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Full Length Research Paper

Digital camera images processing of hard-to-cook beans

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Haricot bean (*Phaseolus vulgaris* L.) is the most widely produced and consumed legume in the world and occupies an important place in human nutrition in many regions of Africa by improving the nutritional status of many low income populations. It is well known that a significant problem with haricot bean is that it does not soften easily and remains hard even after two or more hours of cooking in boiling water. Prolonged storage, especially under high temperature (≥ 25°C) and high relative humidity (≥ 65%), conditions that predominate in tropical regions promotes this phenomenon called hard-to-cook. This hardness of beans and the concomitant need for long boiling times leads to reduced palatability and protein digestibility, waste of time and energy. Several methods have been proposed to study the hard-to-cook of bean but they are laborious, time consuming and invasive since they destroy the analyzed sample. The main objective of this work was to study hard-to-cook bean non invasively by images processing. A computer vision systems (CVS) consisting of a standard lighted box, a camera for images acquisition and images processing software was developed. Red bean images analysis based on RGB and luminance histograms determination, histogram features definition and determination was achieved. Histograms showed a left shift in variation in color of the bean during storage, proving that red bean browned during storage. Four histogram features were defined and calculated on each histogram, that is, the maximum grey level value GLVmax, the minimum grey level value GLVmin, the most representative grey level value MRGLV and the relative amount of pixels corresponding to this value Pmax. Six histograms features which varied significantly ($P < 0.05$) with the storage conditions, highly correlated positively ($0.97 < r < 0.99$) to water capacity absorption (WCA) of bean, a classical attribute of the hard-to-cook, while four histogram features which varied significantly ($P < 0.05$) with the storage conditions, highly correlated negatively ($-0.99 < r < -0.9$). The results obtained confirm that beans undergo color changes during storage, which is related to the hard-to-cook phenomenon. It demonstrates the ability of color histogram-based images processing of beans to assess this phenomenon in terms of color images attributes.

Key words: Images processing, color histogram, haricot beans, hard-to-cook.

INTRODUCTION

Grain legumes are major sources of dietary proteins in developing countries (Tharanathan and Mahadevamma, 2003). In addition to their protein contributions, legumes are also rich in other nutrients such as starch, dietary fiber, protective phytochemicals, oil, vitamins and mineral elements (De Almeid Costa et al., 2006; Luthria et al., 2006). Among the commonly consumed food legumes, haricot bean (*Phaseolus vulgaris* L.) is the most widely produced and consumed legume in the

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world and occupies an important place in human nutrition in many regions of Africa by improving the nutritional status of many low income populations (Sarah et al., 2009; AbdelRahaman et al., 2005; Shimelis and Rakshit, 2005; Mbofung et al., 1999; Geil and Anderson, 1994). It is well known that a significant problem with haricot bean is that it does not soften easily and remains hard even after two or more hours of cooking in boiling water. Prolonged storage, especially under high temperature (≥ 25°C) and high relative humidity (≥65 %) conditions that predominate in tropical regions promote this phenomenon called hard-to-cook (Reyes-Moreno et al., 2000; Cabrejas et al., 1997). This hardness of beans and the concomitant need for long boiling times lead to reduced palatability and protein digestibility (Kigel, 1999), waste of time and energy. Several methods have been proposed to study the hard-to-cook of bean, namely the determination of the cooking time (Hentges et al., 1990; Wang and Daun, 2005), the determination of the water content absorption (Hincks, 1986) and recently the determination of the cooking time-constant (Bitjoka et al., 2008). These methods are laborious, time consuming and invasive since they destroy the analyzed sample.

Color is an important quality attribute that dictates the quality and value of many agricultural products. Vindiola et al. (1986) suggested that the quality of cooking is related to the color of the bean; Cabrejas et al. (1997) showed that the red bean browned during hardening. Consumers tend to associate color with storage time, due to the fact that it correlates well with physical, chemical and sensory evaluations (Pedreschi et al., 2006). All these suggest that beans undergo color changes during storage, which is related to the hard-to-cook phenomenon. These color changes could be automatically analyzed and quantified in order to assess the hard-to-cook phenomenon. The use of computer vision system (CVS) for quality inspection of fruits and vegetables has increased in recent years. Mendoza and Aguilera (2004) demonstrated the ability of average data from CVS to correlate well with those from visual assessment of bananas and colorimeters. Yam and Papadakis (2004) developed a method that uses a combination of digital camera, computer, and graphics software to measure and analyze the surface color of food products in terms of L^*, a^* and b^* attributes. Fernandez et al. (2005) developed a method based on computer vision to analyze the effect of drying on shrinkage, color and image texture of apple discs. A calibrated computer vision system provided another technique that allows capture and quantitative description of mango fruit (Kang et al., 2008). Computer vision system was widely used by Blasco et al. (2009a, 2009b, 2009c, 2003) for quality inspection of fruits. The objectives of this study were to define and determine characteristic parameters of a digital color image of a seed, identify which of these parameters vary significantly with the storage conditions that predominate in tropical regions, and establish correlation between these parameters and the water capacity absorption (WCA), a classical indicator of the degree of hard-to-cook.

MATERIALS AND METHODS

Beans and storage conditions

Red beans (*Phaseolus vulgaris*) were obtained from Ngaoundéré (7° 21'N and 13°33'E). Elevation in Ngaoundéré ranges from 900 to 1100 m above mean sea level. Freshly harvested beans (200) were stored during 10 days in a drying oven (temperature: 60°C; relative humidity: 65 - 70%) in order to accelerate and control the development of the hard-to-cook (Vindiola et al., 1986). The length, width, thickness and weight of individual beans were determined from the randomly selected beans. The mean length, width, thickness and WCA of the beans were 10.36 ± 0.20 mm, 5.70 ± 0.19 mm, 4.08 ± 0.50 mm and 14.18 ± 0.047%, respectively. Every two days, 40 beans were moved from the oven and analyzed; 4 of them were analyzed by the computer vision system (CVS) developed while the 36 others were used to measured the water content absorption.

