Predicting Ripening Stages of Bananas (*Musa cavendish*) by Computer Vision

F. Mendoza[(1)], P. Dejmek[(2)] and J.M. Aguilera[(1)]
[(1)]Department of Chemical Engineering and Bioprocess
Pontificia Universidad Católica de Chile. Santiago, Chile
[(2)]Department of Food Engineering
Lund University. Lund, Sweden

Keywords: Computer vision, ripening of bananas, color features, classification

Abstract

A computer vision system was implemented to predict the ripening stages of bananas. Our objective was to develop a computer vision algorithm to predict the seven ripening stages based on 140 bananas and previously graded by expert visual inspection. Two simple color features from each image (mean value and variance of the intensity histogram of image) were extracted and analyzed using the RGB, HSV and CIELAB color spaces with classification purposes. The classification performance of three color sets of features were compared using discriminant analysis as selection criteria: (1) using color data extracted from full image of the bananas; (2) color data from the background of the bananas free of spots; and (3) combination of the color data extracted separately from the background free of spots and brown spots of the banana. Results show that the three evaluated sets were able to correctly predict with more than 94% the ripening stages of bananas as professional visual perception. The inclusion of color features from brown spot images improves the resolution of the classification performance, and in particular, among stages 4 and 5. In addition, this technique can be extended to evaluate the different quality classes according to the standards proposed by the *Codex Alimentarious*. Computer vision shows promise as a non-destructive method for on-line prediction of ripening stages of bananas.

INTRODUCTION

The peel color of bananas is considered as the first quality parameter evaluated by consumers. In fact, peel color correlates well with physical and chemical changes that take place during the ripening of bananas, including pulp color, pH, conversion of starch into sugar and development of flavor (Ward and Nussinovith, 1996).

In the trade, seven ripening stages of bananas are generally recognized: Stage 1: green; Stage 2: green, traces of yellow; Stage 3: more green than yellow; Stage 4: more yellow than green; Stage 5: green tip and yellow; Stage 6: all yellow, and Stage 7: yellow, flecked with brown (Li et al., 1997). The disappearance of the green color and the corresponding yellowing of the peel are associated with the synthesis of pigments (such as carotenoids) and breakdown of the green pigment chlorophyll (Ammawath et al., 2001).

Ripeness is currently assessed visually by comparing the color of the peel to standardized color charts that describe the seven ripening stages (Li et al., 1997) and sometimes, by instrumental techniques (Dadzie and Orchard, 1997). Human visual inspection is a highly subjective, tedious, time-consuming and labor-intensive process (Brosnan and Sun, 2002). By contrast, instrumental techniques (i.e., colorimeters) allow accurate and reproducible measurements of the colors not influenced by the observer. However, their main disadvantages are that the surface color must be quite uniform (Segnini et al., 1999) and that many locations on the sample must be measured to obtain a representative color profile (O'Sullivan et al., 2003). In addition, in the case of bananas these techniques are usually destructive requiring the removal and flattening of the peel for the measurement.

An interesting alternative is computerized image analysis techniques (also known as computer vision systems), which overcome the deficiencies of visual and instrumental techniques and offer an objective measure for color and other physical factors (Chen et al., 2002). Basically the system consists of standard illuminants, a digital or video camera for image acquisition and a computer software for image analysis (Papadakis et al., 2000). Some recent applications in foods include quality evaluation and variety classification of various materials such as fruits, grains, Cheddar cheese, meats, bakery products and pizza (Brosnan and Sun, 2002).

Recently we have developed a computer vision system to predict ripening stages of good quality bananas. We determined that using the average values of L^*, a^* and b^* color bands, percentage of brown spots area, and contrast of the intensity pixels (as textural feature of the image) was possible to identify 49 bananas in their seven ripening stages with an accuracy of 98% (Mendoza and Aguilera, 2004). However, this study considered bananas stored in the best conditions to allow the natural color changes and development of brown spots during ripening. That is to say, avoiding mechanical damage or friction among fingers that can result in additional brown areas and increase the color variability of the samples.

