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NON-DESTRUCTIVE METHOD FOR INTERNAL QUALITY DETERMINATION OF BELGIAN ENDIVE (*CICHORIUM INTYBUS* L.)

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A b s t r a c t. A method and process were developed to nondestructively measure the length of the floral stalk in Belgian endive *Cichorium intybus* L. Current X-ray technology proved to be a feasible method. A detection algorithm was developed based on the minimal transmitted intensities along the length. The method is very accurate with an absolute precision of 4.9 mm and allows the study of the influence of storage conditions and time on the Belgian endive internal quality. The growth of the floral stalk is an exponential function of the temperature and is variety dependent.

K e y w o r d s: non-destructive method, quality, Belgian endive (*Cichorium intybus* L.), floral spike, X-ray

INTRODUCTION

Belgian endive (*Cichorium intybus* L.) is a biennal herbaceous plant belonging to the Asteraceae family. During the first year of growth, the plant develops a deep taproot and produces a rosette of leaves on a short stem. Following a period of exposure to cold, the plant develops a floral meristem. Commercial production involves harvesting the plant after it has reached of a proper stage of root maturity, followed by floral bud induction (cold storage) and the accelerated development of the floral stalk and surrounding basal leaves in the dark (forcing) to avoid green color. The end product of forcing is a chicon (Fig. 1), a small white head of leaves patches with regions of yellow. Often served as an addition to salads, Belgian endive may also be baked, braised or fried.

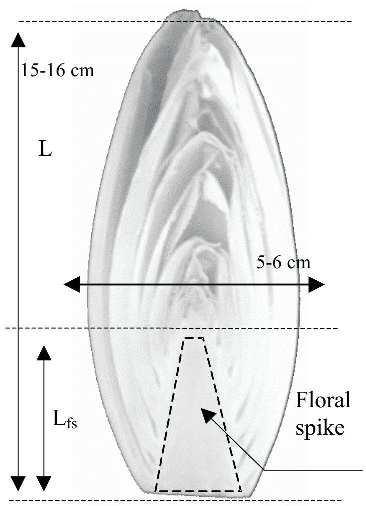

Fig. 1. Belgian endive cross ssection.

Like others fruit and vegetables, Belgian endive quality evolves after harvest. This evolution is mostly influenced by the time and storage conditions. The growth of the floral stalk, associated with the shape of the product, is one of the most important parameters for the loss of internal quality.

The length of the flower stalk (L_{fs}/L) appears in the OECD standard and should be limited to 75% of the chicory length. Other internal quality parameters are the tightness and looseness of the leaves and absence of coloration and/or cavity on the floral stalk.

Non-destructive methods to determine the quality of agricultural products are, according to Chen [2], visible radiation, infrared techniques, ultrasonic, NMR, and X-ray. Of these techniques, X-ray is the only method sensitive enough to detect internal structural discontinuities.

Short wave radiation such as X-rays, can penetrate through most agricultural products. The level of transmission of these rays depends mainly on the mass density and mass absorption coefficient of the material and thickness of the product. Thus, X-rays is suitable for a non-destructive evaluation of quality factors associated with mass density variations.

Researchers have found that X-ray techniques can be used to detect bruises in apples [2]. Since bruised apple flesh was of density different from normal flesh, X-ray scans showed the presence of bruises. The technique has also been experimentally applied for the evaluation of lettuce maturity [5], split pit in peaches [1] and granulation in citrus fruits [4]. In 1978, Finney and Norris [3] found that a hollow heart in potatoes can be detected by calculating the second derivative of the X-ray density profile along the longitudinal axis.

The objectives of this study were to:

determine whether the floral stalk length might be measured by an objective non-destructive method,

use this non-destructive method for modelling the influence of storage conditions and time on the growth of the floral stalk.

The need for a non-destructive method can be justified by the high variability of floral stalk length within a production batch.

