Int. Agrophysics, 1996, 10, 69-76

EFFECTS OF DIFFERENT SHELF STORAGE CONDITIONS OF CHICORY ON THE COLOUR CHANGE USING DIGITAL IMAGE PROCESSING

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Accepted December 13, 1996

A b s t r a c t. The study established a method of evaluating the colour change of chicory under different shelf storage conditions. The RGB system was used for digitising the colour images. The experiments under four storage temperatures and three humidities were made. In the experiments, a comprehensive index, *Sc*, was presented and used for estimating the unfavorable colour change (turning to brown and red). The index is based on comprehensive consideration of the coloured area and degree of the colour change. Other phenomena of overall colour change, such as growth of yellow leaves, greening of leaves under illumination have been analysed. The effects of changing temperature on *Sc* are discussed.

K e y w o r d s: chicory, colour change, digital image processing, shelf storage conditions

INTRODUCTION

Chicory (*Cichorium intybus* L.) is one of many species of Compositae family. Leaves and heads of chicory (witloof in Dutch) have been used as a vegetable since approximately 300BC in Belgium. They are appreciated for their slight bitter taste [16]. Now chicory is not only an important vegetable in Belgium, but also popular in western countries [7].

One of the four main quality disorders of chicory is red and brown core, which is normally caused by inappropriate storage and unfit varieties [6]. There exist few reports on the formation and development of red and brown core during shelf storage. However, this is important to consumers.

There are two evaluation systems for colour change. One is the LCH system consisting of hue, chroma, and value. Thai *et al.* [10,11] presented the colour change of peaches and tomatoes during storage by means of this system. Another system is the RGB system consisted of relative locations of red, green and blue spectral colours when brightness is fixed [3].

In the studies of the digital processing of colour images using the RGB system, three decision algorithms for the classification of the colour distribution on some fruits have been developed [8,9]. Some experiments for the evaluation of colour change of apple, peach, and tomato during storage were made [5,14,15]. Zhang *et al.* [17] reported the effects of different varieties of chicory on the colour change of cut area.

In the application of machine vision, some technical problems must be overcome. The pixels (picture elements) and pixel window(screen unit) in the image were used as unit of the observed area [13,15,17]. Segmentation of the image colour has been applied to many fruits and vegetables [4,5,8,17].

The objective of this article is to establish the methods of judging the red and brown core and other unfavorable colour change in chicory. It is done on the basis of the colour change of the cut area during shelf storage.

The possible relationship between the storage conditions and quality after shelf life was to be established using the digital image processing.

NOMENCLATURE

Rj, Gj, Bj	relative locations of red, green and blue spectral colours of the *jth* pixel window,
r, g, b	rescaled R, G, B ,
Sc	comprehensive colour index for reddening and browning,
$r_{2,4}$	average r value of n samples for replication tests on red and brown areas, 1/EP,
$a_{2,4}$	average area percentage of pixel window of n samples for replication tests on the red and brown area, %,
A_i	amounts of pixels of the *ith* testing sample, EP,
r_{ki}	average r value of the *ith* sample in the *kth* segmented area, 1/EP,
P_{ki}	area percentage of the *ith* sample in the *kth* segmented area, %,
a_3	average area percentage of n samples in the yellow segmented area, %,
g	the average g value of whole cut area, 1/EP,
g_{ki}	average g value of the *kth* segmented area, 1/EP,
K_a	area shrinkage coefficient,
k	number of segementation of colour, k=1,2,3,4,
n	amount of samples in replication tests
EP	each pixel.

MATERIALS AND METHODS

The image system

The measurement setup is shown in Fig. 1. To capture the video image, the sample was illuminated by four quartz tungsten halogen lamps on a black background. A cylindrical diffuser is placed between the light source and the sample to avoid specular reflection spots as much as possible. The sample images were captured using a RGB video camera (JVC TK-1070E). The image was digitised using a frame grabber (Truevision Targa+, 32 bit) installed on a PC-AT 486/66 DX 2 with 16M RAM. Each sample was captured once each day during the shelf life study.

