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Shelf life extension of strawberry by temperatures conditioning, chitosan coating, modified atmosphere, and clay and silica nanocomposite packaging

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ABSTRACT

In order to investigate the changes of gas inside the packaging as well as qualitative and mechanical properties of coated strawberry under modified atmosphere conditions, during the storage period, a study was conducted. First, the C_0S_0, $C_1S_{0.75}$ and $C_2S_{0.75}$ nanocomposite films were prepared using a molten mixture method (S and C represent nanosilica and nanoclay, respectively). Then, the strawberry was packed under modified atmosphere conditions (10% oxygen, 15% carbon dioxide and 75% nitrogen). Treatments included of two different temperature (4 °C and 25 °C), three levels the packaging (C_0S_0, $C_1S_{0.75}$ and $C_2S_{0.75}$) and two levels the coating (chitosan-coated and uncoated). The measurement parameters including chemical properties (pH, soluble solids content), physical properties (weight loss) and mechanical properties (firmness, elasticity modulus), as well as changes in the proportions of gases inside the package were evaluated and analyzed based on the Completely Randomized Multivariate Factorial (CRF) design. The results of variance analysis of weight loss, pH, soluble solids content, firmness, modulus of elasticity and changes in oxygen and carbon dioxide indicated that the main and interaction effects were significant at ($p < 0.05$). According to the SEM images, distribution of nanoparticles is almost uniform and there is no accumulation in various areas of the fracture surface. During the storage period, the variations of the dependent parameters at 4°C were less than ones at 25°C. Moreover, at two temperatures of 4 °C and 25 °C, the trend of variations of oxygen gas in the coated samples was different from the non-coated sample, so that it was slowing down until the second day and then increased. Finally, the results indicated that the coated sample packed with the $C_1S_{0.75}$ nanocomposite film had the most optimal mode in terms of the changes in physical, chemical and mechanical properties during the storage period.

1. Introduction

The revolution in the standard of living, eating habits, and increasing awareness of nutrition has pushed consumers from an energy providing diet to the diet with a balanced nutrient profile along with metabolic, physiological, health and functional benefits (Panghal et al., 2018). So fruits and vegetables often placed on the list of consumer's priorities. Strawberry (*Fragaria ananassa*) contains a diverse range of vitamins and minerals and it has a general acceptance because of its nutritional value. However, strawberry due to its relatively high metabolic activity, is highly perishable and subjected to rapid post-harvest losses, which, in turn, poses a serious challenge to its marketing. Since Strawberry is a luxury high price fruit, so it has to be preserved and may be converted in different types of processed products and marketed scientifically to fetch foreign exchange and to conserve the national economy. (Panghal et al., 2009). Various studies have shown that the methods of coating and proper packaging of agricultural products and combining these procedures are important ways to maintaining strawberry fruit quality, assisting more appropriate storage, and decreasing the damages in storage.

Edible coatings have the advantage of controlling oxygen, carbon dioxide, and moisture transfer (Jayakumar et al., 2007; Lazaridou and Biliaderis, 2002). Improving the mechanical properties of the products is also an advantage of these coatings (Han, 2007). Chitosan is a natural polymer and a non-toxic, eco-friendly and biodegradable compound that also has antimicrobial properties (Tripathi et al., 2008). The beneficial effects of chitosan on titratable acidity, tissue firmness and reduction of rot in strawberry (Miranda-Castro, 2016), and raspberry (Jaqueline et al., 2014) were reported. According to studies conducted by Lazaridou and Biliaderis (2002), chitosan-based coatings have the potential for improving fresh fruit storage duration, decreasing oxygen content, decreasing ethylene production, and increasing internal carbon dioxide.

The polyolefin elastomer (POE) film is very suitable for resistance to moisture penetration, but their resistance against penetration of gases and aromatic materials are low (Du et al., 2012). The use of mineral

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nano-fillers in packaging materials has several advantages including: the improving maintenance, improving aroma, taste, color, texture and stability during storage and transportation, reducing rot, preventing the entry and exit of gases and increasing thermal stability of the polymers (Othman, 2014). Yang et al (2010) indicated that content of acid between nano-containers and containers of conventional polymers to preserve strawberry over storage life has a significant difference. Additionally, strawberries available nano containers had more marketability, compared to ones contained in polymer containers. Other studies also demonstrated that nano packaging had favorable impacts on the organic, physical, chemical and physiological quality of fresh strawberry compared to polyethylene packaging (Zhong et al., 2007).

The packaging method with modified atmosphere conditions is also one of the most important ways to increase the shelf life of strawberry fruit (Gholami et al., 2018). The maintenance with the controlled atmosphere leads to a decrease in the rate of chemical and biochemical reactions, as well as the reduction of growth of pathogenic microorganisms which, in turn, cause maintaining quality and extending storage life of products (Gholami et al., 2018). In a research done, strawberries were packaged in a MAP containing 15% carbon dioxide and 8% oxygen and sachets of ethylene absorbent and moisture (Seckin and Caner, 2011). The results of qualitative properties such as firmness, soluble solids content and color indicated that these characteristics retained in the optimum conditions for 14 days and in addition, the fungal growth, under these storage conditions, significantly decreased (Seckin and Caner, 2011). In a study by Nielson and Leufven (2008), two cultivars of Corona and Honeoye strawberries for seven days of storage, were examined. The effect of controlled atmosphere (9–12% carbon dioxide and 11–14% oxygen) on strawberries were evaluated and then a decrease in respiratory and growth of microbial, were reported.

