Influence of parameters of drying on laser induced diffuse reflectance of banana discs

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Keywords:

machine vision,
digital image processing,
laser backscattering,
banana drying

Abstract. Banana discs of 1 cm thickness were immersed into different antioxidant solutions to slow down potentially disturbing discoloration during drying. Samples were randomly split into 8 groups according to the 2^p experimental design. Two antioxidant solutions with 1.66% and 4.59% ascorbic acid, two levels of drying temperature with 50°C and 80°C, two levels of drying time with 6h and 8h were used or adjusted. Laser diodes of seven wavelengths (532, 635, 650, 780, 808, 850 and 1064 nm) were selected to illuminate the surface and light penetration pattern was evaluated on the basis of radial profiles. Profiles acquired at three wavelengths (532, 635 and 650 nm) were found to respond sensitively to adjusted parameters. As a result of drying, intensity decay was observed to move closer to incident point. Significant effect ($p<0.01$) of temperature, drying time and their interaction was found on extracted descriptive attributes of intensity profiles: full width at half maximum (FWHM), distance of inflection point (DIP) and slope of logarithmic decay (SLD). Beyond their presence, antioxidant concentration was neutral factor without significant contribution to the model. Results were in agreement with reference spectroscopic measurements, especially with NDVI index. Promising results suggest that evaluated method might be suitable for monitoring purposes during drying of fruits.

INTRODUCTION

Banana is one of the market leader fruits, what is also reflected in the continuously increasing production with 106,541,709 t during 2011 (FAO, 2013). Banana is very popular and important produce due to the nutritional value. It is rich in carbohydrates, antioxidants (such as dopamine), minerals (K, Ca), vitamin C (4.5-12.7 mg/100g), β-carotene (50-120 μg/100g), cirtic and malic acids (Debabandya *et al*., 2011). Besides raw fruit, processed forms such as chips, flour, starch, jam and juice are widely consumed, as well. Traditionally, banana was dried using hot air or solar dryers. Recent developments in drying technology provide cutting edge methods especially to preserve high nutritional value (Mujumdar and Law, 2010). These techniques are vacuum drying, freeze-drying, superheated steam drying and osmotic dehydration. Numerous

studies investigated the combination of osmotic dehydration with vacuum, high hydrostatic pressure, pulsed electromagnetic field, ultrasonic treatment, low-pressure superheated steam and far infra-red radiation (Bazhal *et al*., 2003; Nimmol *et al*., 2007; Sagar and Kumar, 2010) in order to improve the efficiency of drying and maintain nutritional value. During the drying process, banana discs typically change their color toward brown, shrink and release volatile compounds (Zhengyong *et al*., 2008). Pre-treatments using sodium-bisulfite or acids, such as citric acid, malic acid, phosphorous acid and ascorbic acid, were found to inhibit browning process (Demirel and Turhan, 2003; Sagar and Kumar, 2010). Alteration in color is important due to the effect on non-destructive quality assessment performed with optical methods. The near infra-red (NIR) spectroscopy was found to be suitable for accurate prediction of soluble solids content, Brix and starch content (Sun, 2008). However it was unable to estimate titratable acidity and firmness. Multispectral and hyperspectral imaging techniques were found to be able to estimate changes in chlorophyll content of peach (Lu and Peng, 2006), predict soluble solids content and firmness of apple (Quing *et al*., 2007), distinguish certain commercial grades of kiwifruit (Baranyai and Zude, 2009) and monitor changes of optical properties and firmness of apple during drying (Romano *et al*., 2011).

The objective of this presented work was to investigate the effect of pre-treatment, adjusted temperature and drying time on optical properties of banana slices. In order to achieve the goal, laser induced diffuse reflectance imaging was used and backscattering profiles were evaluated.

MATERIALS AND METHODS

Materials

Banana samples were received directly from storage facility (MÓ-TA Ltd., Hungary). Fruits were peeled, cut into discs of 1 cm thickness and randomly split into two groups. The first group, called P166, was immersed into a solution containing 1.66% ascorbic acid and other antioxidants (made with "Plussz" effervescent tablet). The second group, called AA459, was immersed into a solution of 4.59% ascorbic acid of medical quality. After 30 min pre-treatment, each group was randomly divided into 4 subgroups according to the 2^p full factorial experimental design and forwarded to the drying chamber (Venticell 222, MMM Medcenter Einrichtungen GmbH, Germany). Drying temperatures of 50°C and 80°C were adjusted and applied for 6 h and 8 h.