The treatment of the samples and steps of the experiments

The fresh chicory of two main commercial varities, Sigma and Focus, were obtained from the Witloof Research Unit at the K. U. Leuven, Belgium. The cut along the axis was selected for observing the colour change and the brown core inside chicory during shelf storage. Each treatment has ten replications. A shelf storage duration (seven days) was chosen. After the measurements were finished each day, the samples were covered, to avoid illumination, and immediately place in the simulated shelf storage rooms. Four climatic rooms were used for the experiments. The climate conditions (temperature and humidity) could be selected according to the need in the particular experiments.

The indices of experiments

For the construction of the HICUPP (Hierarchical Classification using Projection Pursuit) tree, the *rgb* values, after removing the intensity, were used in the segmentation and the tests. The relationship between the two sets of data is as follows:

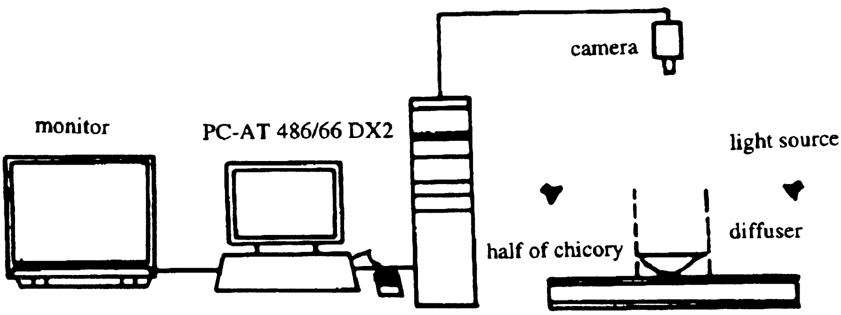


Fig. 1. The video image acquisition setup.

$$r = R/(R+G+B),\ g = G/(R+G+B),$$
$$b = B/(R+G+B) \qquad (1)$$

Four colour areas, which are white, red, yellow and brown, labeled as k=1,2,3,4, respectively, were segmented and determined by means of the HICUPP tree [17]. The unfavourable colour change of the sample consists of turning red and brown during shelf storage, or the increase of red and brown areas and decrease of average r values on both the red and brown areas [17]. So a comprehensive index, Sc can be introduced for which a higher value means that the colour remains:

$$Sc = \frac{r_{2,4}}{a_{2,4}} \qquad (2)$$

where $r_{2,4}$ is the average r value of n samples on the red and brown areas (the 2nd and 4th areas), shown in Eq.(3); $a_{2,4}$ is the pixel area percentage of the red and brown areas, calculated Eq.(4):

$$r_{2,4} = \frac{\sum_{i=1}^{n} A_i(\overline{r_{2i}}\,P_{2i} + \overline{r_{4i}}\,P_{4i})}{\sum_{i=1}^{n} A_i(P_{2i}+P_{4i})} \qquad (3)$$

$$a_{2,4} = \frac{\sum_{i=1}^{n} A_i(P_{2i}+P_{4i})}{\sum_{i=1}^{n} A_i} \qquad (4)$$

where $\overline{r_{ki}}$ is the average r value in the each window of an 8x8 pixel area (about 0.52x0.59 cm^2), calculated as follows:

$$\overline{r_{ki}} = \frac{\sum_{i=1}^{A_iP_{ki}} \frac{R_j}{R_j+G_j+B_j}}{A_i\,P_{ki}} \qquad (5)$$

RESULTS AND DISCUSSION

Effects of different storage temperatures of chicory on the unfavourable colour change

The results of the tests on the two commercial chicory (Sigma, Focus) varieties are shown in Fig. 2. Figure 2 shows that the Sc values of both Focus and Sigma decrease with time, and decrease very slowly at lower temperatures (2 and 5 °C) during the first two days. From the third day on, the values decrease sharply to the level near or lower than the value at higher temperatures (10 and 18 °C).