Water absorption

Water absorption of beans was determined by soaking on a dry weight basis (dwb) in distilled water, corresponding to three times the weight M_0 of the 36 beans, in a bain-marie at the temperature 25°C for up to 4 h (Figure 1). The soaked beans were blotted with a paper towel every 15 min to remove excess water, weighed (M_1) and placed back into the soaking water. Water absorption value was expressed as a percentage of water absorption and calculated as grams of water absorbed per 100 g of beans (dwb) using the following formula:

$$\text{Percentage water absorption} = \frac{M_1(\text{Weight of soaked beans}) - M_0(\text{Weight of dry beans})}{M_0(\text{Weight of dry beans})}$$

Image acquisition

Camera

In this paper, a color digital camera (Fujifilm FinePix F480) was used to take the images of the haricot beans. This camera was equipped with a CCD sensor and automatically balanced white color. Its focal length varied from 4.6 - 18.4 mm, corresponding to 28 - 112 mm for a 35 mm analogical camera. The camera settings in our experiments were manual mode ISO200; shutter speed 1/100; aperture 5.0; no zoom; no flash; resolution 3264 x 2448; format JPEG. It captured images through a 27 mm in diameter hole as shown in Figure 2.

Lighted box

Two halogens lamps (Silvania 50-60Hz, 220V, 36W) were attached at the top corner of a box (Figure 2), in parallel, at an angle of 45° (Papadakis et al., 2000) to the grain sample. These lamps were chosen to set the color temperature to D_{65} (6500 K), a CIE standard and a common light source used in food color measurement (Kang et al., 2008). The box was made in wood,

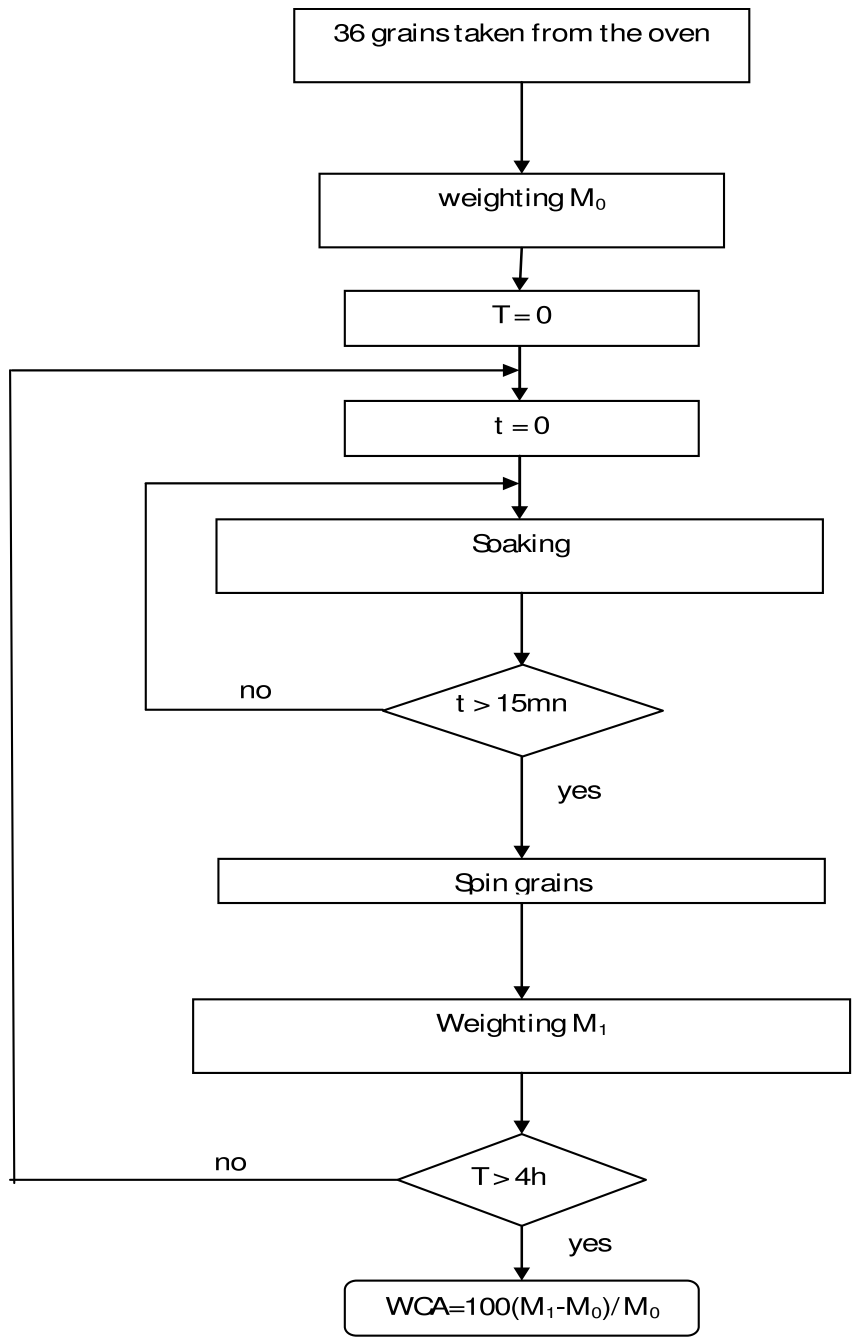


Figure 1. Flow diagram of protocol for measuring the kinetics of water absorption (adapted from Hinks and Stanley, 1986).

200 x 200 x 150 mm^3.

