Tropentag 2021, hybrid conference
September 15-17, 2021
Conference on International Research on Food Security, Natural Resource Management and Rural Development
organised by the University of Hohenheim, Germany

Non-invasive, Real Time In-situ Techniques to Determine the Ripening Stage of Banana - Development of a Banana Ripening Index (BRI)

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Abstract

Bananas were examined starting from ripening stage R2 (green) to stage R7 (overripe), to identify suitable non-invasive, real time *in-situ* technologies to separate the ripening stages:
1) Chlorophyll degradation, measured by the DA meter, decreased from ca. 2.1 (R2) to 0.2 IAD units (R7), i.e. 10-fold decline.
2) Colour CIE-Lab a values dramatically increased as indication of chlorophyll breakdown and enable differentiation between all ripening stages R2 to R7. Colour angles declined from 98.7° hue (R2), 97.3° hue (R3), 92.7° hue (R4), 89.4° hue (R5); 87.5° hue (R6) until 82.0° hue (R7).
3) Spectroscopy showed two light reflectance troughs at 494 nm and 679 nm.
A novel banana ripening index (BRI) was developed and is proposed to identify and distinguish the ripening stages of banana with values starting at 4 at R1 and peaking at 8.1 at ripening stage R7.
The work also identified the fruit centre (rather than the tip) as a suitable candidate due to the most advanced ripening and least curved surface region of the fruit with easy access, when a carton is opened and the hands become accessible.
This novel approach has shown the DA-meter, colorimeter and spectrometer as suitable candidates for the identification of each ripening stage. The combination of these three devices may be suitable for monitoring of banana ripening rooms in terms of temperature and humidity in addition to the present, colour-based ripening scale.

Keywords: Banana (*Musa sapientum*); Chlorophyll degradation, Colour; Non-invasive assessment; fruit quality; food chain; maturation, ripeness stage; spectral index; storgae

Introduction

Non-invasive measurement technologies are becoming more suitable for tropical fruit because of the possibility to analyse the fruit without destroying the peel in a box onboard during shipment, before entering a ripening room or thereafter to predict shelf life (Ringer et al. 2021). After harvest, it is indispensable to mechanize the identification of fruit maturation and, in banana, the particular ripening stage and the optimum ripening treatment to reach the retail and consumer at the intended ripeness.

Ripening of dessert banana (*Musa sapientum*) as a climacteric fruit, which implies ripening continues after harvest (Kotecha and Desai 1995) is associated with biochemical and physical changes. Banana ripening comprises a change in colour from green to yellow starting from the

centre of the banana fruit and then extending to its tips implying colour measurements on many positions on the banana peel (Ringer et al. 2018).

Studies on the change in physical properties started ca. 25 years ago used a destructive method and peeling the fruit (Ward and Nussinovitch 1996). Recently, a new generation of sensor technology has been introduced (Schüsseler et al. 2019). The scientific challenge was to exactly identify the particular banana ripening stage and offer the professional ripening industry support in form of parameters. Pre-requisites are non-invasive, on-site and real-time methods without destruction of the fruit, and without sampling for laborious laboratory analysis.

Material and Methods

Dessert bananas (*Musa sapientum)* of all maturity stages were obtained from our local banana ripening company (Walter Pott Ltd., Leverkusen, Germany, ca. 50 km from Bonn), which supplies ripened fruit to the local supermarket Norma in Bonn as our source for ripe fruit.

Chlorophyll degradation in the banana peel was measured non-invasively *in–situ* and real time by selective disappearance of the green colour using the portable battery-driven DA Meter (Turoni Instruments, Bologna, Italy). Its index of absorption difference (I_{AD}) describes the difference in light reflection between the chlorophyll specific wavelength (670 nm) and a NIR wavelength (720 nm) as reference (Peiffer et al. 2018), 720 nm is at the start of the NIR, where light reflection from biological material such as leaves and fruit increases.

The surface colour of the banana fruit was measured at the tip and centre part with a non-invasive, portable colourimeter (380 - 720 nm) using an i1Pro (X-Rite, Michigan, USA) (Fig. 2) with a resolution of 10 nm and a measuring spot size of 3.5 mm diameter (Table 1). The output of the device, i.e. colour values L (brightness), a (red to green) and b (yellow to blue) in die CIE-Lab colour space, was converted to °hue colour angle.

