Non-invasive determination of surface features of banana during ripening

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Abstract Ripening of dessert banana (*Musa sap.*) is associated with changes in colour (green to yellow starting from the centre), softening, and surface features. These have mostly been investigated using distinct technologies. Hence, here changes in surface features were examined with two novel, non-invasive techniques: a luster sensor and a 3D profilometer. The profiler measures the 3D surface characteristics of an area, rather than a single profile line, and corrects data for curvature of the fruit. The luster sensor detected an increase in glossiness from stage 3 (green) to stage F7a (ripe) of ca. 35%, followed by a decrease in glossiness from stage F7a to F7b (overripe). The profilometer provided visual and parametric roughness values (Ra) for ripening. Cavendish bananas showed an increase from 2.5 to 6.6 μm during ripening stage 3 (green) to stage 7b (overripe). Another roughness value, Rz, increased concomitantly from 13.1 μm at stage 3 (green) to 26.9 μm at stage F7b (overripe). The study showed that the centre of the fruit was the best region for surface imaging, because it was the most advanced ripening part of the banana fruit, easily curved, and the region of the fruit can be accessed when a carton was opened. This study shows that it is now possible to monitor the changes in surface glossiness and roughness during the ripening of Cavendish bananas using two novel non-invasive technologies. The compact luster sensor may become a component of a portable probe and manual control of packing units. Differences in the predicted green life can be used to prioritize containers for unloading in the discharge port or to

implement quality-based warehouse management strategies. Containers that arrive at banana ripening rooms before their green life ends, can be re-routed, in addition to the present, colour-based ripening scale.

Keywords Banana (*Musa sap.*) · Glossiness · Micro-morphology · Non-invasive measurement · Optical examination · Ripening · Roughness

Introduction

Ripening of dessert banana (*Musa sap.*) as a climacteric fruit (Robinson and Saúco 2010) implies ripening after harvest (Salunkhe 1995). The ripening is associated with biochemical and physical changes. Biochemical changes include: (a) a conversion of starch into sugar (Willis et al. 1984; Koteswara Reddy et al. 2015), (b) an increase in osmotic potential in the pulp due to an increase in reducing sugars (glucose and fructose) from 0.31 to 14.7% (Finney et al. 1967), and (c) a subsequent loss in turgor pressure in the peel cells and (d) water displacement from banana peel to pulp as a cause of fruit softening (Williams et al. 1989). Physical changes during banana ripening involve a change in colour (green to yellow starting from the centre of the banana and then extending to its tips), tissue softening, and a change in surface features.

The colour change from green to yellow is a gradual process related to degradation of chlorophyll pigments starting from the centre of the curved fruit. The degradation of chlorophyll a (and to a lesser extent, chlorophyll b) by the enzyme chlorophyllase increases during maturation (Finney et al. 1967; Ammawath et al. 2001), while α - and β -carotene increase (Ammawath et al. 2001). While the

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colour change was previously examined non-destructively using portable instrumentation in the middle section of the peel of harvested banana fruit in the Lab colour scale (Ward and Nussinovitch 1996; Jaiswal et al. 2012), the sole report on the change in physical properties 20 years ago uses a destructive method, i.e. relies on measurements with peeled fruit (Ward and Nussinovitch 1996).

When traditional glossmeters are used to measure luster, e.g., for potato chips (Segnini and Dejmek 1999), colour changes and surface observations require a flat surface. On fruit like banana, curved colour variation from the centre to the tips, needs to be measured in many positions to create a representative colour profile (Yam and Papadakis 2003). This shortcoming can now be overcome by non-invasive methods. To determine the optimum harvest time (OHD) for bananas, Surya Prabha and Satheesh Kumar (2013) used the green colour intensity in conjunction with a fruit size algorithm, to devise a field-based automatic system to detect banana fruit maturity.

Luster sensor technology has advanced since the work of Surya Prabha and Satheesh Kumar (2013). Non-invasive sensors became available (Mukhtar et al. 2014; Klemm et al. 2017), the challenge emerged to test whether these technologies are suitable for banana. Similarly, to our knowledge, the sole report of SEM observation (Williams et al. 1989) on banana showed tangentially elongated epidermis cells, parallel to the circumference of the fruit during ripening of maturity bronzed 'Gros Michel' bananas.

The objective of the current project was to examine bananas for changes in surface features during ripening at their final destination in the food chain by two novel non-invasive techniques: a luster sensor and a 3D profilometer, which measures the 3D characteristics of a fruit surface (rather than a single profile line) as roughness R_a and R_z , and corrects for curved surfaces.