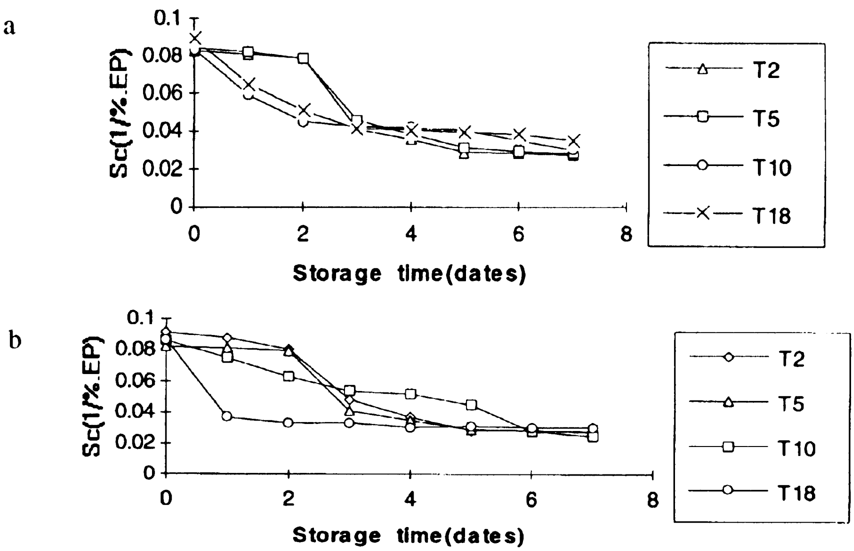


Fig. 2. The Sc values on the red and brown areas under different temperature (65 % RH) for chicory varieties: Focus (a) and Sigma (b).

At the higher temperatures the decrease is even. From visual observation, the so called red and brown core is present at third day for lower temperatures, and from the first day for higher temperatures. And 0.06 1/%. EP may be the critical *Sc* value for avoiding brown core. So suggestion for shelf life of lower temperatures (2-5 °C) as commercial shelf storage is not more than two days.

The difference of *Sc* values between two varieties at the same day is small according to the graphes. This is in accordance with visual observations.

Effect of different humidities on the colour change of the red and brown areas

Because the very low temperature (freezing temperature) would be needed for obtaining the RH lower than 50 %, so the different points among 50-90 % RH (50, 65 and 90 %) at 10 °C were selected. The results are shown in Fig. 3. The *Sc* values for the lower humidities (50, 65 % RH) are much higher than the higher humidity(90 % RH) at same day. So the lower the humidity is, the better the *Sc* value is. The recommended humidity range to avoid colour change is from these experiments of 50-65 % RH.

can indicate the activity of the sample under different storage conditions. The a_3 value represents the percentage change of the yellow area(the 3rd one). It is calculated from:

$$a_3 = \frac{\sum_{i=1}^{n} A_i(P_{3i})}{\sum_{i=1}^{n} A_i} \qquad (6)$$

The results for different storage conditions are shown in Fig. 4. The charts show that a_3 values decrease in first three days, but increase in the later three days. It can be explained by the leaves growing in the later three days, which was also observed during the experiments. The effects of the temperature on the index are greater than that of the humidity. The higher the temperature is, the stronger the leaves grow. The strongest growth was observed at the high temperature of 18 °C (Fig. 4).

