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1. Introduction, Knowledge, Objectives

Currently, bananas entered into the conventional retail sales chain are marked with paper stickers. The paper stickers are most commonly placed on the fruit surface at the packing line or before final packaging. However, a paper sticker has some disadvantages such as labels can easily be detached, lost, exchanged and are quite expensive (Drouillard and Kanner, 1999; Edxeberria et al., 2006; Marx et al., 2013). Applying laser labeling instead of adhesive labels is a promising alternative. There are several advantages of using laser labeling compared to paper labeling particularly permanent mark, high quality mark, high speed as well as high reproducibility.

This study wants to develop a common system for food product traceability, which could be applied on fruits and vegetables. Recently, the traceability technology such as printed coding systems using barcode are widely used in traceability systems (Marx et al., 2013; Aarnisalo et al., 2007). Data Matrix (DM) codes were selected for this study, due to high readability of distorted codes and the small size of the symbols. However, the application of the DM symbol directly on the surface of a product by a laser labeling system can disrupt the cuticular barrier on banana surfaces. Since damage on the cuticular barrier influences the readability of the code, optimal laser power should be applied. Moreover, it is essential to ensure easy decoding of the codes. Generally, the exact size of the DM symbol depends on the exact encoded data. Numbers and characters are encoded in terms of bits, represented by dark or light modules of an identical size. The larger the amount of bits required, the larger the symbol will be, but increases the density of modules in the code (see Figure 1). This study was conducted to determine the success rate for various sizes of DM codes, in order to select the most reliable solution. Also, the effect of the edge length and the laser power on the DM code readability were analyzed, to get a clear symbol and an optimal pattern size applied on banana surfaces.

2. Material and Methods

2.1. Materials

Green bananas (Musa spp., Cavendish subgroup) were collected from Dole® Fresh Fruit Company (Stelle, Germany). The banana fingers separated from the banana hands were selected and then marked using a continuous wave CO_2 laser (wavelength: 10,6 µm, type 48-5, Synrad Inc., USA). In order to initiate ripening, the samples were subjected to ethylene treatment at 1000 µl/L for 24 h, afterward the samples were stored at 16.6 °C (RH

80%) for five days in a ripening chamber to reach a yellow colour. Then the samples were stored in a room with a temperature of 20 °C for 4 days to simulate conditions of the banana supply chain from the ripening room to the market.

2.2. Experimental test

In order to cause minimum damage on the banana peels, the treatments were selected from four levels of a low-power laser. Different levels of DM sizes were chosen based on GS1 (2014) (see Table 1). Maximum DM size was selected according to maximum encoded data that can be stably read by image processing algorithms after laser treatment (this study was limited from 17 to 24 numeric data). Then, various levels of DM edge lengths were referred to the minimum pattern size (edge length) which can be stably decoded. The maximum pattern size was limited to 12 mm due to the diameter of the bananas and their curvature. The laser power used were 1.6 W, 1.8 W, 2.0 W and 2.2 W. The DM codes with edge lengths of 6 mm, 8 mm, 10 mm and 12 mm were generated in four different DM sizes (Figure 1). The size of the resulting DM symbol varied. It based on the maximum amount of the data capacity. Accordingly, the sizes of the DM symbols were given in terms of numbers of rows and columns (10x10 modules, 12x12 modules, 14x14 modules and 16x16 modules). All combination treatments were repeated five times.

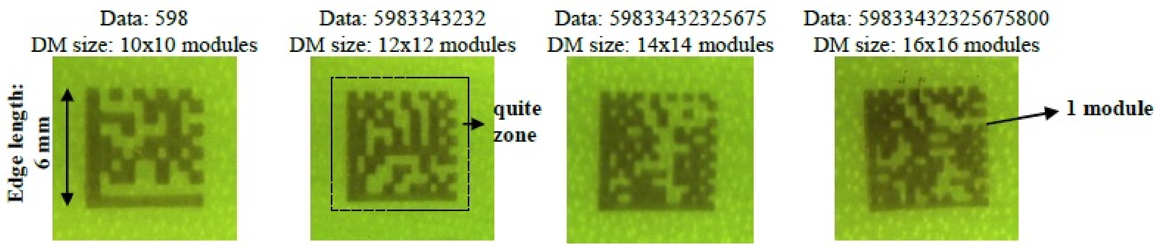

Figure 1. Examples of Data Matrix codes on green bananas at the same laser power immediately after laser treatment

Table 1. Data Matrix symbol attributes (GS1, 2014)

Data Matrix size		Maximum data capacity	
Row	Column	Numeric	Alphanumeric
10	10	6	3
12	12	10	6
14	14	16	10
16	16	24	16

2.3. Readability test

Images of the bananas after laser-marking were captured by using a CCD camera (DBK41BU02.H, The Imaging Source Europe GmbH, Bremen, Germany). The readability of the codes were tested with the image processing software Halcon 11 (MVTec Software GmbH, Munich, Germany). The percentage of readability r was calculated as r = (k*100)/N where k represents the number of read codes and N stands for the sample size.

