Food Research International 64 (2014) 647–655

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Non-destructive evaluation of quality and ammonia content in whole and fresh-cut lettuce by computer vision system

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ARTICLE INFO

Article history:
Received 5 May 2014
Accepted 24 July 2014
Available online 6 August 2014

Keywords:
Computer vision system
Non-destructive evaluation
Quality levels
Ammonia
Prediction models

ABSTRACT

The paper describes the developed hardware and software components of a computer vision system that extracts colour parameters from calibrated colour images and identifies non-destructively the different quality levels exhibited by lettuce (either whole or fresh-cut) during storage. Several colour parameters extracted by computer vision system have been evaluated to characterize the product quality levels. Among these, *brown on total* and *brown on white* proved to achieve a good identification of the different quality levels on whole and fresh-cut lettuce (P-value < 0.0001). In particular, these two parameters were able to discriminate three levels: very good or good products (quality levels from 5 to 4), samples at the limit of marketability (quality level of 3) and waste items (quality levels from 2 to 1). Quality levels were also chemically and physically characterized. Among the parameters analysed, ammonia content proved to discriminate the marketable samples from the waste in both product's typologies (either fresh-cut or whole); even the two classes of waste were well discriminated by ammonia content (P-value < 0.0001).

A function that infers quality levels from the extracted colour parameters has been identified using a multi-regression model ($R^2 = 0.77$). Multi-regression also identified a function that predicts the level of ammonia (an indicator of senescence) in the iceberg lettuce from a colour parameter provided by the computer vision system ($R^2 = 0.73$), allowing a non-destructive evaluation of a chemical parameter that is particularly useful for the objective assessment of lettuce quality.

The developed computer vision system offers flexible and simple non-destructive tool that can be employed in the food processing industry to monitor the quality and shelf life of whole and fresh-cut lettuce in a reliable, objective and quantitative way.

1. Introduction

Computer vision systems (CVS) are an engineering technology that combines mechanics, optical instrumentation, electromagnetic sensing, digital video and image processing technology (Patel, Kar, Jha, & Khan, 2012). It studies methods and techniques that enable computer to automatically and non-destructively extract relevant contents from images and to interpret their most significant characteristics to achieve aims such as classification, grading, quality assessment, and defect detection (Gomes & Leta, 2012). CVS have been widely used to evaluate qualitative parameters or defects of different fruits and vegetables, since colour is a very informative property that can be measured by CVS to determine the market acceptance and to provide useful hints about the global quality of products (i.e. freshness, maturity). CVS, with respect to colorimeters, enable the evaluation of the colour property at a pixel resolution: this provides the opportunity of determining characteristics (such as shape, texture, presence of defects) that can be exploited to reach a fast, objective and consistent grading of products (Du & Sun, 2006; Savakar & Anami, 2009; Zheng & Sun, 2008). Moreover, CVS can observe the whole surface of products avoiding the subjective choice of sample points typical of colour measures by colorimeter. Recently, CVS were used to assess quality and marketability of artichokes (Amodio, Cabezas-Serrano, Peri, & Colelli, 2011) and fresh-cut nectarines (Pace, Cefola, Renna, & Attolico, 2011). Moreover, CVS have proved to be able to predict the nutritional quality of coloured vegetable (Pace et al., 2013).

In the last years, for the increased requirements for quality by consumers, the food industry has paid numerous efforts to measure and control the colour of their products. Thus, the research on the objective assessment of food colour is an expanding field (Wu & Sun, 2013; Zhang et al., 2014). In this context, CVS could be applied for the objective quality evaluation of whole and fresh-cut lettuce during storage. Generally, during postharvest storage of lettuce, visible damages occur, often associated to browning due to the oxidation phenomena and root development. These colour changes are spread all around the vegetable's surface, making the subjective evaluation of surface damages a time-

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http://dx.doi.org/10.1016/j.foodres.2014.07.037
0963-9969/

consuming and hard work. This explains the opportunity of developing an automatic system for the evaluation of surface's damages to replace subjective inspection (Zhang et al., 2014). Zhou et al. (2004) used CVS to evaluate the acceptability during storage of shredded lettuce on the base of percentage of brownish colours; the CVS proposed by Zhou used a commercial 1-CCD camera to acquire colour images that were stored using a (lossy) jpeg format. Their image analysis was mainly done in the HSV colour space that, with respect to the machine dependent RGB, is a human-oriented colour space: in fact its components (hue, saturation, value) are of intuitive comprehension for human beings even if they do not mimic the human evaluation of colour distance as specifically designed colour spaces such as CIELab. The range of each HSV colour component used to identify the region corresponding to brown was manually fixed using tools provided by a commercial image analysis software that was also used to select and quantify the brown part of each image.

This research was aimed to develop a CVS, in both its hardware and software components, to extract colour parameters and identify non-destructively the quality levels of whole and fresh-cut iceberg lettuce. The investigation has been done on the whole colour palette exhibited by lettuce studying and experimentally verifying several colour parameters describing the distribution of pixels in the colour space. Physical and chemical characterization of the different quality levels the lettuce (either whole or fresh-cut) went through during storage was carried out to provide reference data to train and to validate the CVS. Finally, proper multivariate models were developed to predict the quality levels and the related intrinsic quality parameter of lettuce iceberg (with particular reference to the ammonia content) on the base of the colour parameters measured by CVS.