Imaging

The color digital camera (Fujifilm FinePix F480) captured images through a hole, 27 mm in diameter, on the top of the lighted box (Figure 2). The distance between the camera and grain sample was set to 100 mm. In this manner, the observation angle of a CVS color measurement satisfied the CIE standard (Schanda, 1998) and the camera captured the whole grain without zooming. During 10 days, and every two days 4 stored grains were imaged three times. Before starting the experiments, 4 freshly harvested grains were imaged three times. Therefore, in total 72 (6 times x 4 grains x 3 images) images (3264 x 2448 pixels) were taken to be analyzed.

Image analysis and feature extraction

Images were analyzed following the block diagram shown in Figure 3. Bean images analysis in this paper was based on

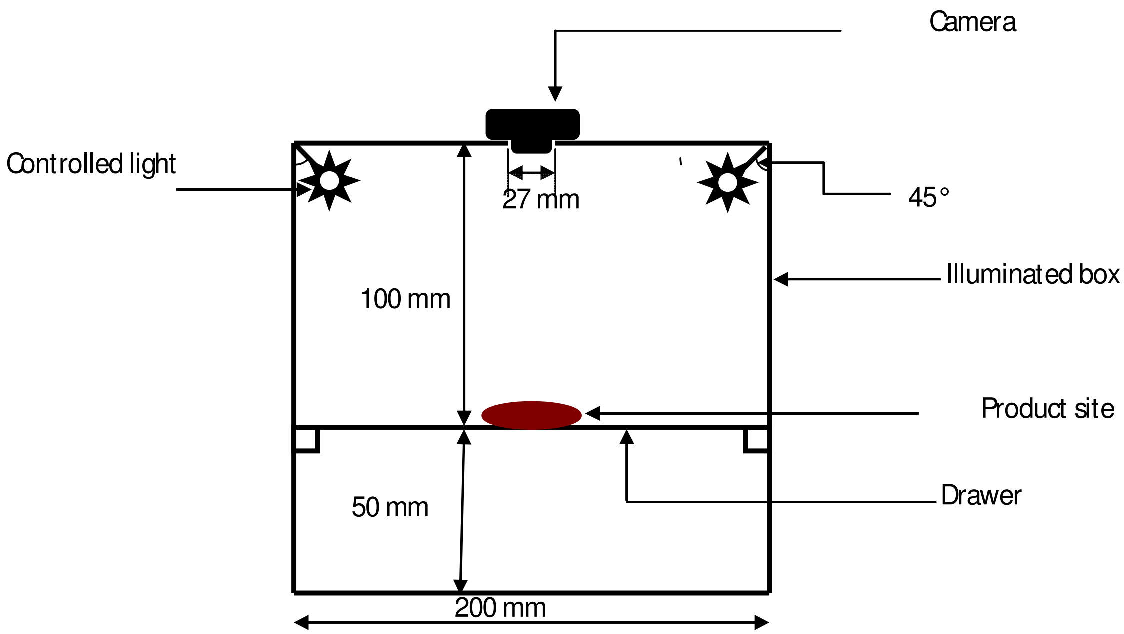


Figure 2. Set up of images capturing.

histograms. Images analysis procedure included three main parts: image segmentation, RGB and luminance histograms determination; histogram features definition and determination.

Image segmentation, red, green and blue (RGB) and luminance histograms

Color image segmentation referred to the partitioning of a multi-channel image into meaningful objects. The segmentation was based on measurements taken from the image and might be grey level, colour, texture, depth or motion.Various approaches to color image segmentation were found in the literature and were roughly classified into several categories: clustering methods (Thalamuthu et al., 2006; Kiddle et al., 2010), edge-based methods (Mohamed Ben Ali, 2009), region growing methods (Day et al., 2009) and variational methods (Houhou, 2009). Clustering methods of the color histogram use 3D information and are time consuming, so methods based on multi-thresholding of color planes might be preferred (Lezoray and Cardot, 2002). In this paper, segmentation was an initial step intended to remove background from the grain. The RGB and luminance histograms of our images are bimodal and low noise. For this reason and taking into account the fact that the human eye is more sensitive to green light than red or blue light and the luminance histogram matches the green histogram more than any other color (Busin et al., 2008), a single thresholding grey level-based histogram segmentation method was implemented. This method is presented in Figure 4. A threshold T that separates the two modes of the green color histogram was determined and applied to all the RGB histograms to extract the grain from the background. After segmentation, the RGB and luminance hhistograms were calculated and normalized as follows:

$$p(x) = \sum_{i=0}^{T} \frac{h(i)}{N},$$

Where, *h(i)* is the histogram of an N pixel image and $x \in [0 \quad T]$ is the grey level. Non segmented and segmented images of bean using this method and their respective histograms are presented in Figure 5.

Histogram features definition and determination

Four histogram features were defined and calculated on each histogram as shown in Figure 6. These features are the maximum grey level value GLVmax, the minimum grey level value GLVmin, the most representative grey level value MRGLV and the relative amount of pixels corresponding to this value Pmax.

Statistical analysis

In the present study, the four features calculated for each histogram were compared to those obtained with the freshly harvested bean. Analysis of variance test (ANOVA) was performed using Statgraphics® plus 5.0 and the difference was considered significant when $P < 0.05$. Then, the histogram features which varied significantly ($P < 0.05$) with the storage conditions were correlated to water capacity absorption (WCA) of bean.