3. Results

Reading results using a laser power of 2.2 W were comparatively low. The readability of the codes with 14x14 modules and 16x16 modules varies from 0% to 20%. Applying 10x10 modules and 12x12 modules increase the readability from 0% to 60% (see Table 2). Applying a laser power of 2.0 W gives better results compared to a laser power of 2.2 W because increasing the laser power lead to more damages on the codes. High readability is obtained at a laser power of 1.8 W, ranging from 80% to 100%. A laser power of 1.6 W shows widely varied results (20%-100% of readability). It clarifies that increasing the amount of modules in the code tend to decrease the readability of the code. Moreover, there is noticeable decrease in code readability if the patterns have smaller sizes.

Table 2. DM size, power and edge length on readability after 9 days

Laser power (W)	Data Matrix size (modules)			
	10 x 10	12 x 12	14 x 14	16 x16
2.2	s1	s1	s1	s1
2.0	s1	s1	s1	s1
1.8	s1	s1	s1	s1
1.6	s1	s1	s1	s1
2.2	s2	s2	s2	s2
2.0	s2	s2	s2	s2
1.8	s2	s2	s2	s2
1.6	s2	s2	s2	s2
2.2	s3	s3	s3	s3
2.0	s3	s3	s3	s3
1.8	s3	s3	s3	s3
1.6	s3	s3	s3	s3
2.2	s4	s4	s4	s4
2.0	s4	s4	s4	s4
1.8	s4	s4	s4	s4
1.6	s4	s4	s4	s4

Edge length (s): s1= 12 mm; s2= 10 mm; s3= 8 mm; s4= 6 mm; n= 5

Color readability
0%
20%
40%
60%
80%
100%

Figure 2 shows the change of the modules which are detected by the image processing algorithms during storage time. The figure shows an example of a DM size (16x16 modules) containing the 17 characters text string "59833432325675800" encoded in the code. The image processing algorithm provides the ability to get the classification contour of the code into foreground and background modules. At the beginning of the storage, the modules can be clearly detected with enough contrast and the code is also readable. However, a week after storage the code becomes unreadable as the damage on the modules increases.

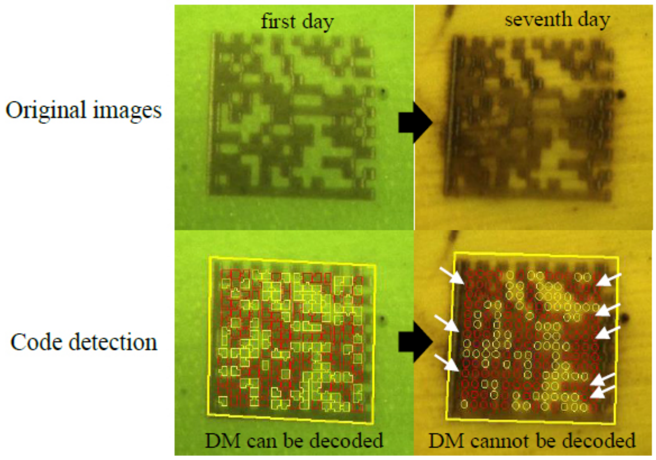

Figure 2. Data Matrix code detection on bananas over storage time with laser power of 2 W (white arrows represent error detection of modules)

4. Discussion

Most of the codes created by high laser power may potentially damage outer cell layers of the bananas and promote unsuccessful readability of the codes. However, labeling at low laser power (1.6 W) tends to produce relatively low readability due to less contrast. The results demonstrated that a laser power of 1.8 W is suitable for labeling of bananas for 9 days of storage (80-100% of readability). Laser labeling on banana affects tiny or insignificant cell damage in the epidermis area. According to Drouillard and Kanner (1999), the depth of the mark should be not exceeding one cell of skin thickness, in order to prevent thermal degradation and breakdown of underlying tissue.

The readability of the code is indirectly affected by the DM size, because the increasing amount of encoded data will increase the density of modules in the code, for this reason the modules become smaller. Therefore, the small modules size will stimulate damage on a banana during storage, since the small damage already arises on the cuticular barrier from the beginning of storage when applying high laser power. Consequently, the decision whether a region belongs to foreground or background is not reliable (see Figure 2). According to Tarjan et al. (2014), the readability of a QR code is not directly influenced by the error correction level, or by the number of code characters, but only by the size of the modules. In this case, a small size of modules increases the possibility of detecting the incorrect modules candidate. Normally, this indicates that the code has poor quality.

Applying laser marking on bananas allows up to 24 numerical characters to be encoded into a symbol with 6 mm edge length. This gives an indication of the very compact nature of the DM codes, which makes them suitable for small part marking. Regarding the DM size, more significant data capacity can be applied to smaller pattern size. However, in several cases a preliminary test should be done in order to determine the minimum requirements in the readability of the code.

5. Conclusions

High readability of DM codes on bananas by laser marking systems depends on laser power, DM size and edge length applied. Applying laser power of 1.8 W shows the best treatment which allows up to 24 numeric characters to be encoded into a symbol of 6 mm edge length. Since most of the bananas are exported from Latin America, investigating of laser marking on unripe bananas would be an interesting work for future study.

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