The objective of this study was to develop a computer vision algorithm to predict the seven ripening stages of bananas based on 140 fingers stored under commercial conditions and previously graded by professional visual inspection. The classification performance of three sets of selected color features was compared.

MATERIALS AND METHODS

Samples of bananas

140 bananas (*Musa cavendish*) were obtained from a commercial distributor in Sweden. The samples were visually selected from a single batch stored at room temperature (15±1º C) and 90±5% relative humidity by expert graders according to the seven ripening stages (20 samples per stage).

Computer vision system (CVS)

The CVS consisted of the following elements:

(i) Lighting system. Samples were illuminated using two parallel fluorescent lamps (Philips, TL-D Deluxe, Natural Daylight, 18W/965) with a color temperature of 6500 K and a color-rendering index (Ra) close to 95%. Both lamps (60 cm long) were situated 35 cm above the sample and at an angle of 45º with the sample. Additionally, light diffusers covering each fluorescent lamp and electronic ballast assured a uniform illumination system.

(ii) *Digital camera and image acquisition*. A Color Digital Camera (CDC), model PowerShot A70 (Canon, USA) was located vertically over the sample at a distance of 22 cm. A black cover was used over the sample illuminators and the CDC to avoid the external light and reflections. Images from one side of the bananas were taken on a matte black background using a resolution of 1024 x 768 pixels and storage in JPEG format. The CDC was connected to the USB port of a PC to acquire the images directly from the computer.

(iii) *Image processing*. All the image processing algorithms for segmentation and color analysis were written in MATLAB 6.5 (The MathWorks, Inc).

Color calibration

Typically, the R'G'B' signals generated by a CDC are device-dependent and not identical to the RGB intensities of the CIE system (CIE, Commission Internationale de I'Eclairage). Therefore, to ensure the correct color reproduction a characterization of the CDC was previously performed. For this, 125 color sheets from Pantone® Colour Formula Guide (Pantone, Inc. USA) were photographed and analyzed using the CVS to obtain the R'G'B' values in the theoretical range of 0-255. Similarly, RGB values of each color sheet were measured by a standard colorimeter Dr. Lange Micro Colour (Dr. Lange, Germany) with D65 as the standard illuminant. The white reference used was according to DIN 5033 (white reference model Weiβ–Standard LZM 076), and its reference values were Xn = 78.2, Yn = 83.1, and Zn = 89.9. The nonlinearity relationship of the R'G'B' values against the RGB values from the standard colorimeter was corrected using a power law correction with exponent 2.5.

Image segmentation

Background was removed from the image in grayscale using a threshold of 50 (that separates in a binary image, the true image of the banana from the background) combined with an edge detection technique based on the Laplacian-of Gauss (LoG) operator.

Similarly, the brown spots on the peel of bananas were segmented from binarized images using the combination of $a*$ and $b*$ color bands of the CIELAB color space, since the combination of these two color bands best represented the appearance and development of brown spots during ripening. Images were binarized using threshold values of $a*<140$ or $b*>156$ (for $a*$ and $b*$ values ranging from 0 to 255).

Color analysis

The calibrated color data in RGB were converted to HSV and CIELAB or $L*a*b*$ color spaces. The average pixel values and variance of the intensity histograms were quantified from each color band in three regions of interest: full image of the banana, background image of the banana free of spots, and brown spots image of the banana. Considering it, many of this separated color information will yield an objective and consistent mean of predicting ripening stages. In total, we measured 54 color features from each color image represented by μ_{Efull}, σ_{Efull}, μ_{Eback}, σ_{Eback}, μ_{Espot}, and σ_{Espot} (where E means the corresponding color band).

Feature selection and classification

For the classification, the discriminating power of three different sets of color features extracted from the 140 bananas was compared. These sets were: (1) using the color data from the full image of the bananas (*full-set*); (2) using the color data from the background of the bananas free of spots (*background-set*); and (3) combination of the color data extracted from the background free of spots and only brown spots of the banana (*combined-set*). The first and second set considered 18 color features per set and the third considered 36 features to be used for classification.

