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Original paper

Non-invasive determination of the quality of pomegranate fruit

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Dedicated to Prof. J. Henze, former Head of Postharvest Division, University of Bonn, who died 29 September 2017, aged 89.

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ABSTRACT

In the apparent absence of non-invasive studies of the glossiness and roughness of pomegranate fruit (cv. 'Hicaz') during storage, we investigated changes in their surface micro-structure using two new non-destructive technologies: a profilometer providing 3D digital photography and surface roughness as visual and parametric roughness (Ra; Rz) as well as glossiness by non-invasive luster sensor technology. The 3D intact sections of the pomegranate showed a shimmering surface with fresh fruit, but a rough structure in the RGB images after three weeks storage, associated with a wider range of values, i.e. higher peaks and lower troughs over time, which was visualised in the images.

The roughness coefficients Ra and Rz, provided by the 3D-profilometer, confirmed the colour-coded visualization in the false images and increased with storage time: The roughness values (Ra) were 11 µm for the fresh pomegranate fruit with a smooth peel; 24 µm with aged pomegranate and 43 µm with the old shriveled fruit. The Rz values were 69 µm for the fresh pomegranate fruit with the smooth surface, 148 µm at the intermediate pomegranate and 255 µm for old fruit.

During the three weeks storage, the luster values of red or yellow, non-russet peel sections decreased more rapidly from 90 to 50 arbitrary units (a.u.) than those of the russet peel; the latter areas with a rough appearance showed significantly lower luster values of ca. 40 a.u. compared with the russet-devoid areas. Luster and roughness values were always inversely correlated and confirmed their visual appearance. The lack of significant differences between the luster values of the red and yellow peel portions supports our hypothesis that colour plays an insignificant role in this luster/gloss detection, and proves the suitability of this innovative real-time, contactless and cost-effective sensor technology as a novel evaluation used in post-harvest technology.

1. Introduction

Pomegranate is a nutritionally highly-valued fruit as part of a modern and balanced Mediterranean diet; its valuable minerals including iron, calcium and potassium as well as vitamin C and flavonoids including anthocyanins and polyphenols have beneficial effects on human metabolism and the immune system. Pomegranate is often referred to as a so-called 'super food' or 'super fruit' (Blanke, 2017) and regular consumption of pomegranates may have useful effects on the cardiovascular system, menopausal complaints, *Diabetes mellitus* and many other human disorders (Mertens-Talcott et al., 2006).

Both ingredients, the nutritional, as well as health compounds and external attractiveness are significant quality factors not only of pomegranates. Moreover, they are important marketing factors influencing the consumer's decision for purchasing pomegranates (Borochov-Neori et al., 2009). Determinants of good external attractiveness include large fruit size, bright red peel colour and a fresh, blemish-free appearance (Stover and Mercure, 2007). These quality factors include peel glossiness, which mainly depends on the stage of maturity and storage, and has not been assessed before. Loss of gloss is undesired in the fruit trade, and pomegranates with matt peel are rejected by consumers (Matityahu et al., 2016), because they prefer a deep red, glossy, smooth and slightly shiny surface (Al-Said et al., 2009) indicating maturity and content-related quality (Morton, 1987). However, during storage surface texture changes to a rather shriveled and matt appearance, primarily due to water loss. This poses difficulties and challenges for transport and quality management. The pomegranate is non-climacteric and therefore is not eligible to post-harvest ripening or ethylene treatment of harvested fruits (Morton, 1987). Thus, the fruit is harvested just before its maturity to reach the consumer at full maturity.

Botanically, the pomegranate consists of the pericarp and mesocarp. The mesocarp encompasses the spongy tissue and arils and their segment membranes (septa) (Stover and Mercure, 2007), whereas the pericarp comprises the cuticle and a fibrous layer. The peel should be free from diseases, sunburn damage, strong russet blemishes, slight

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bruising as well as growth cracks (Elyatem and Kader, 1984; Morton, 1987; Janick and Paull, 2008), which can lead to possible spoilage of the fruits during storage and long-distance transportation. When excessively stored, its external appearance can be diminished by shrinkage and loss of gloss (Morton, 1987).

In the apparent absence of spatial 3D peel measurements of its external appearance, the aim of this study was to:

1) determine the peel topography using colour codes (RGB and false images)
2) relate visual glossiness to measured luster values and surface roughness, once visualised and once parametrized as Ra and Rz
3) spatially visualise micro-morphological changes in colour 3D of the pomegranate peel during storage

Therefore, two newly available non-invasive methods are used, i.e. reflection of the pomegranate peel detected by a luster (gloss) sensor and peel roughness measured by a 3D profilometer, which may lead to novel post-harvest technology. Both methods are tested for significance regarding surface changes and their suitability as a quality indicator.

2. Materials and methods

2.1. Fruit sourcing

Fifteen red peeled cv. ‘Hicaz‘ pomegranate (*Punica granatum* L.) fruit of Turkish origin were locally sourced in December 2016 and stored at ca. 15 °C with ca. 50% relative humidity, simulating shelf-life at a retailer. Throughout this experiment, the pomegranates were examined internally and externally and observed for their surface changes.