RESULTS AND DISCUSSION

Color red, green and blue (R, G, B) and luminance histograms of beans

Figure 7 showed the color (red, green and blue components) and luminance histograms of bean freshly harvested (Figure 7a), after 2 days of storage (Figure 7b), 4 days of storage (Figure 7c), 6 days of storage (Figure 7d), 8 days of storage (Figure 7e) and 10 days of

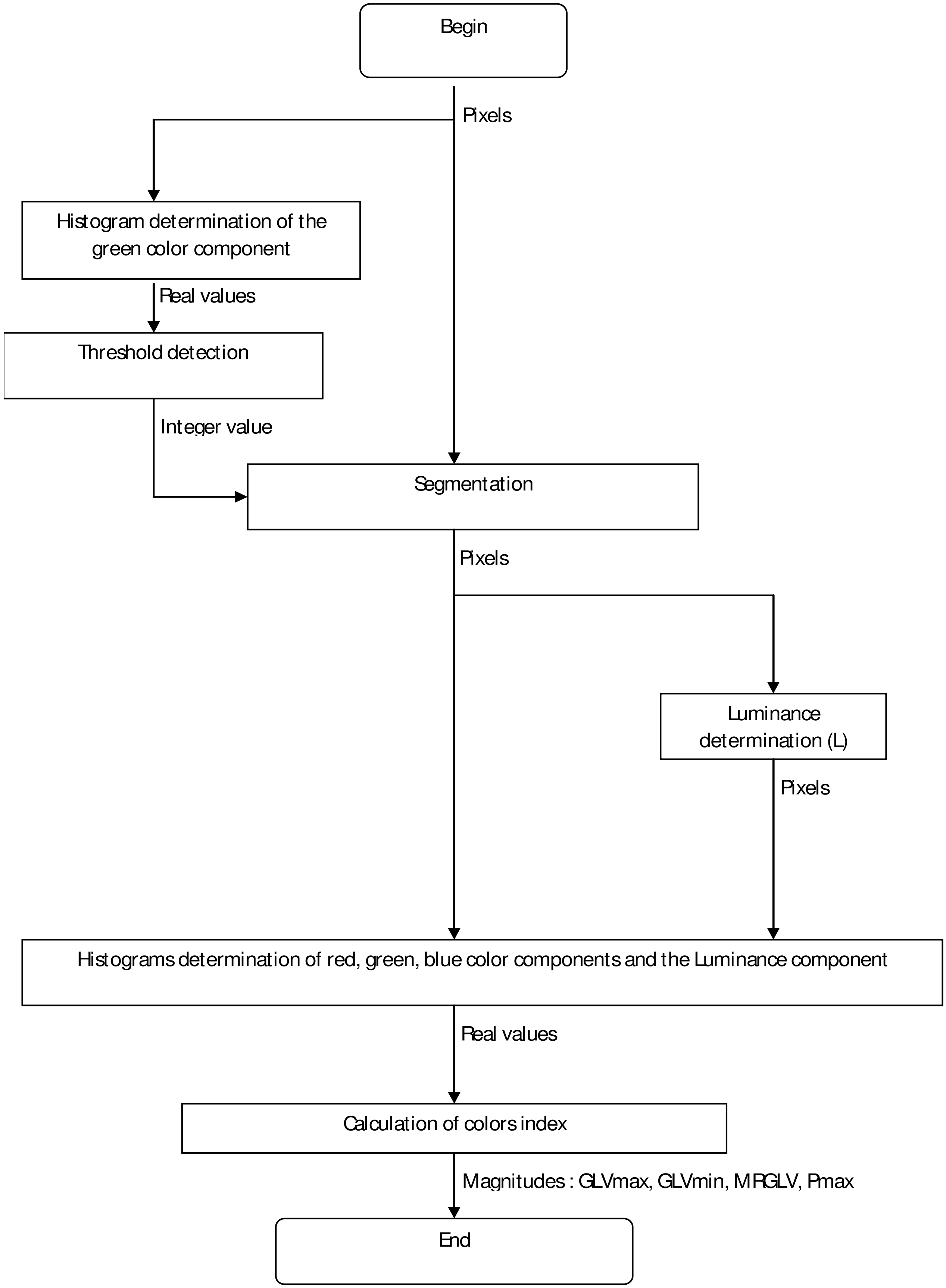


Figure 3. Diagram of images processing.

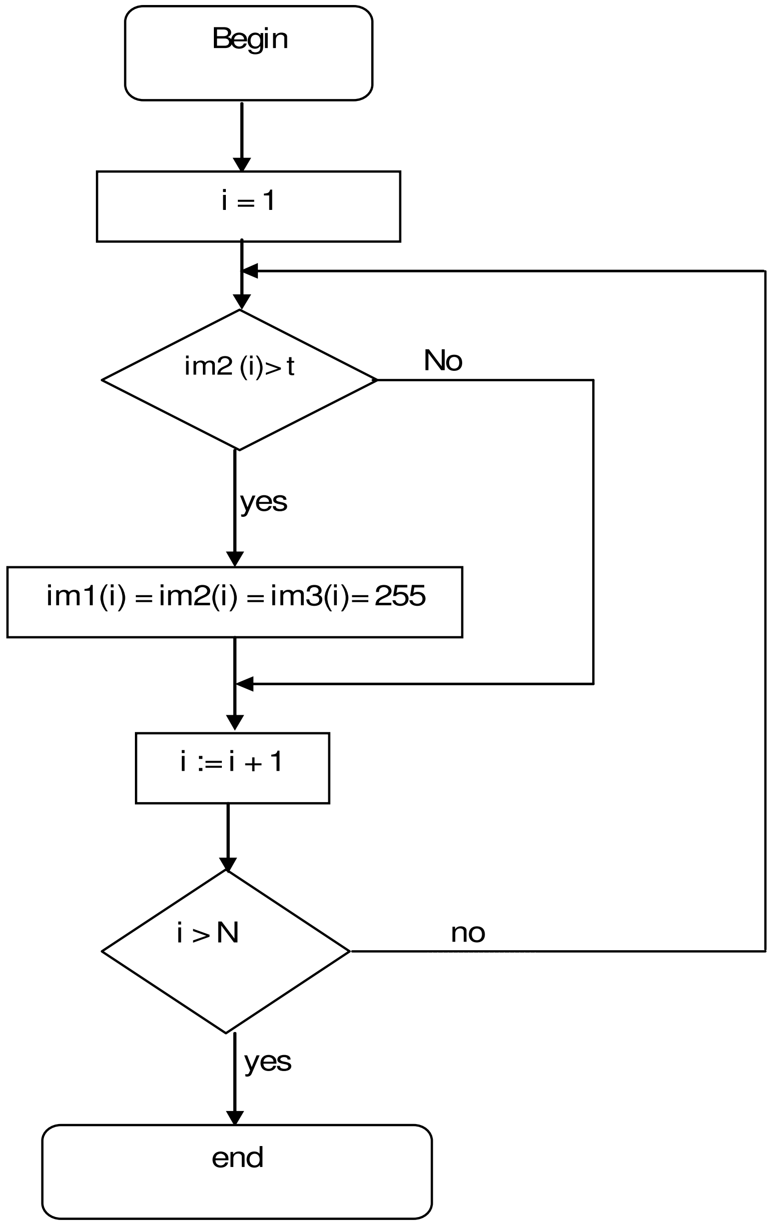
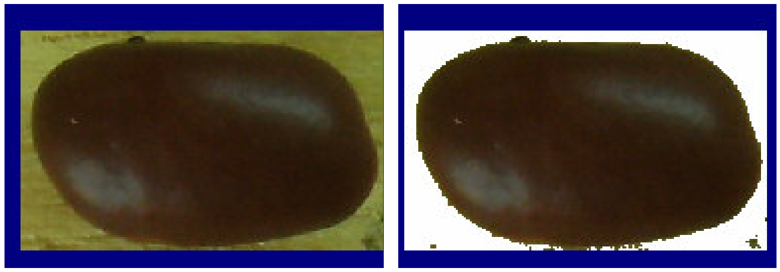