For selecting of best features, we determined by simple statistical analysis (comparison of intra-stages fluctuations with inter-stages changes) that several of them could be discarded as classification parameters. Doing so, we retained 10 and 9 features in the first and second sets, respectively, and 15 in the combined set. However, these sets of features still contained redundant, noisy or even irrelevant information for classification purposes. To choose the best features in each group (those with the largest discriminant power), we used *Sequential Forward Selection* method (SFS). This consists of selecting the best single feature and then adding one extra feature at a time, which in combination with the selected features maximizes the classification performance (Jain et al., 2000). Discriminant analysis implemented in Statgraphics Plus V5.1 for Windows software was used as selection criterion.

RESULTS AND DISCUSSIONS

Classification performance

Classification is the process of reducing images to usable information. This meant to predict the ripening stages of bananas previously classified by expert visual inspection using the smaller number of best features extracted from the images. Table 1 summarizes the final selected features and classification performance for each set.

Results show that using the same four features for the first two sets and seven features for the third set the proposed discriminant functions were able to correctly predict with more than 94% the ripening stages of the 140 bananas. However, the select features from *combined-set* explained more variation in the ripening stages than *full-set* and *background-set*. Better prediction by *combined-set* (97,9%) suggested that the extraction of independent color features from the banana images (background free of spots and brown spots) permit to obtain more consistent and useful information, and to discard information associated to some color bands that can introduce prediction errors. Figure 2 shows the discriminant analysis for the classification of bananas using the selected features in the *combined-set*.

Discriminant power of selected features

The comparison of relationships between the selected features in each set revealed that the average values of L^* and a^* color bands and variance of a^* color band, in all the sets, presented the highest discriminating power in the predicting ripening stages. In fact, CIELAB is consider a perceptually uniform color space, and therefore more suitable for direct comparison with sensory data (Segnini, 1999).

It is of interest to point out that in the three evaluated sets, the most difficult stages to discriminate were between stages 4 (more yellow than green) and 5 (green tip and yellow) due to the high variability of the color data at these stages. Results showed that 4 of 6 prediction errors for *full-set* occurred between these stages, 5 of 8 errors for *background-set*, and 2 of 3 errors for *combined-set*.

Figure 3 shows the relationships between μ_{a*back} and σ_{a*spot}, and μ_{a*back} and μ_{L*back}. The μ_{a*back} values showed a clear increase during all the ripening process and their relation with σ_{a*spot} permitted to discriminate among bananas in stages 4 and 5 (Fig. 3a). It is important to mention that in the first stages the detection of spots in some images were due to defects on the surface of bananas. Visually, we observed that the appearance of brown spots was evident from stage 4 onwards. The combination between μ_{L*back} and μ_{a*back} showed discriminant power to clearly predict the first three ripening stages (Fig. 3b). Thus, using discriminant analysis for only these pairs of features, the classification performance for the 140 bananas was 92% and 90%, respectively. These confirm that the inclusion of selected color features from brown spot images separately improve the resolution of the classification performance, and in particular, among stages 4 and 5.

Practical application of CVS in the trade

The banana industry, however, is interested in predicting mainly the quality of bananas in the first three stages of ripening, which can be marketed on the basis of their shelf life and customer preferences. In these first stages occurs the major and more homogeneous color change during ripening of bananas (Mendoza and Aguilera, 2004). Moreover, injuries due to poor harvest, transport, and inadequate handling conditions frequently are not immediately apparent but may show later (Dadzie and Orchard, 1997). In this study the prediction in the first three ripening stages using any of the evaluated sets was performed with an accuracy of 100%.