Effects of the changing temperatures on colour change

Sometimes practical shelf storage temperature varies in the market chain from producers, over supermarkets, to consumers. So it is necessary to study the changes under these changing temperatures. Here two changing

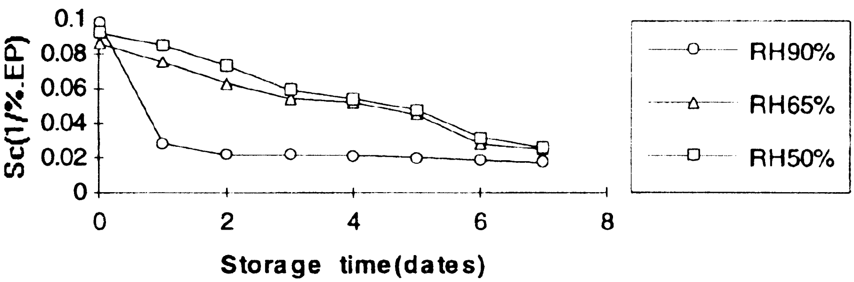
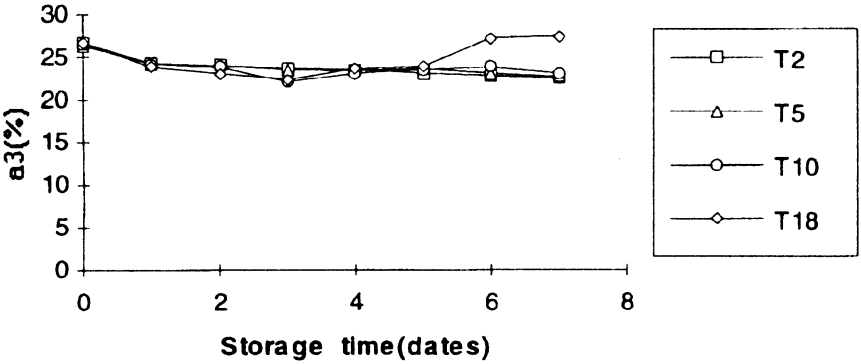


Fig. 3. The *Sc* values change of the cut flesh area under different humidity (10 °C).

Effect of different storage conditions on leaf-growing during the shelf life

The leaf-growth of the cut area during the shelf life is an interesting phenomenon that temperature (CT) methods, CT1 and CT2, were presented for simulating the practice. The CT1 is a combination of half a day at 5 °C (simulating the refrigerating temperature), and halfday at 18 °C (simulating the room tema



b

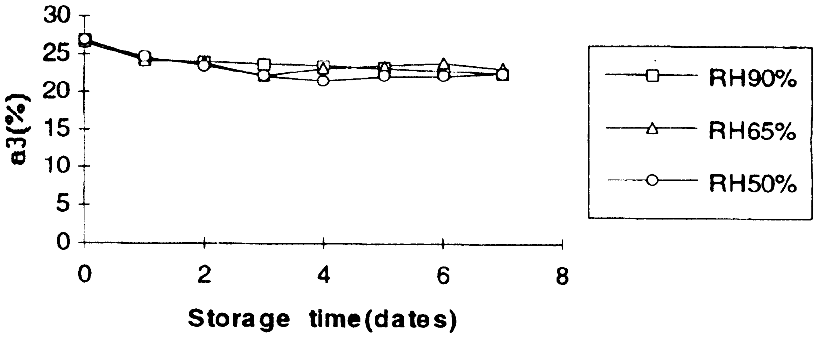


Fig. 4. The sigmented yellow area change (Sigma) under different temperature (65 % RH) (a) and humidity (10 °C) (b).

perature) each shelf life day. The CT2 means 2 h at 18 °C (up to the inside equilibrium), and other time at 5 °C for each shelf life day.

The results are presented in Fig. 5. Compared with Fig. 4 b, the *Sc* values for the two changing temperatures are much lower at the same date. So it is recommended to avoid frequent changes of temperature during storage.

