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Modelling the shelf-life of minimally-processed fresh-cut apples packaged in a modified atmosphere using food quality parameters

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ABSTRACT

The objective of the present study was to determine the shelf-life of minimally-processed fresh-cut apples treated with anti-browning agents under modified atmosphere packaging. Shelf-life is calculated by application of mathematical models with product quality attributes such as: pH; soluble solids content (SSC); CIELab color parameters; sensory evaluation; and microbial spoilage (*Salmonella* spp., *Staphylococcus aureus, Sulfite-Reducing Clostridium, Enterobacteriacae, Escherichia coli, Aerobic mesophilic bacteria (AMB), yeast, mold, Listeria monocytogenes)*. Golden Delicious and Cripps Pink apple cultivars were individually treated with one of several anti-browning treatments and packaged in a modified atmosphere (N_2 = 90.5%; CO_2 = 2.5%; O_2 = 7%), and stored at 4 °C. The treatments were; 1) non-treated (control); 2) dipping in a mixture of ascorbic and citric acids for 3 min with and without ultrasound (40 kHz, 3 min) treatment; and 3) Ca-ascorbate with/without ultrasound (40 kHz, 3 min) treatment. Results revealed that Cripps Pink was the most suitable variety for minimally-processed fresh-cut product. All the investigated treatments were equally effective in improving the quality of the product compared to the control. Shelf-life predictive models were developed based on the following quality attributes: apple cultivar, anti-browning treatment, color parameters, sensory evaluation, pH, and SSC. Maximum growth rates for *Enterobacteriacae* and *Aerobic mesophilic bacteria* were 0.25 ± 0.02 log CFU/g/day and 0.46 ± 0.02 log CFU/g/day, respectively. In order to optimize fresh-cut production, these models can be useful tool for predicting the longest shelf-life time with monitoring microbial activity during production. All models are freely available on-line ("Anti-browning Apple Calculator – C.A.P.P.A.B.L.E.©"; apple.pbf.hr or 31.147.204.87).

1. Introduction

The production of minimally-processed fresh-cut (MPFC) fruits and vegetables soared in recent years due to consumers increased tendency to buy fresh and convenient foods that saves preparation time (Putnik & Bursać Kovačevć, 2017). Fresh-cut apples are commonly found in markets due to their year-round availability, popularity, and versatility of use. However, MPFC apples have a shorter shelf-life than whole apple fruits. Peeling, coring, and cutting induce plant tissue injury that will stimulate a wide range of degenerative changes that increase spoilage and shorten the shelf-life of the product. Spoilage of fresh-cut fruits and vegetables is induced by browning, softening, sensorial changes, and microbial growth (Brody, Zhuang, & Han, 2011). The shelf-life of fresh-cut fruits and vegetables is very short, and spans from a few days up to two weeks (Anese, Lanciotti, Gardini, & Lagazio, 2012; Montero-Calderón & Milagro Cerdas-Araya, 2011). Therefore, an essential task in this type of food manufacturing is to ensure prolonged shelf life and food safety (Oms-Oliu & Soliva-Fortuny, 2011).

Fresh-cut apples can lose their market value because of the superficial browning as they become unattractive to the consumers (Putnik, Roohinejad et al., 2017). However, consumers make their first purchase based on the appearance of MPFC products, but repeat purchases are dependent on sensorial quality. Various

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treatments have been employed to extend the shelf-life of fresh-cut apples. Anti-browning agents, such as ascorbic and citric acids (Rojas-Grau, Sobrino-Lopez, Tapia, & Martin-Belloso, 2006; Son, Moon, & Lee, 2001), and Ca-ascorbate (Aguayo, Requejo-Jackman, Stanley, & Woolf, 2010; Gomes, Fundo, Santos, Amaro, & Almeida, 2010) have been used effectively to delay enzymatic browning. The use of several hurdle steps can improve the shelf-life of MPFC products. One of the recent approaches for the prevention of apple browning was combining anti-browning solutions with advanced technologies, such as ultrasound. It has been reported that this treatment efficiently inhibits browning in fresh-cut fruits (Chemat, Zill-e, & Khan, 2011; Jang & Moon, 2011; Morris, Brody, & Wicker, 2007). Additionally, the factors that are involved in the rate of browning, such sugars content and acidity, can vary with apple cultivar, and thus can influence the final quality of MPFC products (Saftner, Abbott, Bhagwat, & Vinyard, 2005). As a result, right selection of apple cultivar and corresponding anti-browning treatment is crucial for preservation of the natural quality of MPFC apple products and extension of their shelf-life.

Aside from taste and visual appeal, microbial spoilage is another limiting factor for the shelf-life of MPFC apples, as it has direct consequences on public health (Graca et al., 2015; Ragaert, Jacxsens, Vandekinderen, Baert, & Devlieghere, 2011). As a result, maximum shelf-life for MPFC apples can be determined from at least two important food quality components: (i) food physicochemical parameters, and (ii) microbial spoilage of the product. Food physicochemical parameters for MPFC apples can be represented by color, pH, soluble solids content (SSC), and sensory evaluation. Microbial spoilage for this class of food products is commonly measured by the presence of characteristic microorganisms for particular foods such as *Enterobacteriacae (EBac)* and *Aerobic mesophilic bacteria (AMB)* in fruits (Benner, 2014). Mathematical models can integrate the abovementioned aspects of food quality and can be used to predict the optimal shelf-life for MPFC apple products using predictive food microbiology models, which is an efficient method to determine products' shelf-life (Kreyenschmidt & Ibald, 2012). Current literature suggested that there is a large number of data focused on the shelf-life of fresh-cut apples under laboratory settings (Putnik & Bursać Kovačevć, 2017; Putnik, Bursać Kovačević, Herceg, & Levaj, 2016a; Soliva-Fortuny, Grigelmo-Miguel, Odriozola-Serrano, Gorinstein, & Martin-Belloso, 2001). However, predicting the shelf-life of MPFC apples from food physicochemical parameters and microbial spoilage under industrial setting had not been studied yet.