MATERIALS AND METHODS

Modelling of the X-ray transmission in Belgian endive

Beer's law was used to describe the X-ray absorption process. According to this equation, the amount of X-ray absorbed depends on the thickness of the material and on the average linear coefficient of absorption:

$$I_T = I_0 e^{-\mu_m t} \tag{1}$$

where: I_T - transmitted X-ray photon intensity, I_0 - initial X-ray photon intensity, μ_m - X-ray linear absorption coefficient (m^{-1}), t - length of the transmission path (m).

Because of the non homogenous structure of Belgian endive, which consists of a floral spike - leaves - air, the X-ray linear absorption coefficient is proportional to the relative thickness of each of the constituents on the transmission path and will vary on each transmission path along the length of the Belgian endive (Fig. 2):

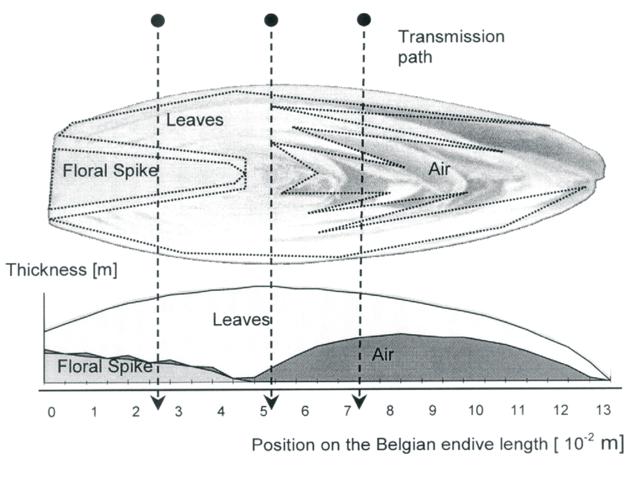

Fig. 2. Thickness of the floral spike, leaves and air on each transmission path on the length of the Belgian endive.

$$I_T = I_0 e^{-\left[\mu_{fs}\frac{t_{fs}}{t} + \mu_l \frac{t_l}{t} + \mu_a \frac{t_a}{t}\right] t}$$

$$t = t_{fs} + t_l + t_a \qquad (2)$$

where: μ_{fs}, μ_l, μ_a - X-ray linear absorption coefficient of the floral spike, leave, air (m^{-1}), t_{fs}, t_l, t_a - length of the transmission path in the floral spike, leave, air (m), t - total length of the transmission path (m).

Application of the previous equation to each transmission path leads to the transmission pattern along the length of the Belgian endive (Fig. 3). On the basis of the transmission pattern, it can be established that the apical bud corresponds to the point of the minimum transmission. The parameters which affect this minimum transmission value are:

higher density of the apical bud and associated young leaves,

occurrence of air on top of the apical bud,

shape of the Belgian endive.

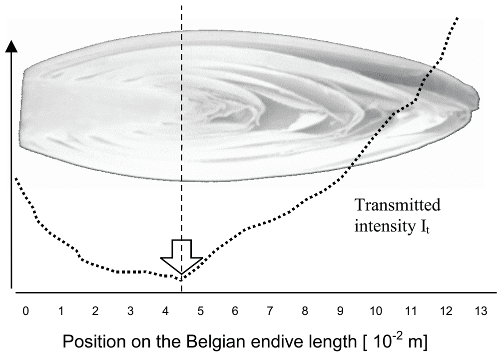

Fig. 3. Transmission pattern on the length of the Belgian endive

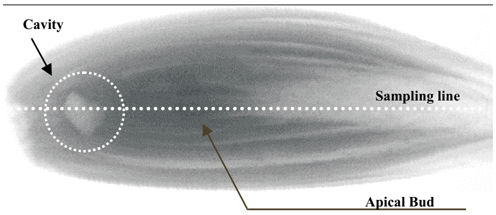

Fig. 4. X-ray image of a Belgian endive with cavity in the floral spike.

