



Monitoring methods and predictive models for water status in Jonathan apples



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ABSTRACT

Evaluation of water status in Jonathan apples was performed for 20 days. Loss moisture content (LMC) was carried out through slow drying of whole apples and the moisture content (MC) was carried out through oven drying and lyophilisation for apple samples (chunks, crushed and juice).

We approached a non-destructive method to evaluate LMC and MC of apples using image processing and multilayer neural networks (NN) predictor. We proposed a new simple algorithm that selects the texture descriptors based on initial set heuristically chosen. Both structure and weights of NN are optimised by a genetic algorithm with variable length genotype that led to a high precision of the predictive model ($R^2 = 0.9534$).

In our opinion, the developing of this non-destructive method for the assessment of LMC and MC (and of other chemical parameters) seems to be very promising in online inspection of food quality.

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1. Introduction

Water is the main component of the most foods. Depending on the availability and biological activity, water's status includes free water and bound water forms (Goñi, Muñoz, Ruiz-Cabello, Escrivano, & Merodio, 2007; Rahman, 2006). Currently, the scientific literature presents characterization of water forms from a level of general concept (Schmidt, 2007) with limitations determined by the specialized field approached (biochemically, physiologically or technologically). In food, generally free water is associated with the loss of the moisture content (LMC) while bound water is determined as moisture content (MC).

In food industry, LMC provides information for the rate of the metabolic and physiologic processes (perspiration, respiration) that continue in vegetal products even after harvesting. Also, LMC is correlated with the weight loss, the changes of layout/shape or the variations of the biochemical composition for dried/dehydrated products (Jan & Rab, 2012) and it's easily determined as the weight loss (of the food product) by slow drying (Veraverbeke, Verboven, Van Oostveldt, & Nicolai, 2003).

Food freshness can be associated with MC. To determine food moisture content, most standard methods rely either on the

normal process of drying in the oven, or with IR radiation (El-Sayd & Makawy, 2010). Classical methods are time-consuming and do not ensure high-precision determination because of the potential errors induced by the too many factors involved in the drying process (Bradley, 2010; Fontana, 2007). The modern methods are fast but require calibration based on the reference method (Isengard, Merkh, Schreib, Labitzke, & Dubois, 2010). These drawbacks explain the general need to look for modern and innovative methods either for rapid evaluation or precise prediction of food quality. One of the most suitable non-destructive techniques relies on image processing (Gonzalez & Woods, 2008). Imagistic analysis parameters can be used as inputs in neural network (NN) predictive models (Haykin, 1999) in order to reduce the importance of experimental errors in the analytic process.

In our approach, we proposed a non-destructive method to evaluate LMC from apples using image processing and multilayer neural networks predictor. The NN predictor was also used for prediction of MC obtained for various samples and methods. We approached a new simple algorithm that selects the texture descriptors based on initial set, heuristically chosen. Both structure and weights of NN are optimised by a genetic algorithm with variable length genotype.

In our opinion, the developing of this non-destructive method for the assessment of MC and LMC (and of other chemical parameters) seems to be very promising in online inspection of food quality.

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2. Material and methods

Apples are very popular fruits in Europe. There are many variety of apple fruits having different colours (green, red, yellow, or mixed red-yellow) and different changes in aspect and structure during storage.

There are many approaches that deal with the subject of drying fruits, most of them being focused on pieces of fruits (Fernández, Castillero, & Aguilera, 2005; Seiedlou, Ghasemzadeh, Hamdami, Talati, & Moghaddam, 2010). Our approach is focused on the modification of the moisture content in apples during storage at ordinary temperature.

At early November, 100 healthy-looking Jonathan apples, that weren't exposed to preservation treatments, were selected randomly from the same source, with roughly the same shape and weight (91–103 g), as being the gross sample of analysis. Chemical and imagistic tests have been conducted every 5 days: lots of 15 apples were investigated in every testing day for MC evaluation. Also, 15 other apples were analysed all experimental period for LMC determination. All apples were stored during experimental period at 20 °C room temperature and 70% relative humidity.

A balance type RADWAG AS 220/C/2 with accuracy of 10^{-4} g was used for weighing, a SLW 115 ECO drying oven was used for drying apple samples at temperature of 90 °C and a Freeze Dryer ALPHA type 1–4 LD was used for lyophilisation.

For image capturing an AF-S DX Zoom-Nikon ED 18–70 mm, f/3.5–4.5 GIF was used.

2.1. Methods for chemical analysis

Analyses were performed for a period of 20 days. For LMC evaluation each entire apple was weighed and photographed.