2.2. Luster sensor technology

For measuring the gloss of the pomegranate surface, the luster sensor CZ-H72 (Keyence, 2005) was used as described by Mukhtar et al. (2014) and Klemm et al. (2017). This sensor includes a measuring head with integrated gloss detection and can thus determine surface reflection without being influenced by surface colour. The red light, provided by a red LED (665 nm), is emitted via an optical fibre and a light spot of 3 mm diameter is generated (Fig. 1a). In addition to the previous set-up (Mukhtar et al., 2014), a holder was designed and machined in our workshop. The distance between the light source and the measured surface was kept constant at 15 mm; the gloss or luster values have no units (Keyence, 2005) and are hence given as a.u.- arbitrary units in Fig. 6.

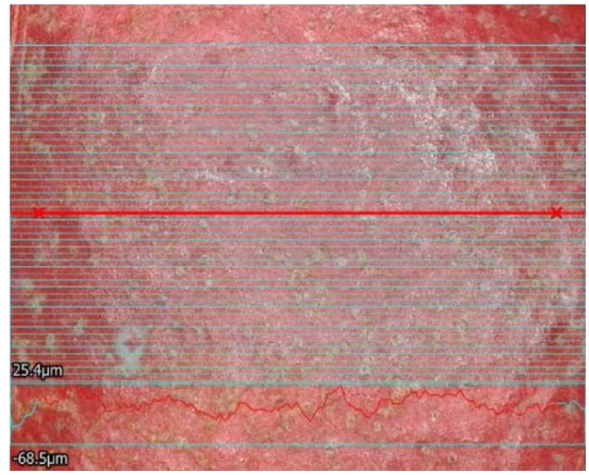

Fig. 2. Split beam technology of the 3D profilometer showing the 51 lines on the pomegranate peel to determine the fruit surface roughness.

2.3. Gloss measurement – pomegranate surfaces

The surfaces of 15 pomegranate fruit were examined *in-situ* from 2 Dec. - 23 Dec. 2016, with a measurement interval of three days. Each pomegranate fruit was measured 20 times at different measuring points on the fruit at each date. These measuring points were subdivided into five yellow, light red, dark red and russet points, respectively.

2.4. Roughness measurements with the colour 3D profilometer

The roughness of the fruit peel/surface was measured using a new 3D profilometer VR-3000 (Keyence, 2016). For a proper comparison and surface analysis over time, three pomegranate fruits of different age were examined at the same measuring date (17 Jan. 2017):

Stage a) Pomegranate I: 1 d old
Stage b) Pomegranate II: 30 d old
Stage c) Pomegranate III: 48 d old

Surface viz peel peaks and troughs were examined non-destructively with three tele-centric lenses. The measuring principle of the 3D profilometer is based on split-beam technology, i.e. an optical process of 51 lines observed from different viewing angles (Fig. 2) and in accordance with EN ISO 25178. The diagonal distance between the corners of the measured pomegranate surface area was 3 cm and corrected for tilt. i.e. the natural curvature of the pomegranate fruit viz surface was normalized by the device to one flat level.

The 3D profilometer provided the arithmetic roughness value Ra

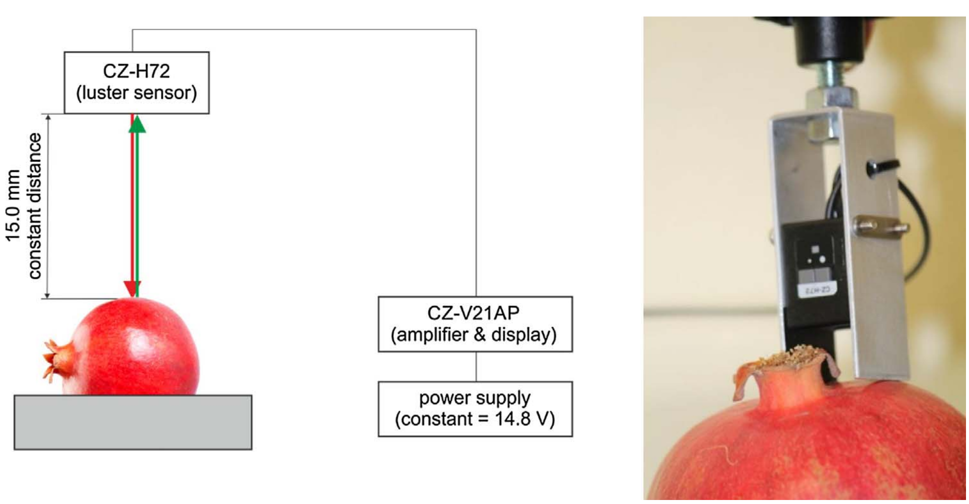

Fig. 1. Gloss measurement using the luster sensor technology and a) measuring scheme, b) the newly machined distance holder.