Figure 4. Flow-Chart of the segmentation.

storage (Figure 7f). Colors (pixels) shift from a red range of 45 - 80 to 5 - 25 range (blue). The pick of luminance histogram was close to the pick of the green component histogram in all these figures. In fact, luminance histogram matches the green histogram more than any other color. Also noticeable was a shift in variation in color of the bean during storage. Compared to histogram at time T_1, histogram at time $T_2 > T_1$ was left shifted which means that the red bean used in our experiments browned during storage. Similar result was reported by Cabrejas et al. (1997) and Reyes-Moreno (2000), who showed that the red bean browned during hardening. At the beginning of storage, green color for example spanned a 22 - 50 range, while at 8 days of storage, this range was compressed to a 15 - 30 range.

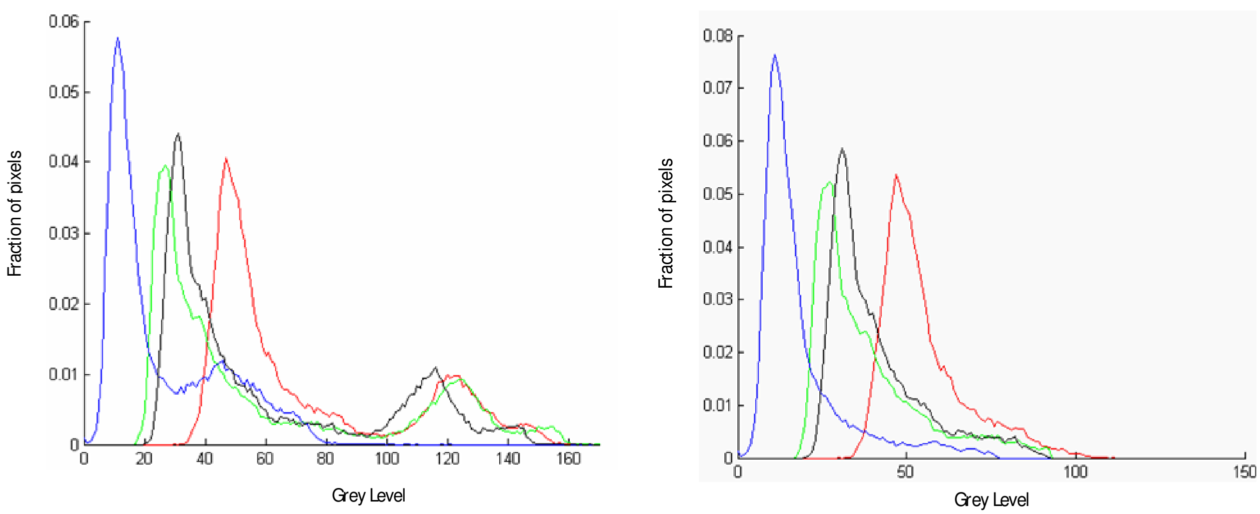
Histogram features

The four histogram features, that is, the maximum grey level value GLVmax, the minimum grey level value GLVmin, the most representative grey level value MRGLV and the relative amount of pixels corresponding to this value Pmax were presented in Figure 8a, b, c and d respectively. The first three histogram features, that is, GLVmax, GLVmin and MRGLV decreased during



a **b**

Figure 5 (a). Non segmented image, b. Segmented image.



c **d**

Figure 5c. Histograms of non segmented image, **d.** Histograms of segmented image.