Reference measurements

The NIR spectrophotometer of OceanOptics USB2000 (Ocean Optics, USA) was used to acquire spectra over the range of 550-1100 nm. The instrument was calibrated against the ColorLite SPH850 white standard. The integration time of 100 ms and noise filtering (Boxcar) on 9 neighbor values were adjusted. The NDVI (Normalized Difference Vegetation Index) and NAI (Normalized Anthocyanin Index) indices were used as reference data. NDVI and NAI were computed as relative differences of readings at 780 nm vs. 680 nm and 780 nm vs. 570 nm, respectively.

Machine vision system

The vision system was assembled from a high performance monochrome CMOS camera (MV1-D1312, Photonfocus AG,

Switzerland), lenses optimized for camera spectral range of 320-1080 nm and image size of 1312×1082 pixels (SV-L5014MP), seven laser diodes emitting at 532, 635, 650, 780, 808, 850 and 1064 nm. The incident angle of laser beams was adjusted to 15° and beams were focused within a circular area of Ø1 mm. Digital images of 0.1127 mm/pixel resolution were captured and processed. Intensity profiles were calculated with radial averaging relative to the incident point. Three parameters were extracted: the distance of inflection point (DIP), full width at half maximum (FWHM) and slope of logarithmic profile (SLP).

Statistical analysis

Raw data was collected and visualized in Microsoft Excel® 2003. Selected parameters of intensity profiles were extracted and statistical computations were performed with R (2.13.2, R Foundation for Statistical Computing, Vienna, Austria).

RESULTS AND DISCUSSION

The optical properties observed around 780 nm were expected to response sensitively to changes in tissue during drying. Collected data confirmed some changes in all evaluated parameters but larger differences were obtained at lower wavelengths (532, 635 and 650 nm). This was in agreement with the first derivatives of acquired reference spectra. According to the literature, differences at lower wavelengths can be the result of typical absorption of anthocyanin in the range of 475-560 nm (Phillips, 2006). Figure 1 shows how intensity profiles of 532 nm changed during the experiment. It can be observed that profiles moved closer to the incident point, starting at 20°C 0h, with increasing temperature and drying time. On the other hand intensity decay, the shape of the profiles, also changed similarly. This observation is in agreement with literature (Romano *et al.*, 2011).
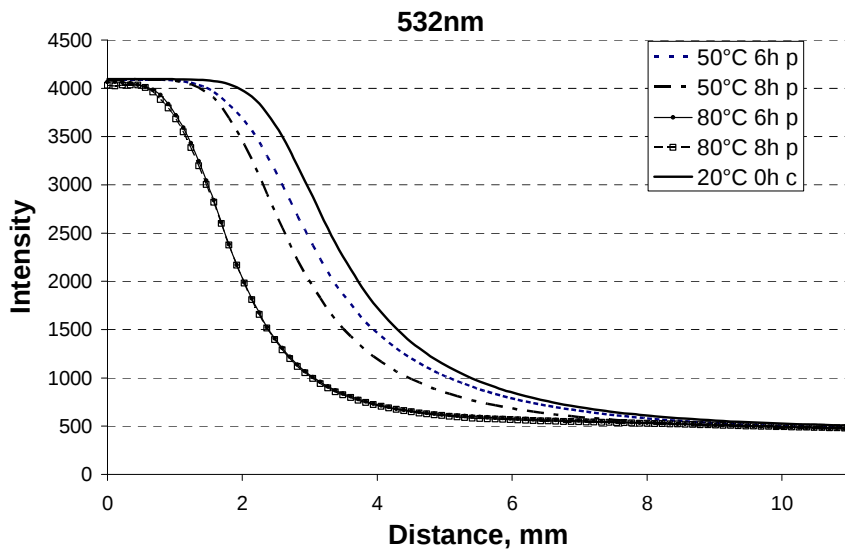
Table 1: Analysis of variances on FWHM at 532 nm

