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Development of computer vision system to predict peroxidase and polyphenol oxidase enzymes to evaluate the process of banana peel browning using genetic programming modeling

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ABSTRACT

The process of enzymatic browning is one of the most important chemical reactions, which effects on color, appearance and quality of fruits and vegetables. Polyphenol oxidase (PPO) and peroxidase (POD) enzymes are associated with enzymatic browning in the tissue of agricultural products. Quality of banana as a climacteric fruit is reduced by enzymatic browning during storage. Therefore, to evaluate enzymatic browning in banana, first, images of the fruits were taken at 25 °C for 9 days. Then, these images were investigated using digital image processing in order to predict and study POD and PPO enzymes during the browning process of banana peel. To this end, seventeen color parameters ($\overline{R}$, $\overline{G}$, $\overline{B}$, V_R, V_G; V_B, r, g, b, C_1, C_2, C_3, C_4, C_5, C_6, C_7, C_8) were extracted from each image as non-destructive parameters. In the following, PPO and POD both were measured through the laboratory methods Finally, using genetic programming (GP) modeling, two equations were obtained which can be used to predict and detect the changes of the activity of the PPO and POD enzymes during the storage period (9 days). The correlation coefficients between the measured values and the predicted values for PPO and POD enzymes were 0.98 and 0.97, respectively. Furthermore, there were no significant differences between predicted values with measured values of PPO and POD enzymes ($p > 0.05$); these results indicate the proper performance of the designed models.

1. Introduction

Bananas (*Musa* spp.) belong to the family of Musaceae, which is one of the widely cultivated crops in the tropical and subtropical zones. The banana fruit market in Iran is still growing (> 121,000 t, on over 4000 ha in 2014 according to FAO statistics). The world banana market is also growing, because more consumers demand fresh, convenient and nutritious foods. Since the optical appearance is the first quality attribute of food evaluated by consumers, hence consumers consider the beginning of peel spotting as a hallmark for good eatable quality. During the storage period, quality deterioration occurs due to physiological disturbances (such as enzymatic browning), microbial growth and unsatisfactory processing conditions (Lu et al., 2007; Cho et al., 2016). The enzymatic browning has a notable effect on the texture, color and taste of the banana, which reduces the quality of the fruit; this chemical process during the banana ripening period is one of the important factors that end shelf life of this fruit (Cho et al., 2016; Huang et al., 2013). So, it can be said that the fruit disorders like browning play an important role not only for fruit quality but also for economic losses; it should be noted that enzymatic browning may be responsible for up to 50% of all losses during fresh fruits and vegetables production (Luo and Barbosa, 1997; Martinez and Whitaker, 1995). Enzymatic browning can also be detrimental to the quality of fresh fruits, juices and some seafoods, particularly in post-harvest storage. Therefore, a fast and reliable detection and quantification of browning is needed to overcome these problems.

During the storage period of the banana, dark spots gradually appear on the peel of this fruit, this phenomenon is called senescent spotting, and it is typical in over-ripe bananas. Usually the enzymatic browning caused by this phenomenon and observed where some regions in the sample are darker compared to other regions (Quevedo et al., 2011). In fact, enzymatic browning is a chemical process which occurs in the tissue of agricultural products by the enzyme activity of polyphenol oxidase (PPO), which results in brown pigments. PPO has been extensively studied in banana fruit for its role in enzymatic browning; PPO and phenolic compounds are ubiquitous in vegetative tissue of banana, and measuring them requires expensive laboratory equipment and a great deal of time (Wuyts et al., 2006).

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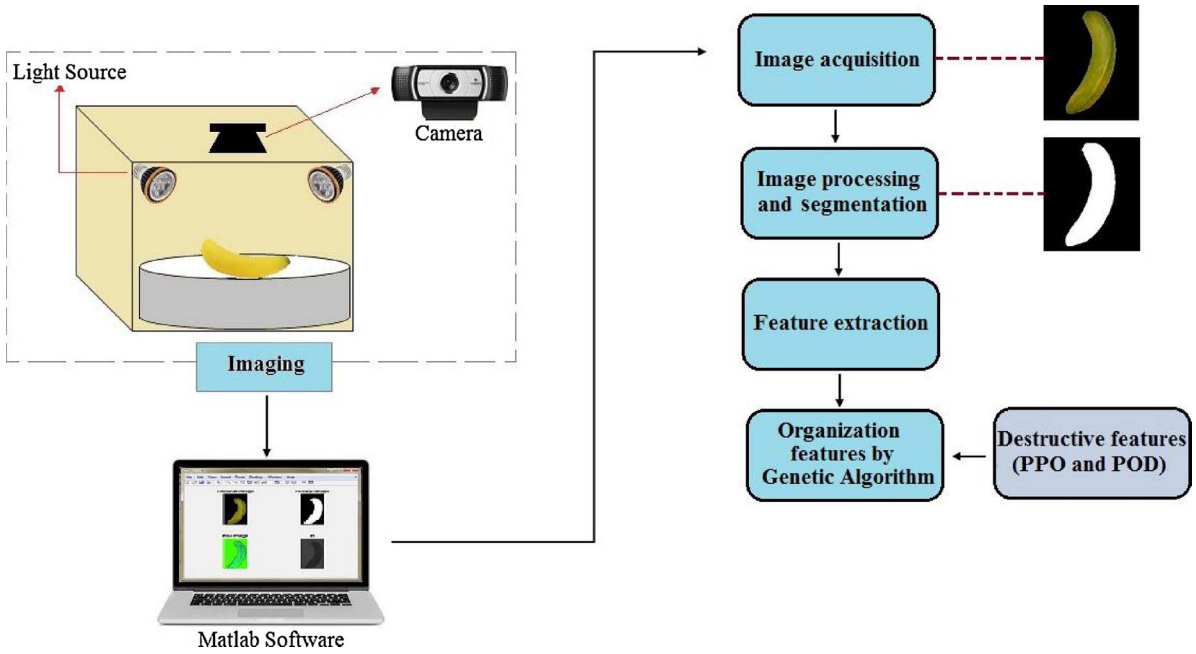