Materials and methods

Fruit source

Dessert bananas (*Musa sap.*) of different maturity stages were obtained from local dedicated banana ripening rooms (Walter Pott Ltd., Leverkusen, Germany, ca. 50 km from Bonn) and local supermarkets (EDEKA, REWE in Bonn), where fruit from fresh shipments without blemishes were selected.

Sampling procedure

The glossiness of the fruit surface was examined on three regions of the bananas, the tip, centre/middle part and the

stalk end; these spots were marked for replicate measurements (Fig. 1). Bananas were examined for glossiness with a luster sensor at different ripening stages. At each ripening stage, 15 fingers were removed off bananas hands from fresh shipments. For each banana, six measurements were conducted, two at the tip (20 mm from the blossom end), and two close to the stalk (30 mm from the stalk end) and two in the middle of the fruit (Fig. 2b). Tip and stalk end were selected as measuring spots (Fig. 2c), because they turn colour from green to yellow much later than the centre part. All measurements were taken perpendicular to the longitudinal axis of the banana. Similarly, the 3D measurements were obtained in the middle of the banana for reasons described above.

Banana ripening scale

Banana ripening starts with a full green fruit (stage 1 in Fig. 1a), pale green (stages 2), green yellow (stage 3), yellow with green tips (stage 4), bright yellow (stage 5), pale yellow (stage 6) and yellow with brown spots (stage 7) (Fig. 1a).

Fig. 1 a Banana ripening scale. © Don Edwards, UC Davis, Postharvest, California, USA (top) and **b** cavendish bananas of different ripeness stages used for the roughness measurements (from right to left: B1 = stage 3 green, B2 = stage 5 yellow with green tips, B3 = stage 7a yellow with brown dots, B4 = stage 7b overripe) (bottom)

Fig. 2 **a** Position of the luster sensor (CZ-H72) and banana during glossiness measurements, banana image (copyright of banana image by Ingo Henze) (top) and **b** position of the three measuring spots on the fruit (middle) and **c** Measuring spot for (non-invasive) observation of surface features on a banana identified by the red light emitted by luster sensor CZ-H72 (bottom)

Instrumentation

The non-invasive gloss measurement employed a luster sensor type CZ-H72 and amplifier (Keyence Co., Japan) operated at 14.8 volts. The distance between the banana surface and sensor was kept constant at 15 mm by our own manufactured holder (Fig. 2c) and the spot size set to 5 mm (Mukhtar et al. 2014). The sensor emits red light (665 nm; LED, Fig. 2a) and measures the reflected light.

The 3D profilometer (VR-3000) is the latest technology in digital microscopy (resolution 0.1 μm) for non-invasive examination of surfaces (24 mm $\times$ 18 mm); it differs from other or previous instruments in that it enables the examination of whole/complete surface areas rather than single profile lines and calculates Ra (arithmetic mean between peaks and troughs).

$$Ra = \frac{1}{L_r} \int_0^{L_r} |Z(x)| dx \quad (1)$$

where Ra = arithmetic mean between peaks and troughs, Lr = profile length, Z = amounts of the ordinate values of the roughness profile, and RZ (sum of the height of the highest peak and the depth of the deepest trough within one line, RZ is the arithmetic mean of several lines) as a measure of extreme roughness.

$$Rz = Rp + Rv \quad (2)$$

where Rp = max (Z(x)), maximum height (or peak) of the profile line, Rv = |min (Z(x))|, maximum trough of the profile line.

Statistics

The experimental data were subjected to ANOVA using SPSS version 24 (IBM, USA) and the Welch test and the Tamhane Post-Hoc procedure at a significance level of $\alpha = 0.05$.

Results

Glossiness

Figure 3 shows the development of glossiness during ripening from stage F3 (before entering the ripening room) to F7b (overripe, covered with brown spots) (Fig. 1b) at three different measuring spots on the banana fruit, stalk, centre and tip. The degree of glossiness increased from stage F3 (more green than yellow) to stage F7a (yellow with brown spots) in both the stalk and the centre of the banana (Fig. 2a). Hence, the centre of the fruit was chosen for the subsequent non-invasive evaluation of glossiness during banana maturation (Fig. 2a), because of its easy access and a less curved surface. While examining the bananas starting from stage 3 (green) to stage F7b, gloss increased from stage 3 to stage 7a in the order of ca. 35% followed by a decrease of gloss from stage 7a to 7b (Fig. 3).