Effects of different temperature on the greening of leaves under light illumination

Another colour quality problem for chicory during shelf storage is the control of the greening of the leaves in supermarkets exposed to light. For simulating the practical condition of lighting, a 20 W fluorescent lamp with a distance of 1m was used as light source

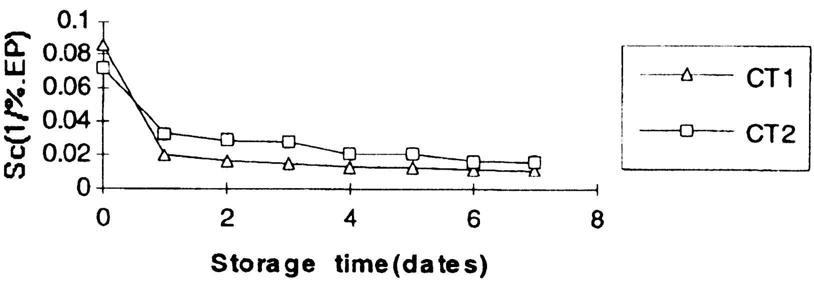


Fig. 5. The effect of the changing temperature on the color change (65 % RH, Sigma).

for observing the greening of the leaves. The judging index is g, the average g value on whole cut area, calculated from:

$$g = (\sum_{i=1}^{n} \sum_{k=1}^{4} \overline{g_{ki}})/4n \qquad (7)$$

Where $\overline{g_{ki}}$ is the average g value on the *kth* segmented area:

$$\overline{g_{ki}} = \frac{\sum_{j=1}^{A_i P_{ki}} \frac{G_j}{R_j+G_j+B_j}}{A_i P_{ki}} \qquad (8)$$

The results are shown in Fig. 6. Compared to covered samples at 18 °C (T 18 °C(C)), the samples at same temperature receiving the illumination during the storage have higher g values. All the curves (T 5 °C, T 10 °C and T 18 °C) have the common characteristic of first decreasing, then increasing and finally decreasing again. Furthermore, the g values are all similar at the seventh day. This can be explained by that the *rgb* values decrease due to browning during the shelf storage [17]. The greening of the leaves occurs during the time from the 1st day to 3rd day and remains stable in later days. This explains why the g values increase and decrease.

Effects of different temperatures on shrinkage of the cut area during the storage time

The area shrinkage during the storage indicates the shortage of the appearance of the products. For observing the effects of temperature on the shrinkage of the cut area, the area shrinkage coefficient K_a is introduced as the evaluation index shown in Eq.(9).

$$K_a = \frac{\sum_{i=1}^{n} A_i}{nA_0} \qquad (9)$$

The results of the measurement are as shown in Fig. 7. The charts show that at the lower temperatures (2 and 5 °C) a serious

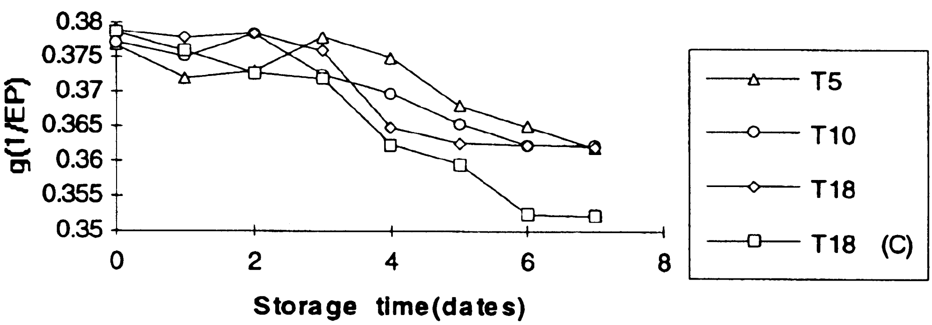


Fig. 6. The g values change under different temperature (65 % RH, Sigma).