The *Codex Alimentarius* (1997) defines three quality classes for commercial bananas grown from *Musa* spp. (AAA), in green stage. The '*Extra'* class or superior quality class, which includes fingers free of defects with a tolerance of 5% by number or weight of bananas not satisfying the requirements of the class. The class *'I'* which includes good quality bananas with slight defects in shape and peel color due to rubbing and other superficial defects not exceeding 2 cm^2 of the total surface area, while class *'II'* permits bananas with more serious defects not exceeding 4 cm^2 of the total surface area. For these two last classes the tolerances allowed are 10%.

In spite of the high performance using the *full-set* and *combined-set* that consider the color features of spots, they can be less efficient and consistent than *background-set* when the variability between samples is bigger, such as could occur in the class *'II'*. Therefore, an interesting alternative for quality assessment of bananas in the first commercial stages can be to integrate the discriminant functions from *background-set* as mean to predict the ripening stages, and the information extracted from the spot images in order to evaluate rubbing and other superficial defects.

Finally, this study demonstrates that the image analysis technique can be used effectively to predict the seven ripening stages of bananas using any of the color feature sets proposed here. In addition, this technique can be extended to evaluate the different quality classes according to the standards proposed by the *Codex Alimentarious* (1997). However, the classification performance using the complete hands and clusters must be investigated.

CONCLUSIONS

The three evaluated sets of color features were able to correctly predict with more than 94% the ripening stages of the 140 bananas as professional visual perception. The selected features extracted from banana images free of spots combined with spot images (*combined-set*) more accurately predicted the ripening stages of bananas, and in particular, among the stages 4 and 5 which showed more prediction errors in all the evaluated sets. The relationships between μ_{a*back} and σ_{a*spot}, and μ_{a*back} and μ_{L*back} color features showed the highest discriminating power as indicators of banana ripeness and the agreement with the visual assessment.

Computer vision is more versatile, consistent, efficient and economical for the prediction of the quality of bananas in comparison to current visual assessment and instrumental techniques. It permits identification and quantification of appearance features and defects without destroying the sample due to the capability to examined curved surfaces. In addition, this technique can be extended to evaluate the different quality classes according to the standards proposed by the *Codex Alimentarious* (1997). Computer vision shows promise as a non-destructive method of predicting ripening stages of bananas that can be implemented on-line.

ACKNOWLEDGMENTS

Thanks to MECESUP/PUC 9903 Project (Chile) for granting the first author a doctoral scholarship at the Pontificia Universidad Católica de Chile, and ALFA Programme (EC) for financial assistance to develop part of this investigation at Lund University. We also thank to CONICYT Chile the grant support to participate in the present Symposium.

Literature Cited

Ammawath, W., Che Man, Y.B., Yusof, S. and Rahman, R.A. 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.

Brosnan, T. and Sun, D-W. 2002. Inspection and grading of agricultural and food products by computer vision systems – a review. Comp. Electron. Agric. 36: 193-213.

Chen, Y-R., Chao, K. and Kim, M.S. 2002. Machine vision technology for agriculture applications. Comp. Electron. Agric. 36: 173-191.

Codex Alimentarious. 1997. Codex Standard for Bananas. Codex Stan 205-1997. http://www.codexalimentarius.net/docsearch/docs/en/v5b26en.doc

Dadzie, B.K. and Orchard, J.E. 1997. Routine Post-Harvest Screening of Banana/Plantain Hybrids: Criteria and Methods. INIBAP Technical Guidelines 2. International Plant Genetic Resources Institute, Rome, Italy. p 5-30.

Jain, A.K., Duin, R.P.W. and Mao, J. 2000. Statistical pattern recognition: a review. IEEE Trans. Pattern Anal. Mach. Intellig. 22(1): 4-37.

Li, M., Slaughter, D.C. and Thompson, J.E. 1997. Optical chlorophyll sensing system for banana ripening. Postharvest Biol. Technol. 12(3): 273-283.