X-rays measurement

X-rays images were produced with a HOMX 161 Microfocus X-ray system (50 KV/ 0.70 mA) combined with the image intensifying system. At such a radiation intensity, the internal structure of the Belgian endive is visible (Fig. 4) and allows for the detection of the floral stalk, apical bud and internal defect (cavity).

The X-ray image can be considered as a XY matrix of gray levels. The value of the gray level is proportional to the intensity of the transmitted X-rays.

Detection of the apical bud is based on image processing and extraction of X-rays intensity distribution profile along the center part of the Belgian endive length. Some of the image processing functions used in order to detect the apical bud are:

Intensity distribution profile.

This function shows the profile of intensity on the sampling line and allows to detect the coordinate of the point showing the mimimum intensity on the sampling line. The second point is given by the edge of the Belgian endive. The distance between these two point coordinates gives the length of the floral stalk.

For the measurement of the distance between the two point coordinates the system must be calibrated (pixel/distance ratio). This scale is given by using the standard for a given length.

Noise reduction by integration.

This function averages the input video images in real time to obtain high quality images. The average is expressed with the following formula:

$$V_N = V_{N-1} + \frac{V_{IN} - V_{N-1}}{N} \qquad (3)$$

where: V_N - output image, V_{N-1} output image for the previous frame, V_{IN} - input image, N - number of integration (2,4,8,128).

The data processing algorithm is given in Fig. 5. The analysis of the X-ray intensity

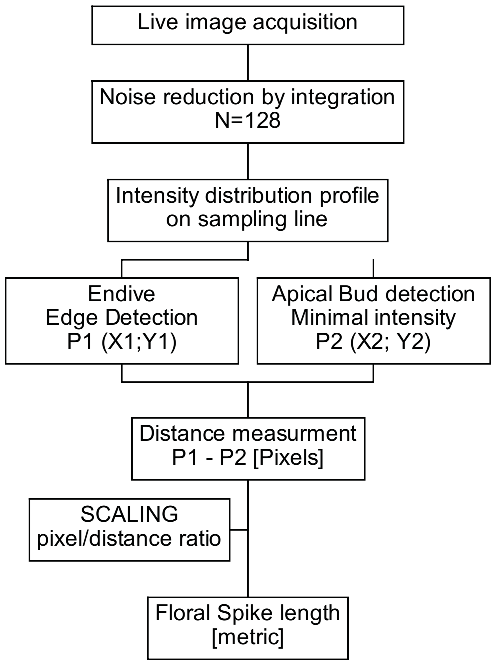

Fig. 5. Measurement flow chart of an X-ray image.

distribution profile at the center part along the Belgian endive length (sampling line) allows for the evaluation of three internal quality parameters (Fig. 6). The apical bud corresponds to the point of the minimum of the intensity transmitted X-rays (1). The presence of the cavity in the floral stalk induces an intensity jump in the transmitted intensity. This defect can be detected using the second derivative (2). The slope of the transmission pattern gives information on the tightness and looseness of the leaves (3).

Experimental design

The Belgian endive is taken from two different varieties: Monitor and Atlas. Samples of Belgian endive (124 Monitor and 60 Atlas), were obtained from a local producer. The endives are divided into one calibration set (64 Monitor) and two experimental sets (60 Monitor and 60 Atlas).

The X-ray method was used to measure the influence of the storage temperature on the growth of the floral stalk. Three storage temperatures were considered (1°C/10°C/20 °C). Relative humidity was kept constant (95% RH).

RESULTS

In order to measure the accuracy of the X-ray transmission method, 64 Belgian endives (Monitor) were measured (Fig. 7). The method appears to be very accurate with an absolute precision of 4.9 mm and allows to study the influence of storage conditions and storage time on the internal quality of Belgian endive.

Figure 8 shows the evolution of the ratio of the measured length to the initial length as a function of the storage time and temperature for the Monitor variety (n=60). On the basis of the slopes we can extract growth rate for each storage temperature level. The growth rate is an exponential function of the temperature and is variety dependent (Fig. 9).