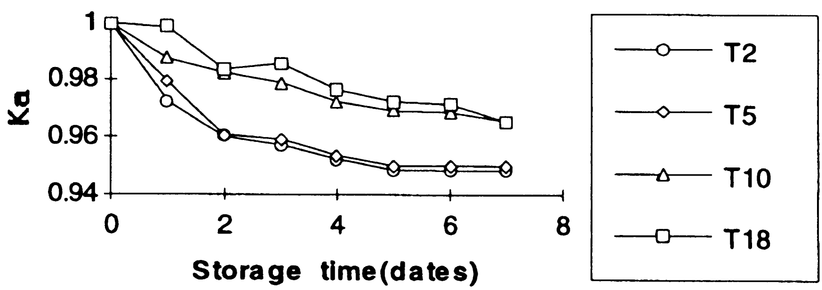


Fig. 7. The change of the area pixel during the storage time (RH=65 %, Sigma)

shrinkage occurs compared with the higher temperatures(10 and 18 °C). The differences both between 2 and 5 °C or between 10 and 18 °C are small. Too much shrinkage of the observed area during shelf storage will lead to a complication for calculating the values of the indices.

CONCLUSIONS

The results obtained are summarised as follows:

1. Higher temperatures (T 10-18 °C) during the first two days of shelf storage lead to more serious red and brown colouring compared with the lower temperatures (T 2-5 °C) for both Sigma and Focus. The duration for the colour change of cut areas of Focus and Sigma is about two days at low temperature.
2. The lower the humidity, the slower the colour change is. The recommended humidity range for shelf storage is between 50-65 % RH.
3. The higher temperature also leads to stronger leaf-growth; the effect of humidity on the leaf-growth is small.
4. Changing temperatures during storage often lead to a serious red and brown colouring. So avoiding to change temperature during shelf storage is reasonable.
5. The difference of *g* values between the covered and the illumination are great. The greening appears during storage between the 1st day and 3rd day.

APPENDIX

The average RGB values of the window area with 8x8 pixels (0.52x0.59 cm^2) can be calculated by the Treuvision Plus. Then about 600 RGB values selected from all samples were used for the segmentation of the colour by the Projection Pursuit Method. The segmentation tree is shown as Fig. 8. The thresholding values in three projections were determined by the segmentation curves.

According to the segmentation (Fig. 8), four colour areas, white, red, yellow, and brown, k=1,2,3,4, respectively, are split by means of the software Vision v 3.12 developed based on Borland Pascal. The unfavourable colour change of the sample in the red and brown areas during the shelf storage can indicate the shelf life, while degree and area of the colour change are two prominent indices. So a comprehensive value of Sc (Eq.(2)) can be introduced for which a lower the Sc value means the more serious colour change on the cut area of the sample.

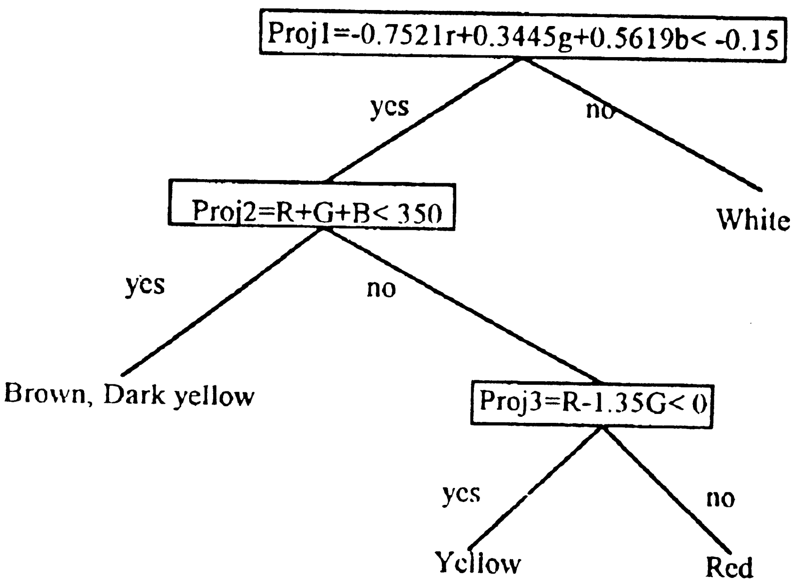


Fig. 8. The segmentation tree for chicory storage.

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