Mendoza, F. and Aguilera, J.M. 2004. Image classification of bananas (*Musa cavendish*) during ripening. J. Food Sci. (forthcoming).
O'Sullivan, M.G., Byrne, D.V., Martens, H., Gidskehaug, L.H., Andersen, H.J. and Martens, M. 2003. Evaluation of pork color: prediction of visual sensory quality of meat from instrumental and computer vision methods of color analysis. Meat Sci. 65: 909-918.
Papadakis, S., Abdul-Malek, S., Kamdem, R.E. and Jam, K.L. 2000. A versatile and inexpensive technique for measuring color of foods. Food Technol. 54(12): 48-51.
Segnini, S., Dejmek, P. and Öste, R. 1999. A low cost video technique for color measurement of potato chips. Lebensm-Wiss u-Technol. 32: 216-222.
Ward, G. and Nussinovitch, A. 1996. Peel gloss as a potential indicator of banana ripeness. Lebensm-Wiss u-Technol. 29: 289-294.

Table

Table 1. Selected color features and classification performance for each set.

Set	Selecting color features	Performance (%)
Full image-set	μ_{L^*full}, μ_{a^*full}, $\sigma_{R\,full}$, σ_{a^*fullt}	95,7
Background-set	μ_{L^*back}, μ_{a^*back}, σ_{Rback}, σ_{a^*back}	94,3
Combined-set	μ_{L^*back}, μ_{a^*back}, μ_{Rspot}, μ_{a^*spot}, σ_{Rback}, σ_{a^*back}, σ_{a^*spot}	97,9

Figures

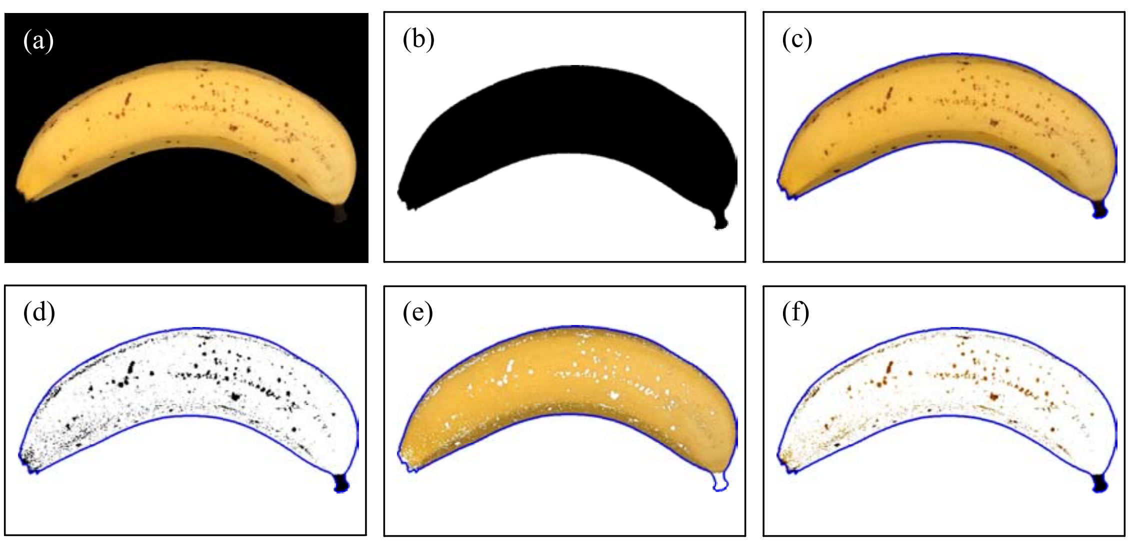
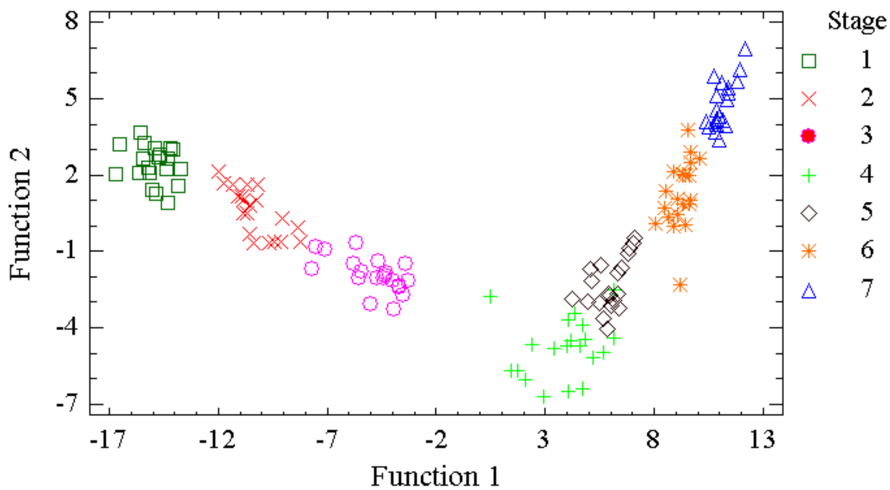