Spectral reflection of the banana peel was measured in real time and non-invasively by a spectrometer (Stellar Net Inc., Florida, USA) using a 'BLUE wave box' and a SL1 light source (190 – 1100 nm) with a resolution of 0.2 nm – 6.0 nm depending on wavelength and a measuring spot of 2 mm with a measuring time of <1 sec following Schüsseler et al. (2019). Reflection values were processed using the software 'SpectraWiz Shortcut' supplied as part of the package.

After testing for normal distribution (Kolmogorov-Smirnov-Test and Shapiro-Wilk test) and for variance homogeneity (Levene test), data were subjected to a one-factorial analysis of variance (ANOVA) or the Welch test (in case of variance heterogeneity) and the Tukey-test using SPSS version 24 (IBM, USA) at an error level of $\alpha = 0.05$.

Results and Discussion

Chlorophyll breakdown

Chlorophyll degradation during banana ripening, measured by a DA-meter and expressed as the I_{AD}-index(Peiffer et al., 2018), declined in line with the chlorophyll degradation, measured as decrease in chlorophyll reflection at 670 nm. With ripening banana, values decreased from ca. 2.1 to 0.2 I_{AD} units (Figure 1); this 10-fold decline is ideal and very suitable for the identification of the current ripening stage with significant differences ($\alpha = 0.05$) detected between all ripening stages from R2 to R7 (Fig. 1).

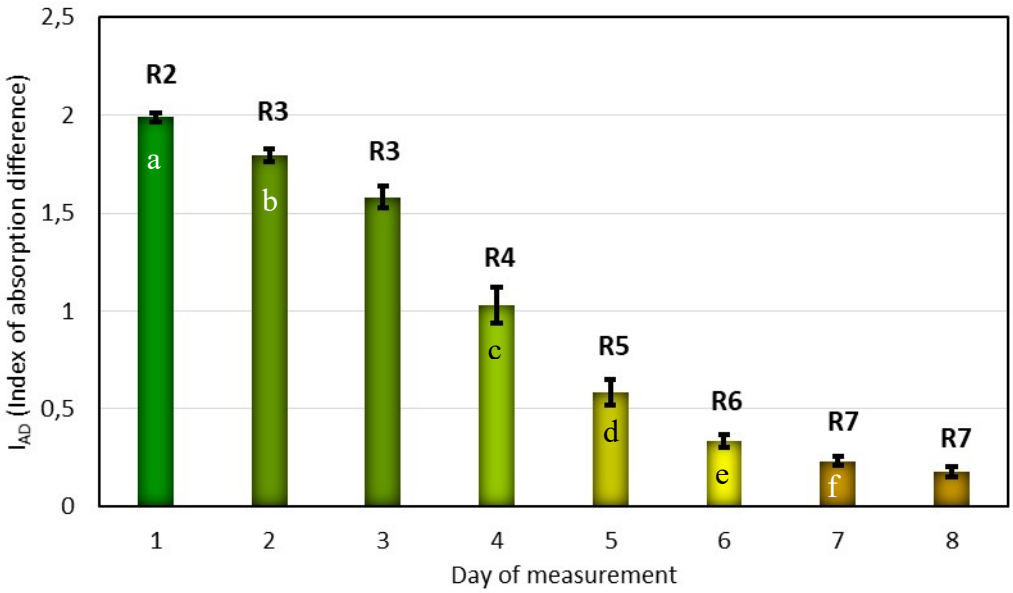

Fig. 1 Chlorophyll degradation of banana during fruit maturation from R2 to R7, expressed as I_{AD} (Index of Absorbance Difference), (± SE, n= 15 bananas; 4 spots per fruit, at the 5% error level)

Non-invasive assessment of changes in peel colour

Banana ripening was associated with only one change in the CIE-Lab colour scheme. The b-values fluctuated between 56 and 72 from ripening stages R2 to R7, without differentiation of the ripening stages. However, CIE-LAB a values dramatically increased as indication of chlorophyll breakdown (Fig. 2) and enable differentiation between all ripening stages R2 to R7. Similarly, colour angles declined from 98.7° hue (R2), 97.3° hue (R3), 92.7° hue (R4), 89.4° hue (R5); 87.5° hue (R6) until 82.0° hue (R7) (Fig. 2)