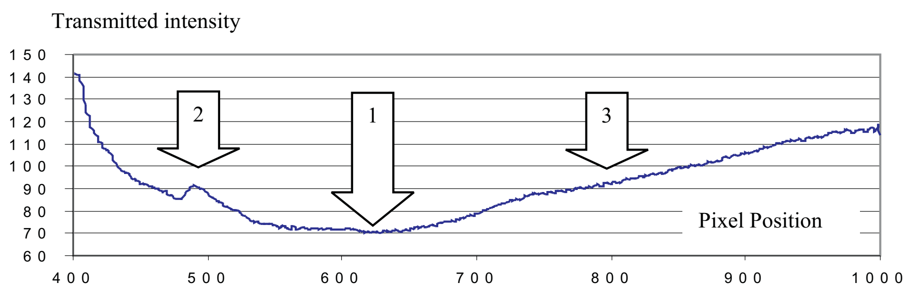

Fig. 6. X-ray intensity distribution profile on the center part along the Belgian endive length (sampling line).

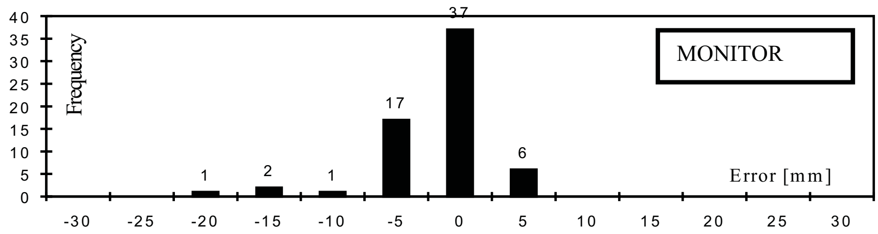

Fig. 7. Histogram of the measurement error for 63 Belgian endives.

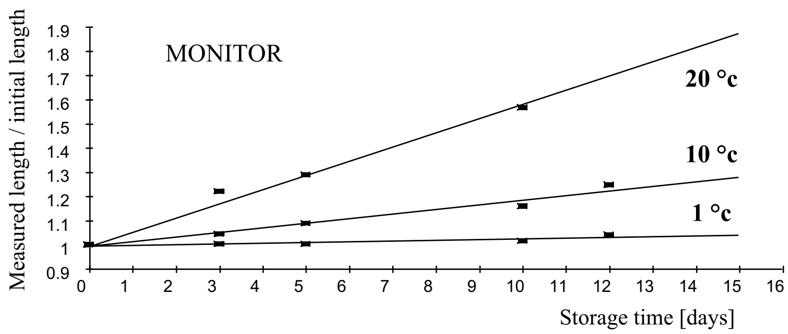

Fig. 8. Evolution of the floral spike relative length as function of the storage time for three different temperature levels.

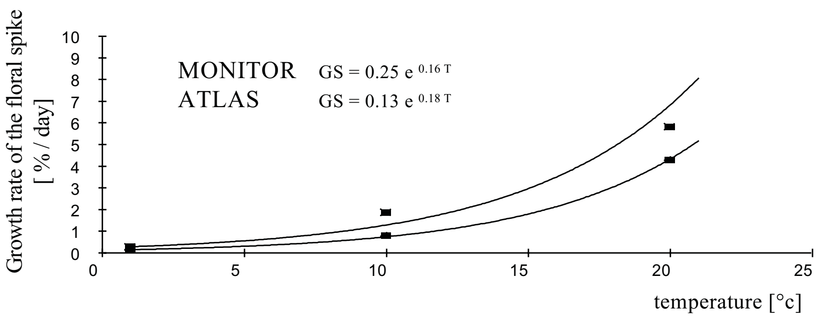

Fig. 9. Growth rate of the floral spike as a function of storage temperature.

CONCLUSIONS

1) X-ray transmission is suitable for a non-destructive measurement of the length of the floral stalk in Belgian endive.

2) Growth of the floral stalk is an exponential function of the storage temperature.

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