Fig. 1. Imaging and image processing system.

Generally, the amount of enzyme activity changes with the increase of fruit storage time, and in fact, it can be said that the quality of the fruit with the changes of enzyme activity in this course is relevant (Cho et al., 2016). In recent studies, the problem of the browning reaction has been investigated using the image processing technique in some agricultural products such as banana, apple, pear and avocado (Quevedo et al., 2009; Yoruk et al., 2004).

Color grading is used for grading quality in many fruit. However, the uniform color grading of fruit through eyes has resulted in a serious problem because false judgment occurs frequently due to the diversity in grading criteria, the difference among production areas and the fatigue of grading workers. Furthermore, color can be measured using non-destructive methods such as computer vision system (CVS) (Amodio et al., 2011). One such method is permission one to examine and extract image features in order to simplify the analysis and make a classification pattern. The CVS is a fast and low-cost way to determine the stage of maturity of fruit by maintaining accuracy and consistency while eliminating the subjectivity of manual inspections (Du and Sun, 2004). For this reason, image analysis has been used to detect color changes in many studies (Pace et al., 2011; Cho and Moon, 2014). Some studies have been conducted in order to non-destructive measurements of the quality parameters of banana; for example, image analysis to evaluate the browning degree of banana peel (Cho et al., 2016). Likewise, Quevedo et al. (2009) to study description of the kinetic enzymatic browning in banana slices used non-uniform color information from digital images. Yoruk et al. (2004) estimated the non-homogeneous colored surfaces in apple samples during the browning reaction. These researchers were used the RGB color space information at the product surface instead of information which obtained from evaluation of temporal changes in color spectra.

This study investigates patterns of change in polyphenol oxidase (PPO) enzyme activity as well as peroxidase (POD) enzyme activity in banana fruit composition during storage for 9 days at 25 °C. To this end, the banana peel browning was evaluated using image analysis, and the accuracy of this method confirmed through comparison with laboratory measurement of enzyme activity of PPO and POD. Finally, nonlinear mathematical models were developed using genetic programming (GP) to predict the changes of POD and PPO enzymes activity during the process of banana peel browning. It is necessary to mention that the amount of damage to the fruit can be estimated by predicting of these enzymes (POD and PPO) during the storage period, and ultimately, the economic losses of this damage can be controlled by taking timely and appropriate actions.

2. Materials and methods

Two hundred bananas were bought from a market on the first day of the experiments. Distance of this market from the research lab was 2 km. It is worth noting that all samples were harvested at one time, in other words, the bananas were all of the same age and from the same grower. After buying the samples, they were immediately transferred to the laboratory (within 10 min). In general, the almost uniform samples were selected in this research. The samples were kept at temperature of +25 °C during experiments. All experiments were carried out during the spring of 2016 in a central laboratory located at Ramin Agriculture and Natural Resources University of Khuzestan (Mollasani, 31°N, 48°E, 35 km north east of Ahvaz, Iran).

2.1. Image acquisition system

Samples were placed in a box, which the bottom of this box had been covered with white paper. The camera was installed on top of the box, at a fixed distance of 35 cm from the horizontal surface of the image in the middle of the lamps. In order to distribute light uniformly across the imaging chamber, two types of halogen lamps 50 W were used; the angle of light radiation with the horizontal plane of the image was considered 45° to eliminate the shadows (Fig. 1). Imaging was performed using a digital camera (Logitech, model C920, China) with the resolution 2048 pixels × 1536 pixels; then, the captured images were transmitted through a USB cable to the computer. Finally, image processing was carried out using Matlab 2016a software. As shown in Fig. 1, to design and develop the nonlinear mathematical model by the genetic algorithm, non-destructive parameters (through image processing operations) and destructive parameters (by laboratory method) from banana samples were measured, which are described in more detail in the next sections.

2.2. Image processing

In this study, to design and develop the desired model, the captured