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Continuous real-time monitoring and neural network modeling of apple slices color changes during hot air drying

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A B S T R A C T

A hot air drying system equipped with real-time computer vision system was used to investigate the effects of drying variables on apple slices color changes. Drying experiments were conducted at drying air temperatures of 50–70 °C, drying air velocities of 1–2 m/s, and samples thicknesses of 2–6 mm. A multilayer perceptron (MLP) artificial neural network (ANN) was also used to correlate color parameters and moisture content of apple slices with drying variables and drying time. The effects of drying air temperature and sample thickness on color changes were dominated over the effect of drying air velocity. However, non-linear and somewhat complex trends were obtained for all color parameters as function of moisture content. The MLP ANN satisfactorily approximated the color and moisture variations of apple slices with correlation coefficient higher than 0.92. Therefore, the computer vision system supplemented with ANN can be used as a non-invasive, low cost, and easy method for fast and in-line assessing and controlling of foodstuffs color and moisture changes during drying.

Keywords: Apple slices drying; Computer vision system; Color kinetics; Real-time monitoring; Artificial neural network (ANN)

1. Introduction

Drying is probably the oldest methods of food perseveration practiced by humankind for saving date, fig, apricot, grape, herb, carrot, corn, milk, meat, and fish (Doymaz, 2004, 2007; Doymaz et al., 2006; Aghbashlo et al., 2009). Drying of perishable fresh-cut fruits and vegetables improves final products stability, reduces materials volume and storage cost, prolongs storage time, reduces microbiological activity, and inactivates enzymes (Mayor and Sereno, 2004; Demirhan and Ozbek, 2009). Hot air drying process is one of the most commonly used methods in food industry to produce dried fruit. The main drawbacks of hot air drying method are undesirable physical, structural, chemical, organoleptic, and nutritional changes occurred during drying, which deteriorate finished products quality and reduce consumer acceptance (Scala and Crapiste, 2008; Arslan and Özcan, 2011). Fortunately, appearance of dried foods such as shape, color, and texture can profoundly reflect these unfavorable changes and can be employed as indicators for foods quality evaluation. Moreover, the color of foodstuffs is evaluated as a first quality parameter by consumers (Hatcher et al., 2004; Abdullah et al., 2004). Therefore, the original color of processed foodstuffs should be adequately persevered for increasing their functionality and marketability. Although, the sensorial attributes of dried products such as color parameters is a key factor for in-process monitoring and controlling of drying process, real-time, reliable, accurate, and cost-effective color measuring systems are lacking.

Traditionally, the color measurement of food products under different unit operations was extremely challenging and has been usually limited to the inaccurate and invasive measurement techniques. For example, the surface to

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be measured by colorimeters must be uniform and rather small (2 cm^2), which leads to quite unrepresentative results and moreover restricts global analysis (Mendoza and Aguilera, 2004). As well, the invasive methods can disturb mechanisms and conditions of undergoing processes causing interference with realistic process measurements. Nevertheless, the off-line invasive methods are easy to use and do not require specialists for successful measurements in compared with real-time monitoring. However, due to dynamic and complex nature of the drying process, all these approaches are unsuitable for real-time industrial applications because of highly operator-dependency and poor repeatability.