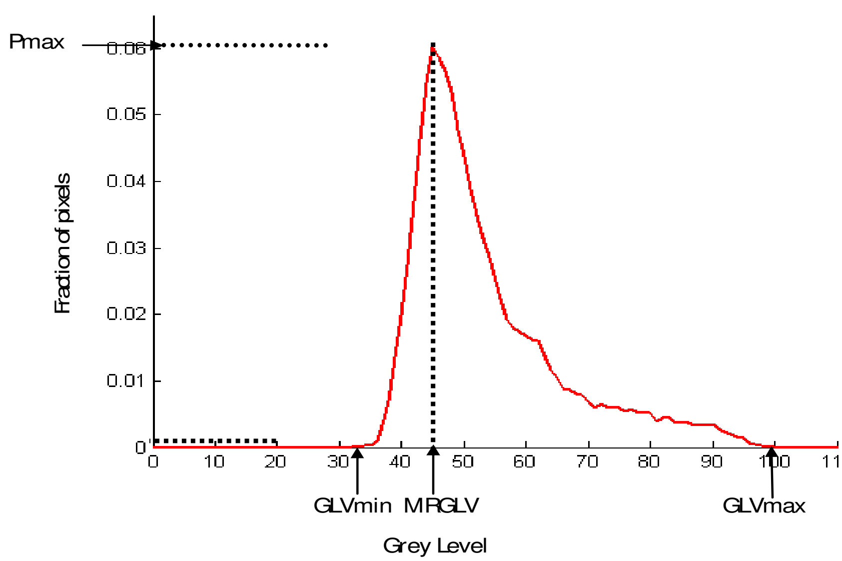


Figure 6a. Features definition on histogram.

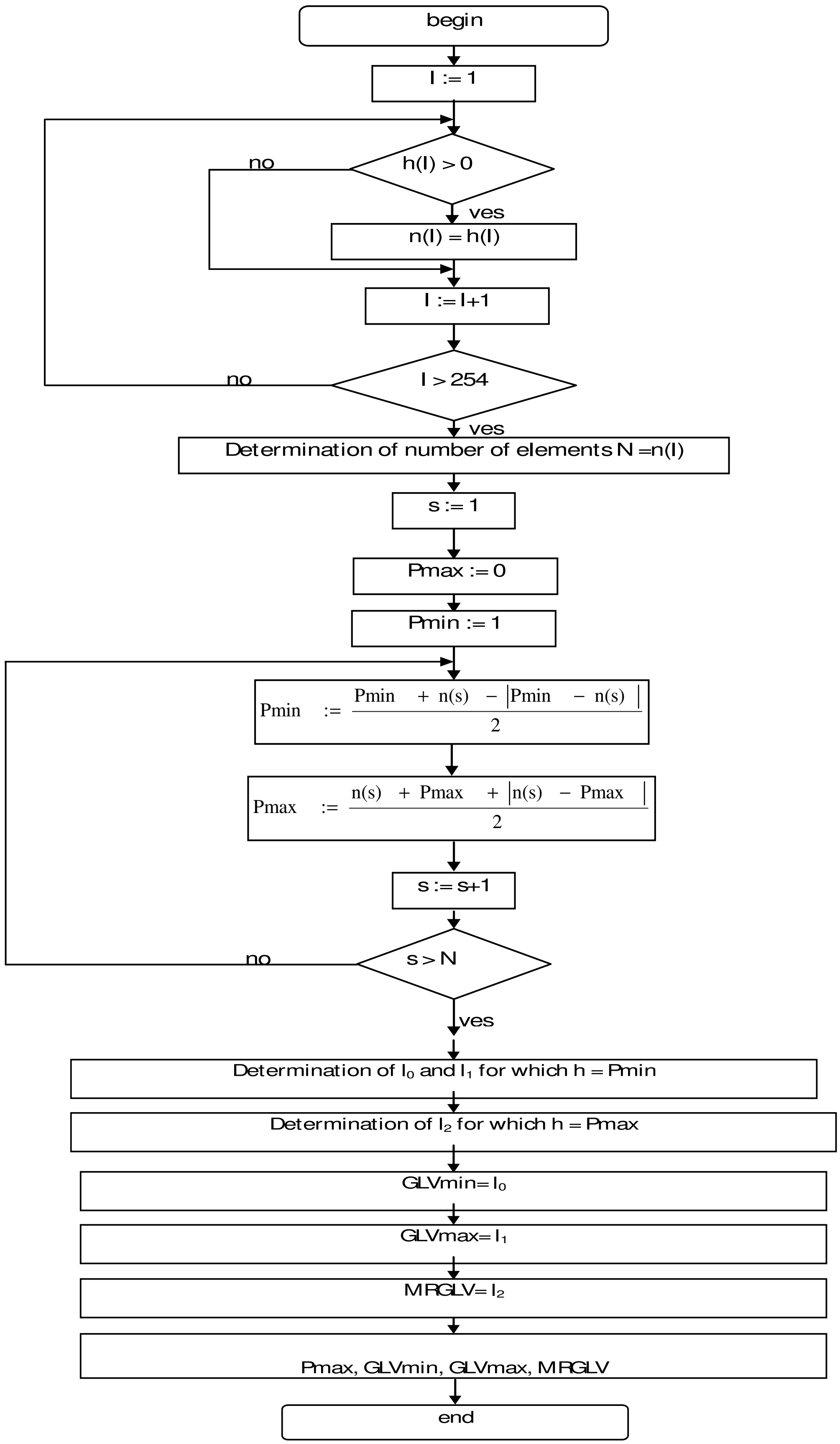


Figure 6 (b). Flow-chart of histogram feature determination.