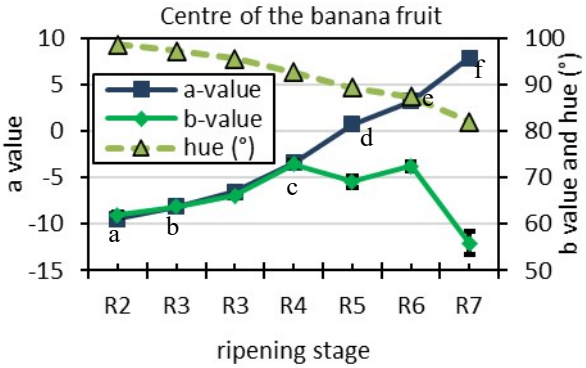

Fig. 2 Changes in peel colour measured as a- and b-values (continuous lines) in the CIE-Lab colour scheme and converted to hue values (± SE) (n=15 bananas per ripening stage)

Spectral reflection of banana during ripening

All ripening stages (unripe fruit stage R3 via the edible fruit stage R6 to overripe R7) were chosen for the non-invasive, real-time, in-situ measurement of the light reflection spectra. Therein, the first, short wave, trough at 487 - 493 nm changed relatively little during banana ripening (Fig. 3). By contrast, the chlorophyll peak viz trough at 673 - 683 nm was more pronounced with green banana than with yellow fruit. By contrast, light reflection from the green banana exceeded that of the yellow banana at the fruit center above 712 nm. The changes (disappearance) of the green chlorophyll trough at 673 - 683 nm were greater than those at the

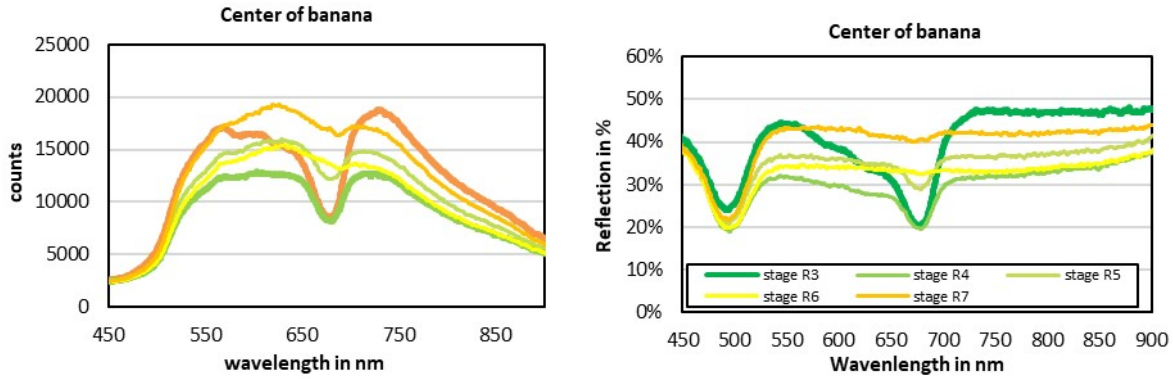

Fig. 3. a) Spectral reflection (left) and b) percentage reflection after division by the white calibration (bottom) of banana fruits (R3 to R7) showing i) the greater changes (disappearance) of the green chlorophyll trough at 673 - 683 nm than the smaller changes at the short wave trough at 487 - 497 nm and ii) the flattening of the curves with ripening.

second trough at ca. 487 - 497 nm; both troughs disappeared with ripening resulting in "flatter curves". Figure 3 also shows the slower disappearance of the green chlorophyll trough at 676 - 680 nm at the tip relative to the fruit centre.
A new ripening index is suggested as depending on the troughs shown in Fig. 3 based on the first short wave trough at 494 nm and chlorophyll absorbance at 679 nm and normalised (formula 1):

$$Banana\ ripening\ index\ (BRI) = \frac{R494+R679}{10} \quad (1),$$

where R494 = light reflection at 494 nm and R679 = light reflection at R679 nm.
The BRI values increased from 4.2 for unripe bananas (R3) to peak at 8.1 for ripe bananas (R6) and then decreased to 5.9 for over-ripe fruit based on the spectra and the particular two troughs for banana during ripening.

Conclusions and Outlook

This study has shown that three non-invasive, real time in-situ devices, i.e. DA-meter, colourimeter and spectrometer enabled the differentiation between all ripening stages of banana fruit using the centre of the fruit as measuring position and the novel banana ripening index (BRI) as decision support, particularly for banana ripening rooms, where it is most needed.

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