Recently, off-line computer vision systems were extensively employed to analyze surface color of different foodstuffs during drying due to having enormous advantages over the traditional destructive methods (Sun and Brosnan, 2003; Brosnan and Sun, 2004; Yam and Papadakis, 2004; León et al., 2006; Shafafi Zenoozian and Devahastin, 2009; Mohebbi et al., 2009; Fathi et al., 2011). Results of previous investigations showed that the off-line computer vision system is a promising technology for monitoring of foodstuffs color changes during processing. Although, it provides acceptable results, but analysis time is very long and it is unsuitable for in-process monitoring of drying process. On the other hand, real-time computer vision system can be the best alternative for ill-defined processes monitoring, automating, and controlling due to its rapidness, cheapness, non-destructiveness, sensitiveness, and preciseness. Thus, automatic real-time color tracking units in food dryers are strictly necessary to meet stringent product quality characteristics and attain a better understanding of the process for further optimization of the standard operating methods. Despite the wide scholarly interest in the computer vision system for foodstuffs color evaluation, there are only few available reports on the real-time color tracking of foodstuffs during drying using computer vision systems (Hosseinpour et al., 2013; Chen and Martynenko, 2013). Therefore, the main objective of this study was to investigate the effect of drying air temperature, drying air velocity, and slab thickness on apple slices color variations during hot air drying. Based on authors' best knowledge, little insight is available on the color variations of foodstuffs as function of slices thickness using both off-line and in-line computer vision systems. Furthermore, ANN approach has been successfully applied for color kinetics modeling of different foods during drying and dehydration (Shafafi Zenoozian and Devahastin, 2009; Fathi et al., 2011). However, all existing investigations for the estimation of color changes using ANN modeling are based on off-line color measuring approaches. Therefore, this study differs from previously published papers in the use of real-time color kinetics data for ANN modeling. It seems that the real-time measurement of color kinetics by computer vision systems and subsequent ANN modeling might provide a possible solution to improve and control the finished product quality and drying progress, respectively, with automated manipulation of drying variables.

2. Materials and methods

2.1. Experimental setup

The detailed information on the laboratory system and its construction, controlling, and monitoring can be found in previous studies (Hosseinpour et al., 2011, 2013). Briefly, a schematic diagram of the lab-scale hot air dryer, equipped with a CCD color camera (Canon G9 digital color camera, Japan) with remote capturing capability, is shown in Fig. 1. The experimental system consisted of a centrifugal fan, an air duct, four electrical heating elements, a straightener, a control unit, an illumination and imaging chamber, a single point load cell with an accuracy of ±0.001 g, measurement sensors, and a drying tray. To avoid thermal loss and eliminate experimental uncertainties, the dryer body was covered by glass wool. The maximum airflow rate of centrifugal fan was 6300 m^3/h. The heating system consisted of an electric 750 W preheater placed in the centrifugal fan and three 2000 W elements inside the air duct. The air flow was measured by an anemometer and adjusted by an inverter. The drying air temperature was controlled with an accuracy of ±1 °C using a programmable logic controller, a power controller, and two PT-100 temperature sensors. Drying chamber was illuminated by two fluorescent lamps to minimize glitter. Top-view images were captured during drying by CCD camera and saved into a PC for color analysis.

2.2. Experimental procedure

Apples (Golden Delicious variety) were purchased from local market and cold-stored until the moment of experiment in order to slow down the respiration, physiological, and chemical changes. The initial moisture content of apple slices was found to be 84.61 ± 1.53% (w.b.), according to the vacuum oven method at 105 °C for 12 h. Apples were cut into slices with uniform thickness of 2, 4 and 6 mm perpendicular to the fruit axis using a slicer machine after washing, peeling, and removing the central part. The prepared slices were sunk in combinations of ascorbic acid (0.5%) with citric acid (0.5%) for 5 minutes, according to the method has been described by Zhu et al. (2007). The pre-treated slices were gently blotted with a paper towel to eliminate the pre-treatment solution. The samples were put on the tray after reaching the dryer to a steady state condition for the operation temperatures. Drying experiments were conducted at air temperatures of 50, 60, and 70 °C and air velocities of 1, 1.5 and 2 m/s. During drying experiments, the temperature and relative humidity of ambient and inlet and outlet temperatures of the drying air in the air duct and drying chamber were successively recorded. The experiments were continued until a constant mass was obtained. The moisture loss and visual top-view image was recorded at 1 min intervals during drying for monitoring the moisture loss and color changes. All experiments were replicated three times.

2.3. Image analysis

The detailed information on the image processing steps including image acquisition, image segmentation, conversion of RGB images into CIE $L^*a^*b^*$ system, and color feature extraction were completely explained in the papers published by Mohebbi et al. (2009) and Hosseinpour et al. (2013).

A typical example of the segmentation process to achieve the $L^*a^*b^*$ values using the top-view images are displayed in Fig. 2. The L^*, a^*, and b^* average values were computed for whole pixels in the images at any processing time. Additionally, the color values of 12 colored papers were measured using a Hunter Lab colorimeter. The values of corresponding regions were also measured using MATLAB program in order to calibrate the digital color system. Then, the results obtained using