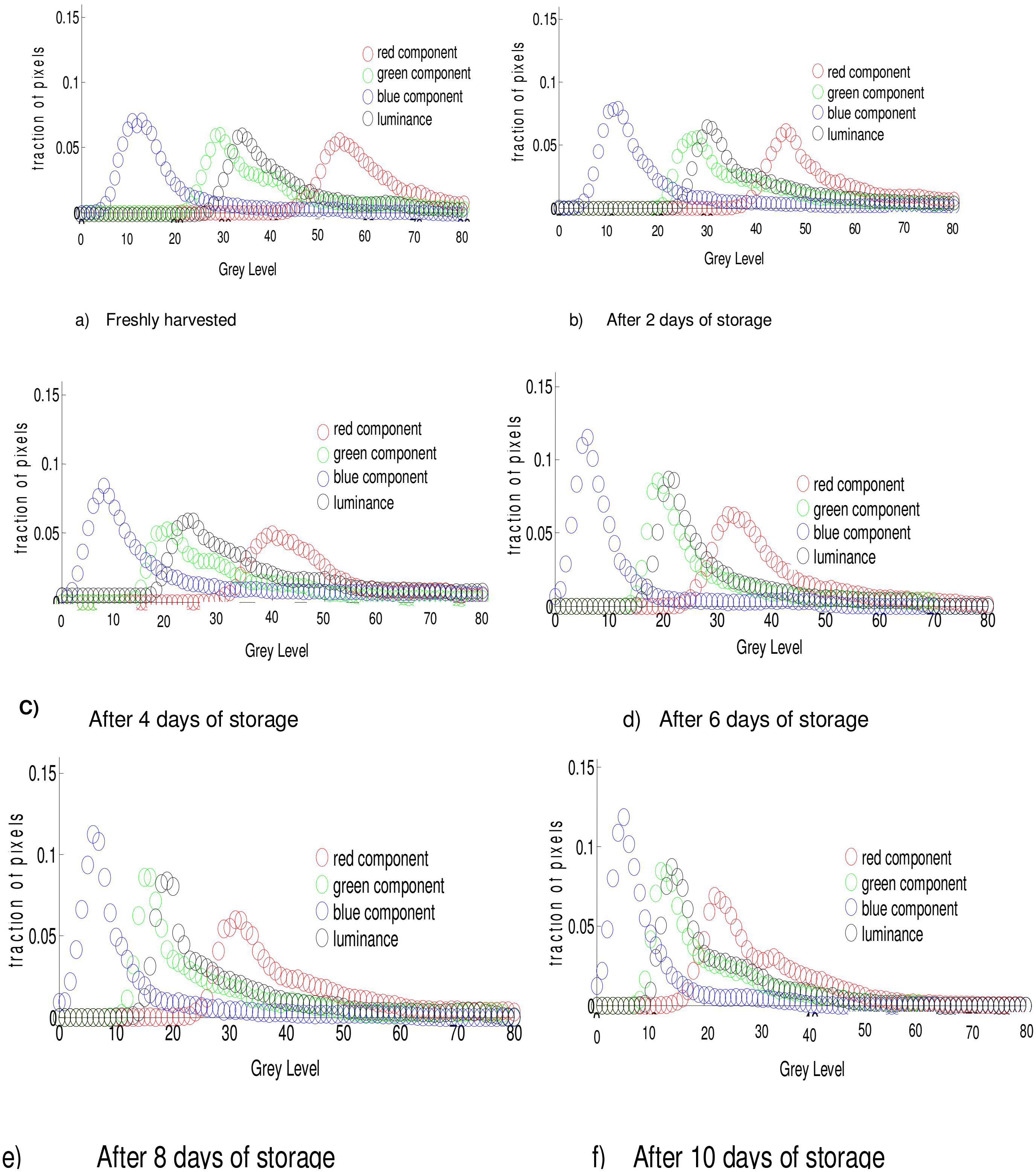
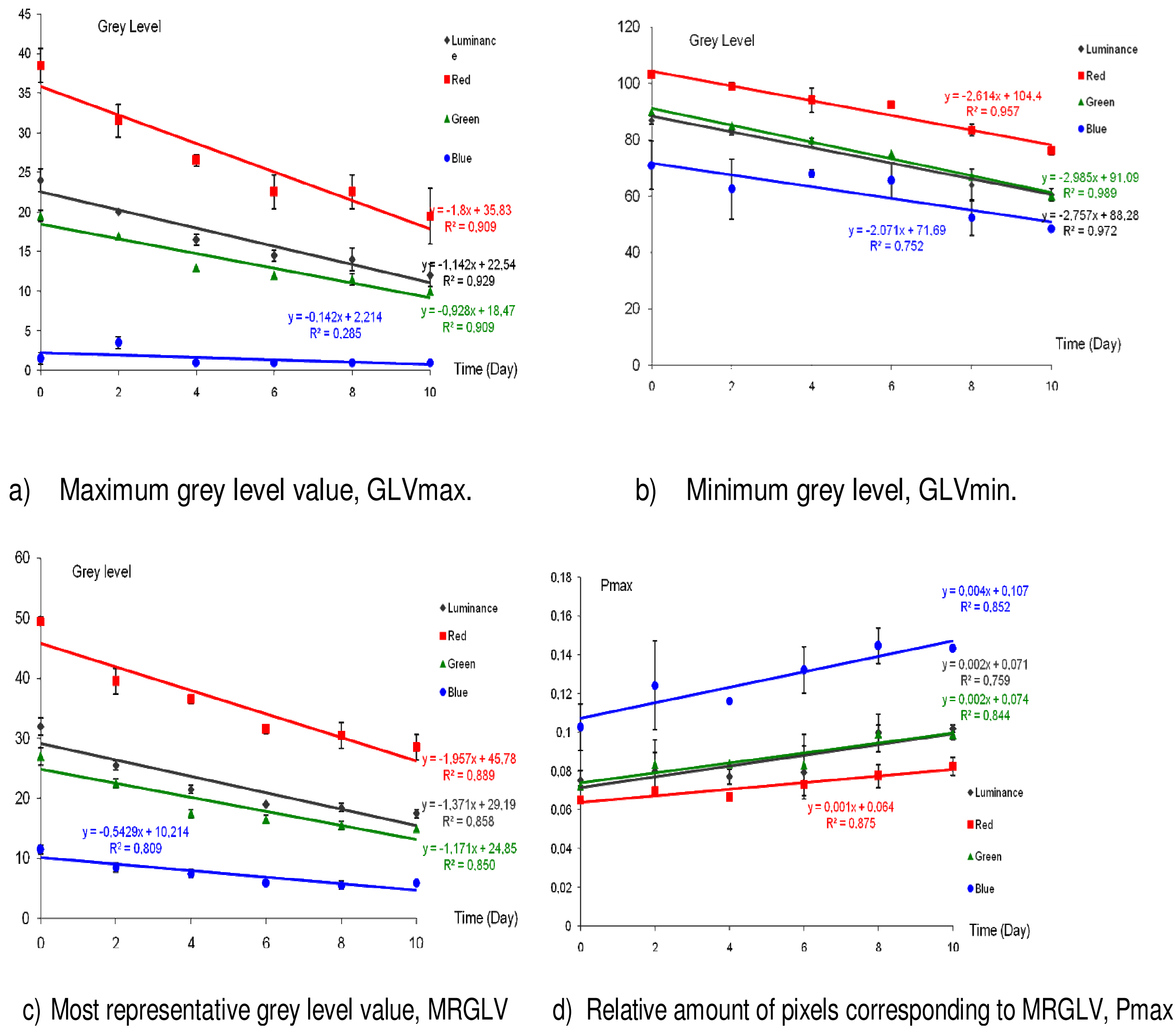


