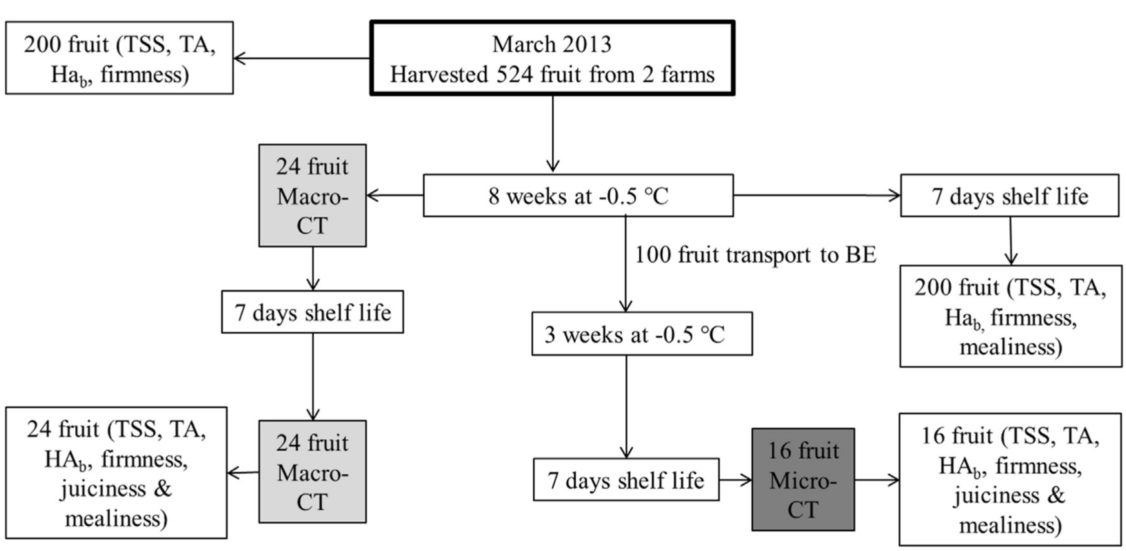

Fig. 1. Schematic presentation of fruit collection, quality measurements, mealiness assessment and macro- and micro-CT scanning of 'Forelle' pear fruit (TSS—total soluble solids, TA—titratable acidity, HA_b—hue angle at blush side, BE—Belgium).