2. Materials and methods

2.1. Plant material and processing

Iceberg (*Lactuca sativa* L.) was provided by a farm (Ortomad srl) located in Pontecagnano (SA, Italy), and transported in cold condition to the Postharvest Laboratory of the Institute of Sciences of Food Production. Plants were selected, in order to avoid damaged samples, washed in chlorinate water (100 mg L^{-1}) and drained. Twenty plants were cut (Robotcup CL 52, Vincennes, France) in pieces (approx. 5 cm); whereas other thirty were stored as whole items. Both whole and fresh-cut lettuces were placed in open low density polyethylene (LDPE) bags with high permeability and stored at 4 (±0.5) °C. Each replicate was made by one iceberg lettuce head or by 300 g of fresh-cut product. Thirty bags (6 replicates × 5 quality levels) for each typology (whole or fresh-cut) were prepared. They have been divided in a data set for the prediction step (containing 45 bags divided randomly between whole and fresh-cut products) and a data set for the validation phase (containing the remaining 15 bags). All items, at any time during storage, were graded using a five quality level scale, based on sensory evaluation, as reported below. Images of samples belonging to each quality level were acquired and processed by CVS; moreover the same samples underwent a chemical-physical analysis (ammonia content, total chlorophyll, antioxidant activity and colour analysis by colorimeter).

2.2. Quality level classification

Along the storage, fresh-cut and whole iceberg lettuces were classified using 5 quality levels (QL) according to the following scale: 5 = very good (very fresh, no signs of wilting, decay or bruises), 4 = good (slight signs of shrivelling, bruises), 3 = limit of acceptability or marketability (moderate signs of shrivelling, browning, dryness, wilting, bruises), 2 = poor (severe bruises, evident signs of shrivelling, pitting, decay), and 1 = very poor (unacceptable quality due to decay, bruises, leaky juice). The QL 3 was considered the minimum threshold of acceptance for sale or consumption (Nunes, Emondb, Rautha, Deac, & Chau, 2009); therefore values below 3 indicated a waste product.

2.3. Colour analysis by computer vision system

The images used in the experiments were acquired using a 3CCD (Charged Coupled Device) sensor digital camera (JAI CV-M9GE). The camera has a dedicated CCD for each colour channel and provides a reliable colour measure at full resolution, without the artefacts of most digital cameras (based on the Bayer filter). To avoid any colour artefacts induced by lossy compression algorithms the uncompressed the TIFF format was used to save images. The camera mounted a Linos MeVis 12 mm lens system and its optical axis was perpendicular to the black background onto which the products were placed. Eight halogen lamps, divided along two rows placed at the two sides of the imaged area, were used. They were oriented with a direction of 45° with respect to the optical axis of the CCD camera and to the plane on which the products are placed (Fig. 1). Two light diffusers were placed between light sources and products to reduce highlights. A flat uniform white surface was used to evaluate the unevenness of light distribution throughout the scene and a built-in function of the camera was used to correct shadows. The lamps were connected to a direct current power supply to avoid the periodic fluctuations of light intensity due to alternating current.

White referencing was achieved using the white patches of a colour reference plate (Munsell Digital ColourChecker SG by X-Rite). The camera can set separately the electronic gain for each colour channel: the best values for these parameters were set to obtain a satisfactory white value on the reference patches, achieving the white calibration. An image of the X-Rite ColourChecker was also acquired at regular intervals to check the acquisition set-up with respect to colour accuracy. A further smaller colour-chart (Kodak Colour Control Patches) was placed in every scene to estimate and reduce colour variations between images acquired at different times: the correction of each colour channel was accomplished using a different polynomial transformation whose parameters were estimated comparing the expected and the measured colours on the Kodak Colour Control Patches. A more detailed explanation of the acquisition set-up and on the techniques and algorithms used to evaluate and correct colour differences due to changes in acquisition conditions (lighting, geometry, set-up of the camera) can be found in the previous work (Pace et al., 2011). All the processing used code specifically developed using Matlab 7 (MathWorks, Inc., USA).

The evaluation of the colour properties of products using the CVS involved the solution of two problems: to acquire calibrated colour images and to extract colour parameters providing the desired information about products.

Solving the former problem involves maximizing the homogeneity of colour measures extracted from images acquired at different times.

It is important to note that the system does not aim to provide absolute colour evaluation (as a colorimeter does): its goal is to provide measures that are consistent and repeatable in time. The choice of the CIELab space is motivated by its perceptual uniformity (Kang, East, & Trujillo, 2008): the goal of the system is to provide consistent measures in this perceptual colour space. To achieve this result two tasks need to be accomplished: to reduce the instability of the acquisition conditions and to map the device dependent RGB space to the device independent perceptual CIELab space. Some authors use polynomial function to solve both these problems: they identify the polynomial parameters to map the RGB values of the colour chart to the corresponding expected CIELab colours. Instead we use all the available degrees of freedom of the transformation only to correct the RGB values of the acquired image (reducing their differences from the reference RGB values of the colour-chart) and use a standard mathematical transform between the consistent RGB colours obtained and the CIELab space. A polynomial function with 11 parameters (Lee, Chang, Archibald, & Greco, 2008) is evaluated