The purpose of this study was to model the shelf-life of MPFC apple packed in modified atmosphere at refrigeration temperature of 4 ± 2 °C. The specific research objectives were to: (i) identify the most suitable apple cultivar and anti-browning treatment combination (ascorbic acid, citric acid, Ca-ascorbate with and without the use of ultrasound) for the industrial processing; (ii) mathematically predict the relative shelf-life of the product as a function of physicochemical parameters; (iii) develop models able to determine food spoilage by measuring *EBac* and *AMB* growth during storage; (iv) embed all created mathematical models to the free on-line computer simulation ("Anti-browning Apple Calculator - C.A.P.P.A.B.L.E.©") for free use.

2. Materials and methods

2.1. Raw materials

Our previous laboratory results (Putnik, Bursać Kovačević, Herceg, & Levaj, 2016b, 2016c) predicted that MPFC Cripps Pink (CP) and Golden Delicious (GD) (*Malus domestica* L.) were the most suitable apple cultivars for an industrial experiments. This was based on the following criteria: (i) these cultivars demonstrated best sensory, physical and chemical characteristics in laboratory experiments; (ii) cultivars had excellent synergy with anti-browning agents (exhibited the least browning while having the highest possible sensory quality), and (iii) these cultivars had uniform maturity, size, and no blemishes. According to the results from previous studies (Putnik, Bursać Kovačević, Herceg, & Levaj, 2016a, 2016b; Putnik, Bursać Kovačević, & Dragović-Uzelac, 2016b) a mixture of ascorbic and citric acid or Ca-ascorbate were used as anti-browning agents.

2.2. Production of the packaged fresh-cut apples in the modified atmosphere

20 Kgs of each apple cultivar were washed with water and processed under industrial settings (Fragaria d.o.o., Zagreb, Croatia). Apple pieces (1 cm thick) were then subjected to one of the following treatments for 3 min: (i) no treatment (control); (ii) mixture of ascorbic (10 g/dm^3) and citric acid (2 g/dm^3) with/without exposure to ultrasound; and (iii) Ca-ascorbate (10 g/dm^3) with/without exposure to ultrasound (Aguayo et al., 2010; Pizzocaro, Torreggiani, & Gilardi, 1993; Soliva-Fortuny et al., 2001; Son et al., 2001). The apple pieces were dipped in 30 L of the anti-browning solution (T = 4–7 °C) in plastic basins and the ultrasound treatment was carried out using an ultrasonic bath (Bandelin Sonorex, Germany) at frequency of 40 kHz for 3 min. The treated samples were then industrially packaged in 20 × 20 cm polypropylene bags (average weight = 200 ± 10 g/bag) under the modified atmosphere (MA) using an AV 65/CX GNA packaging system (Sorma Group S&B Verpackungsmaschinen GmbH, Germany). The bags were made of a semipermeable, heat-sealable polypropylene film (35 μm thick), with O_2 and CO_2 transmission rates of 625.33 ± 55.73 cm^3/m^{2}d^{1}bar^1 and 327 ± 11 cm^3/m^{2}d^{1}bar^1, respectively at T = 23 °C and RH = 0%. The MA gas was generated by a quaternary gas mixer, and bags were sealed by compensated vacuum packing welding machine. The MA gas composition/ratio used for packaging was N_2 = 90.5%, CO_2 = 2.5% and O_2 = 7%. The bags were made in 3 replicates (all combinations of selected apple cultivar and anti-browning treatments), totaling of 30 packages that were stored at temperature of T_{SL} = 4 ± 2 °C. The total tested length of the shelf-life was 14 days, and evaluation of randomly selected samples took place at 1, 5, 7, and 14 days (n = 120 samples). The samples were analyzed for SSC, pH, color parameters, and sensory evaluation.

2.3. Monitoring of food physicochemical parameters

2.3.1. Determination of soluble solid content and pH

The SSC (°Brix) and pH values of each sample were measured in triplicates. The sample was homogenized in a blender (Mixy, Zepter International, Switzerland) and the °Brix and pH were measured at T = 22 ± 1 °C using digital hand-held refractometer (ATAGO, PAL-3, Japan), and pH-meter (S20 SevenEasy, Mettler Toledo Instruments (Shanghai) Co., Ltd., China), respectively. Prior analysis, the pH sample (10 g) was placed into a beaker and stirred continuously with a magnetic stirrer and the pH-meter was calibrated with commercial buffer solutions (pH = 4.0 and 7.0).

2.3.2. Color measurement

The surface browning of the apples (color change) was measured by Konica Minolta colorimeter (Model CM 3500d, designed for industrial purposes) at CIE Standard Illuminant D65 using a 8 mm thick plate. Color variables L*, a*, and b* were