Figure 7. Colour change of an individual red bean (*Phaseolus vulgaris*) seed stored at 60℃ and 65 - 70% HR.

storage, while Pmax increased. While studying change in color, as described by histograms of hue angle of mango fruit, Kang et al. (2008) reported the left shift of the peaks of histograms. Our results showed that these features varied linearly for the luminance ($R^2 > 0.86$), the red ($R^2 > 0.89$), the green ($R^2 > 0.85$), and the blue



a) Maximum grey level value, GLVmax.

b) Minimum grey level, GLVmin.

c) Most representative grey level value, MRGLV

d) Relative amount of pixels corresponding to MRGLV, Pmax

Figure 8. Histogram features of red bean (*Phaseolus vulgaris*) seed stored at 60°C and 65 - 70% HR.

(R^2 > 0.75) except for GLVmin (R^2 = 0.285). GLVmax decreased more rapidly, compared to GLVmin and MRGLV (Figure 8). This result in histograms left shifted and the browning of red bean during storage.

Correlation between the histogram features and the water capacity absorption

Statistical results concerning the histogram features obtained with freshly harvested beans and stored beansare presented in Table 1. The histogram features which varied significantly ($P<0.05$) with the storage conditions were correlated to water capacity absorption (WCA) of significantly ($P < 0.05$) with the storage conditions; the relative amount of pixels corresponding to the most representative grey level value varied significantly for the bean. Table 1 showed that ten histograms features varied luminance histogram, Pmax (L), from freshly harvested bean to stored bean (2 days to 10 days of storage). The other parameters varied significantly only after 4 days, namely GLVmin(L), MRGLV(L), Pmax(R) and GLVmin(G); or 6 days, namely GLVmin(R), MRGLV(R) and Pmax(B); or 8 days, namely MRGLV(G) and Pmax(G). Among these features, six are highly correlated positively (0.97 < r < 0.99) to water capacity absorption (WCA) of bean, that is, GLVmin (L), GLVmin(R), GLVmin (G), MRGLV (L), MRGLV (R) and

Table 1. Comparison (Anova test) of the histograms features of freshly harvested and stored beans.

Storage (day)/ feature	2	4	6	8	10
GLVmin(L)	-	+	+	+	+
MRGLV(L)	-	+	+	+	+
GLVmax(L)	-	-	-	-	-
Pmax(L)	+	+	+	+	+
GLVmin(R)	-	-	+	+	+
MRGLV(R)	-	-	+	+	+
GLVmax(R)	-	-	-	-	-
Pmax(R)	-	+	+	+	+
GLVmin(G)	-	+	+	+	+
MRGLV(G)	-	-	-	+	+
GLVmax(G)	-	-	-	-	-
Pmax(G)	-	-	-	+	+
GLVmin(B)	-	-	-	-	-
MRGLV(B)	-	-	-	-	-
GLVmax(B)	-	-	-	-	-
Pmax(B)	-	-	+	+	+

+ : significant difference: non significant difference, R: Red, G: Green, B: Blue and L: Luminance.

Table 2. Correlation of histograms features with water absorption capacity (WAC) of bean.

GLVmin(L)	GLVmin(R)	GLVmin(G)	MRGLV(L)	MRGLV(R)	MRGLV(G)	Pmax (L)	Pmax (R)	Pmax(G)	Pmax(B)
0.99	0.98	0.98	0.97	0.98	0.97	-0.90	-0.99	-0.92	-0.97

MRGLV (G); four are highly correlated negatively (-0.99 < r < - 0.9), that is, Pmax (L), Pmax (R), Pmax (G) and Pmax (B) (Table 2).

Conclusion

This paper presented a computer vision systems (CVS) consisting of a standard lighted box, a camera for image acquisition of beans and image processing software. Red bean images analysis based on histograms, including image segmentation, RGB and luminance histograms determination, histogram features definition and determination, that is, the maximum grey level value GLVmax, the minimum grey level value GLVmin, the most representative grey level value MRGLV and the relative amount of pixels corresponding to this value Pmax was achieved. Histograms showed a left shift in variation in color of the bean during storage proving that red bean browned during storage. Ten histogram features which varied significantly ($P < 0.05$) with the storage conditions, highly correlated to water capacity absorption (WCA) of bean; a classical characteristic of the degree of hard-to-cook. The results obtained confirm that beans undergo color changes during storage, which is related to the hard-to-cook phenomenon. It demonstrates the ability of images processing of beans to assess this phenomenon in terms of color images attributes.

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