Fig. 1. Selected images of the segmentation process: (a) Original image, (b) Detection of full banana (using a threshold value of 50), (c) Segmented color image (*full*), (d) Detection of

brown spots from *a** and *b** color bands (threshold values of 140 and 156, respectively), (e) Segmented color background free of spots (*back*), (f) Segmented color spots (*spot*).



$$\text{Function 1} = 0.4\mu_{L^*back} + 1.1\mu_{a^*back} - 0.1\mu_{Rspot} + 0.2\mu_{a^*spot} - 0.1\sigma_{Rback} + 0.1\sigma_{a^*back} - 0.3\sigma_{a^*spot}$$
$$\text{Function 2} = -0.3\mu_{L^*back} - 0.3\mu_{a^*back} - 0.7\mu_{Rspot} + 0.4\mu_{a^*back} - 0.2\sigma_{Rback} - 0.6\sigma_{a^*back} - 0.6\sigma_{a^*spot}$$

Fig. 2. Discriminant functions for classification of bananas using color features from the background and spots (*combined-set*).

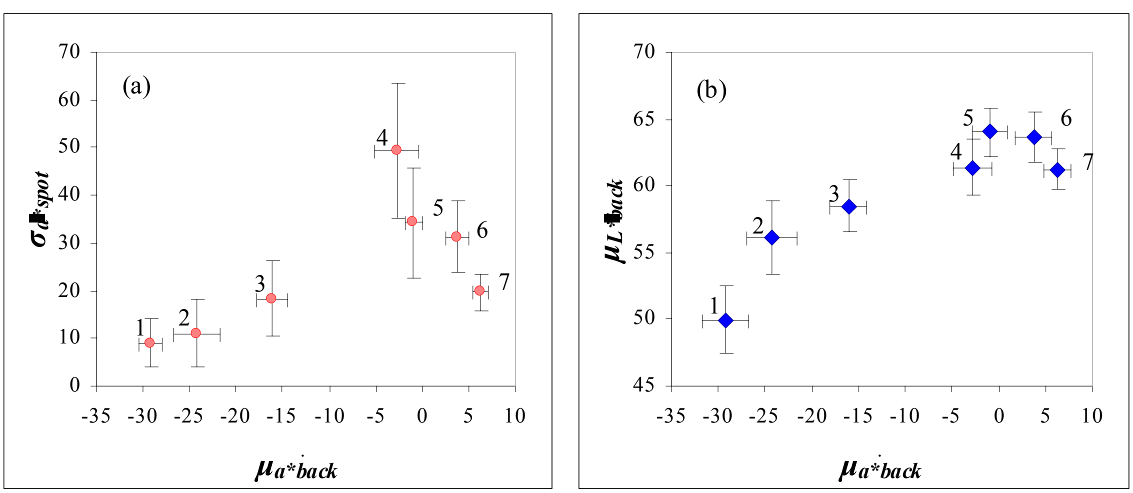


Fig. 3. Relationships between some color features with the highest discriminating power (The numbers from 1 to 7 indicate the ripening stages).