Source	F	Sig.
Time	18.434	0.000
Temperature	585.524	0.000
Treatment	0.053	0.819
Time × Temperature	15.525	0.000
Time × Treatment	2.671	0.105
Temperature × Treatment	5.192	0.024
Time × Temperature × Treatment	2.907	0.091
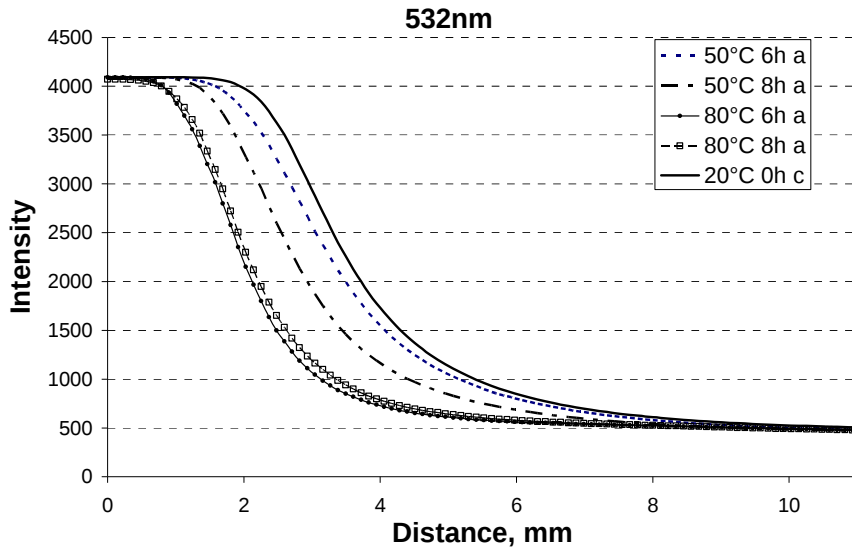
(a)

(b)

Figure 1
Average intensity profiles for sample groups AA459 (a) and P166 (b)

Table 2: Summary of primary effects on backscattering and reference attributes

	532 nm			635 nm		
	FWHM	DIP	SLP	FWHM	DIP	SLP
Time	+	+	+	+	+	+
Temp.	+	+	−	−	−	−
Treat.	−	−	−	−	−	−

	650 nm			NDVI	NAI
	FWHM	DIP	SLP		
Time	+	+	+	+	+
Temp.	+	−	−	+	+
Treat.	−	−	−	−	+

Mark '+' indicates significant primary effect with $p<0.05$

The analysis of variances (ANOVA) is introduced in Table 1. Temperature contributed the most to the model (F=585.524), FWHM was most sensitive to this factor. It is followed by drying time and their interaction. Treatment factor, pre-processing with different solutions, did not turn out to be significant. The strong interaction of primary factors indicates different kinetics depending on the temperature. It is interesting that treatment alone was not significant but its interaction with temperature should be considered as well ($p<0.05$).

Table 2 shows the summary of primary effects observed using parameters FWHM, DIP, SLP and reference attributes NDVI, NAI. Among factors, drying time was found to be the most important with significant effect on all investigated parameters.

Temperature itself was found to have effect only at two wavelengths (532 nm and 650 nm). Additionally, FWHM was in close agreement with NDVI at the same wavelengths. The parameter DIP obtained similar results as FWHM at 532 nm. The difference between DIP and FWHM at the other wavelengths indicates alteration of the shape of backscattering profiles since both parameters measure the extent of diffuse reflectance but they are using different approaches. Only reference attribute NAI found significant primary effects for all factors.

4. CONCLUSIONS

Banana slices of 1 cm thickness were dried after pre-treatment, immersion into antioxidant solutions, adjusting different temperature and drying time. Full factorial 2^p experimental design was applied to evaluate primary effects and interactions based on parameters of diffuse reflectance profiles. It was found that factor temperature had outstanding contribution to the model affecting all parameters (FWHM, DIP, SLP). The agreement

between FWHM and reference attribute NDVI indicates the potential of the laser induced diffuse reflectance technique. It might be suitable for monitoring purposes during drying of banana and similar produces. The selected optimal wavelengths (532, 635 and 650 nm) and the results of the reference attribute NAI may lead to the conclusion that methods more sensitive to anthocyanin absorption might perform better. According to the results, machine vision system and laser backscattering could be applied to monitor postharvest processing of horticultural produces.

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