The non-invasive examination showed that glossiness increased from banana ripening stage 5 (yellow fruit with green tips) from ca. 190 luster level to a peak of 210 luster level at the edible stage F7 (yellow fruit with brown dots) (Fig. 4). After the optimal consumption stage (overripe), the glossiness declined to ca. 190 luster level at a stage with brown streaks (Fig. 4).

Fig. 3 Development of glossiness during banana ripening measured on tip, centre and stalk from ripeness stage 3 (before entering the ripening room) to stage 7b (after removal from the ripening room) ($\pm$ SD); colours indicate the respective ripening stage

Fig. 4 Increase in glossiness, **a** before entering the ripening room measured in the centre of the fruit from ripeness stage 2 to stage 6 ($\pm$ SD) ($n = 30$; 2 measurement spots per fruit) Top and **b** after removal from the ripening room, measured in the centre of the fruit from ripeness stage 5 to stage 7 ($\pm$ SD) ($n = 30$; 2 measurement spots per fruit) (bottom)

Fig. 5 Peel roughness (Ra and Rz in μm) of bananas of different ripeness stages ($n = 11$ lines observed for roughness by the profilometer, $\pm$ SD)

Roughness

This differentiation based on non-destructive glossiness evaluation enables a parametric distinction between F7 stages, which has not been reported before. This result was attributed to more flattening of epidermal cells with numerous fine cracks at the anticlinal walls (Williams et al. 1989).

Banana peel roughness increased from ripening stage 3 over stage 5 to stage 7b, as shown in absolute values of the mean arithmetic roughness (Ra) increased from 2.5 μm at stage 3–2.9 μm at stage 5–4.4 μm at stage 7a–6.6 at stage

7b (Fig. 5 and 6). In Fig. 6, the dramatic increase in roughness within stage 5 and 7a is visualized by a colour scale, while blue is the minima and red is the maxima roughness (Ra). This contribution (Fig. 6) shows pictorial evidence of the roughness distribution over the banana peel using colour coding of the profile-meter.

ANOVA

Statistical data analysis showed significant differences in the gloss measurements between developmental stages F3 versus F5, while the roughness measurements showed

Fig. 6 3D Surface profile of bananas of different ripeness stages on a 24×18 mm surface (red and blue = peak [$+ 90 \mu\text{m}$], orange [$+ 40 \mu\text{m}$] and blue—trough [$- 70 \mu\text{m}$])

statistically significant differences between all stages, i.e. F3 versus F5, F5 versus F7a and F7a versus F7b (results not shown).

Discussion

This work showed the changes in surface glossiness and roughness during the ripening of the Cavendish bananas (Figs. 3, 4, 5) using a novel non-invasive luster sensor and roughness measurement technology. Our first results of a peak in glossiness during the first stage of banana ripening (stage 7a) using non-destructive technology (measurements at 90°) are partly in contrast to those of Ward and Nussinovitch (1996), who used detached peel of the banana fruit and found a decrease in glossiness during ripening measured at 85°. Our subsequent decrease in glossiness after ripening stage 7a (Fig. 5) is again in line with the results of Ward and Nussinovitch (1996). The glossiness sensor used in this study may be suitable for the exact monitoring of the banana ripening rooms in terms of temperature and humidity in addition to the present, colour-based ripening scale (Fig. 1a). For all surface measurements, the fruit centre seems to be a suitable candidate due to the least curved surface and provides easy access.

Our visual (Fig. 6) and parametric (Fig. 5) roughness values (R_a) for ripening Cavendish bananas are in line with the R_a values of Ward and Nussinovitch (1996), while visual assessment has not been reported before. The 2.3-fold increase in R_a reported by Ward and Nussinovitch (1996) of 4.2–9.5 μm during ripening stage 3 to stage 8, compares favourably with our 2.6-fold increase from 2.5 to 6.6 μm during ripening stage 3 to stage 7b in our studies; in both cases the increase in the R_a value was ca. 2.5 μm . Comparing the roughness values of the ripening stages 3, 5, 7a and 7b showed a significant difference between certain ripening stages, similar to Ward and Nussinovitch (1996). For the first time, the 3D profilometer was able to examine the surface characteristics of the banana at high resolution on a 24×18 mm area in the centre of the fruit. The 3D profilometer converted the data from a curved surface, using a proprietary algorithm, into a plain area for comparable roughness results, while Ward and Nussinovitch (1996) used a portable surface roughness tester, which touched the object surface with a small needle and measured the parameter R_a each time for a single profile line. To our knowledge R_z has not been measured before, so discussion does not apply.