Also, MC analysis had involved the weighing and photographing of each lot of 15 apples, in the first step. For MC evaluation, in the second step, chemical analyses were performed on the samples immediately obtained by processing the apple as chunks, crushed and juice. The apple has been peeled and then has been shredded with a special device to get apple chunks (0.4×2 cm). Also, peeled apple was crushed in order to get crushed apple or pressed to get apple juice.

2.1.1. Loss moisture content determination

At every 5 days, apples were weighed regularly. By weighing the difference was attributed to the loss of moisture content (LMC, %), in accordance with the Eq. (1):

$$\text{LMC, \%} = 100 \times (m_i - m_f) / m_i \quad (1)$$

where m_i = initial mass of sample (g), m_f = final mass of sample (g).

2.1.2. Oven drying

5 g of fresh sample (each apple was processed to get chunks, crushed or juice) were dried at 90 °C until a constant mass $\leq 10^{-2}$ g was reached. Moisture content (MC, %) was determined in accordance with the Eq. (2):

$$\text{MC, \%} = 100 \times (m - m_1) / m_2 \quad (2)$$

where m = mass of the sample before drying (g), m_1 = mass of the sample after drying (g), m_2 = mass of the analysed sample (g).

2.1.3. Freeze drying (lyophilisation)

Lyophilisation is dehydration process at cold: water freezes faster than other ingredients and is removed in the form of ice without changing the food structure.

Lyophilisation was carried out in a type 1–4 LD plus, Freeze-Dryer ALPHA.

5 g of fresh apple sample (chunks, crushed or juice) were subjected to freeze drying at temperature of -50 to 60 °C, and pressure ranging from 0.02 to 0.03 mbar until constant mass. Water content was determined using the Eq. (2).

2.2. Methods for imagistic analysis

Non-destructive methods are usually based on image processing techniques (Gonzalez & Woods, 2008; Petrou & Sevilla, 2006; Yam & Papadakis, 2004). The images are acquired under special conditions (illumination, angle between axis of camera lens and the lighting source – 45°, in order to capture the diffused reflection, colour temperature of the fluorescent lamp and so on.) in accordance with the image's acquisition standards (Francis, 2005)

Analysis of texture can offer useful information about quality of fruits (Gonzalez & Woods, 2008). At apples, the wrinkles usually denote long time storage: more wrinkles involve a larger storage period and a higher loss of the moisture content. Also, it looks like wrinkle's texture parameters are related with the variation of LMC (Vesali, Gharibkhani, & Komarizadeh, 2011)

Fourier descriptors for 2-D digital images seem to be useful for characterization of LMC. However, usually way to use Fourier descriptors are related to shape shrinking due to drying process. For rectangular pieces of apples, the change in shape due to drying process is significant. The evolution of shape in time can be measured if the shape is coded in a vector form by Fourier descriptors (Fernández et al., 2005). In our case, these descriptors doesn't offer useful information related to LMC due faintly the fact that Jonathan apple variety provides in time a very small change in their shape. The experiment achievement until the moment that the shape of apple significantly changed was not of interest to us, because in this case, the apple cannot be accepted by consumers.

Unlike the data presented in the literature (Fernández et al., 2005; Seiedlou et al., 2010) for which investigations have been conducted on apple's cuticle, our experiments focused on the image acquired for the entire apple.

Tests have been conducted every five days: lots of 15 apples were investigated in every testing day for MC evaluation. Also, 15 other apples were analysed all experimental period for LMC determination. For LMC evaluation each entire apple was photographed. Also, MC analysis had involved the photographing of each lot of 15 apples, in the first step.

For image capturing an AF-S DX Zoom-Nikon ED 18–70 mm, f/3.5–4.5 GIF was used. The pictures were saved in RGB colour space with 1936×1926 pixels size. In order to ensure the same calibration of dimension in all pictures, a box was designed ($16 \times 16 \times 32$ cm) to provide a fixed distance between photo camera and apples.

The photos were processed and specific texture parameters were determined (see discussion at Section 3.2.) in order to build NN predictive models for LMC and MC of apples.

2.3. Predictive methods

2.3.1. Neural networks predictive methods

Neural networks (NN) proven to be universal approximators (Haykin, 1999). In 1989, Cybenko demonstrated, using a Kolmogorov's older result, that multilayer feed-forward network with a single hidden layer, which contains finite number of hidden neurons, is a universal approximator (Cybenko, 1989). The demonstration has been made for sigmoid activation function. In the most common sense, the universal approximator can approximate any non-linear function with a desired precision, if its architecture is large enough. We will use a multilayer neural network (multilayer perceptron, MLP) as predictor for LMC and MC. The structure and weights of MLP are simultaneous adapted using a genetic

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