Both the glossiness and roughness results of our study and that of Ward and Nussinovitch (1996) can be explained by SEM observations. Williams et al. (1989) observed the characteristics of the surface of banana peel of cultivars

susceptive and resistant to maturity bronzing disorder. For the cultivars of those bananas resistant to maturity bronzing they found that the epidermal cells of the ‘Ducasse’ cultivar had expanded and elongated parallel to the fruit circumference at fruit maturity. Furthermore there was a slight separation of the epidermal cells. On banana fruit of the cultivar ‘Blue Torres Strait’ there were large amorphous globules of epicuticular wax positioned between the papillae outgrowths. Ward and Nussinovitch (1996) reported that banana ripening was associated with a decrease in epicuticular wax content from $196 \mu\text{g}/\text{cm}^2 \pm 33$ at stage 1 of ripening to $129 \mu\text{g}/\text{cm}^2 \pm 36$ at stage 8, which is in line with our results of increasing roughness (Fig. 5) and a peak in glossiness (Fig. 4).

Conclusion

This work has shown that the new luster sensor and 3D roughness technology may enable non-invasive examination of banana, and possibly other fruits, during their maturation. In case of banana this is based on an increase in roughness throughout maturation combined with a peak in glossiness at fruit maturity. The preferred measuring spot for the non-invasive examination was found to be the centre of the banana fruit due to the minimal curvature, least variation of the luster value and representation of the most advanced, i.e. critical ripening stage of the fruit. There was a significant change in glossiness from ripening stage 3 to stage 5 and in roughness (R_a) between ripening stage 3, 5, 7a and 7b, a differentiation, which was not possible before. We regard this as a major advancement in technology compared to the previous visual examinations using colour charts in a situation where the banana tips can be still green, but the banana centre is bright yellow.

The small, low cost and low energy luster sensor may become a component of a portable probe for the control of packing units. Differences in the predicted green life can be used to prioritize containers for unloading in the discharge port or to implement quality-based warehouse management strategies such as FEFO. The goal of such strategies is to increase the number of containers that arrive at the ripening rooms before their green life ends, by swapping routes for subsequent transports.

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References

- Ammawath W, Che Man YB, Yusof S, Rahman RA (2001) Effects of variety and stage of fruit ripeness on the physicochemical and sensory characteristics of deep-fat fried banana chips. *J Sci Food Agric* 81:1166–1171
- Finney EE, Bengera I, Massie D (1967) An objective evaluation of changes in firmness of ripening bananas using a sonic technique. *J Food Sci* 32:642–646
- Klemm M, Röttger O, Damerow L, Blanke MM (2017) Non-invasive determination of russet on pome fruits—[Kann man Berostung nicht-destruktiv bestimmen?] *Erwerbs-Obstbau* (Springer Heidelberg) 59(1): 1–11. <https://doi.org/10.1007/s10341-016-0299-1>
- Jaiswal P, Jha SN, Kaur PP (2012) Prediction of textural attributes using color values of banana (*Musa sapientum*) during ripening. *J Food Sci Technol* 51(6):1179–1184
- Koteswara Reddy C, Haripriya S, Vidya PV (2015) Morphology, physico-chemical and functional characteristics of starches from different banana cultivars. *J Food Sci Technol* 52(11):7289–7296
- Mukhtar A, Damerow L, Blanke MM (2014) Non-invasive assessment of the wax bloom and glossiness of European plum. *Postharvest Biol Technol* 87(1):144–151
- Robinson JC, Saúco VG (2010) Bananas and plantains. CABI, Wallingford, pp 259–262
- Salunkhe DK (1995) Handbook of fruit science and technology: production, composition, storage and processing. Taylor & Francis, Abington
- Segnini S, Dejmeck P (1999) A low cost video technique for colour measurement of potato chips. *Lebensm-Wiss u Technol* 32:216–222
- Surya Prabha D, Satheesh Kumar J (2013) Assessment of banana fruit maturity by image processing technique. *J Food Sci Technol* 52(3):1316–1327
- Ward G, Nussinovitch A (1996) Peel gloss as a potential indicator of banana ripeness. *Lebensm-Wiss u Technol* 29:289–294
- Williams MH, Vesik M, Mullins MG (1989) A scanning electron microscope study of the formation and surface characteristics of the peel of the banana fruit during its development. *Bot Gaz* 150:30–40
- Willis RBH, Lim JBK, Greenfield H (1984) Changes in chemical composition of Cavendish banana (*Musa acuminata*) during ripening. *J Food Biochem* 8:69–77
- Yam KL, Papadakis SP (2003) A simple digital imaging method for measuring and analyzing color of food surfaces. *J Food Eng* 61:137–142