As above-mentioned Strawberry is prone to mechanical damage, drying and physiological impairment during storage period. In addition, due to the having general acceptance and the nutritional value of strawberries, packaging, storage and transportation of this fruits are important. In this study, in order to maintain the quality of this fruit during the storage period, we combined the methods of the chitosan-based coating and packaging of nanocomposites under modified atmosphere conditions. Then, we examined the qualitative, mechanical characteristics and changes in the gas inside the strawberry package with using clay-silica PE/POE/PA6 nanocomposites film and coating chitosan under modified atmosphere conditions during storage period.

2. Materials and methods

Strawberry cultivar Gavita (Sphericity coefficient: 0.897 ± 0.051, Diameter: 27.25 ± 2.05, Mass: 13.85 ± 0.35), was provided from a hydroponic based greenhouse, Hamedan, Iran. Experiment period data: August 11, 2017–September 28, 2017. All samples were harvested arranged in rows at $16 \times 13\ cm^2$ dimensions boxes. Samples were kept at ambient (25°C and 30% humidity) and cold storage conditions (4°C and 95% humidity). In order to conduct the experiments, fruits were exposed to temperatures of 4°C and 25°C and kept at three packaging type including C_0S_0, $C_1S_{0.75}$, $C_2S_{0.75}$; C and S denotes nano-clay and nano-silica, respectively.

2.1. Coating strawberry

Strawberry fruits were completely evaluated in terms of physical damages, fungal infections, and size homogeneity after harvesting from hydroponic culturing greenhouse. Then, the fruits were divided into coated and un-coated fruits. Fruits to be coated were prepared with chitosan emulsion, submerged for 2 min, and kept at 20°C for 1 h for drying the surface coating through airflow. Chitosan emulsion was prepared by addition of 5 g r chitosan (SIGMA) into 1 l acetic acid 1% to making 0.5% chitosan concentrations. After complete dissolution of chitosan, pH was adjusted at 5 via 1 N NaOH and eventually 2 ml tween 80 was added to the solution (Petriccione et al., 2015).

Table 1
Combined mass of materials for producing the films of PE/POE/PA6 nanocomposites contains clay and silica nanoparticles.

Variable	E-g-MA (%)	S (%)	C (%)	POE (%)	LDPE (%)	PA6[a] (%)
C_0S_0	5	0	0	0	85.5	9.5
$C_1S_{0.75}$	5	0.75	1	14	71.4	7.9
$C_2S_{0.75}$	5	0.75	2	27	58.62	6.2

[a] Polyamide 6.

2.2. Nanocomposite film production and its structure analysis

Melt mixing of clay nanocomposite was done by using a co-rotating twin-screw extruder (Coperion-Germany) with L/D = 62, D = 75, and speed = 500 rpm. The temperature at various areas of the extruder from feeding portion to exit parts was established at 125, 145, 155, 170, 185, 195, and 200 °C. The pressure of the melt and the temperature at dying were equal to 5 bar and 200 °C, respectively. After assuring the cleanness of the route and establishing above-mentioned conditions, polyethylene, Polyolefin Elastomers (POE), Polyamide 6 (PA6), soil clay nano-particles and organically modified silica at specified percents (Table 1) weighed (including C_0S_0, $C_1S_{0.75}$, $C_2S_{0.75}$; C and S denotes nano-clay and nano-silica, respectively), mixed, and entered the extruder case via loss in weight feeder. Finally nano composite compound cut into granule by strand pelletizer. For producing the film, a single screw extruder and casting roll (Brabender-Germany) was used. At this stage, granules were placed in the machine via feeding section after melting and primary film shaping, melted film were dispersed on the cooling roller as a thin film. Finally, during the cooling, they were pulled via several cold rollers and finally rotated around a tube.

Scanning electron microscopy (SEM) was conducted for observing the failure surface of nano-composites. In order to achieving the optimum failure surface, samples put in liquid nitrogen. After complete fractionation, samples fractures and their fracture section area coated by a thin gold layer via coating instrument and evaluated by scanning electron microscopy (MIRA3 SEM-FEG, Italy) at 3 kV under neutral atmosphere at 35 kx (Zhong et al., 2007).

2.3. Strawberry fruit packaging and analyzing their different properties

In this step, 1080 strawberries samples were divided into three groups of 360 samples for three types of nanocomposite packaging containing C_0S_0, $C_1S_{0.75}$ and $C_2S_{0.75}$. Also, each 360-strawberries group was divided into two coated and uncoated groups, each containing 180 strawberries. These steps were replicated for 25°C. Totally, 2160 strawberries were selected (180 (number of fruits for each level) × 2 (coating levels) × 3 (packaging film levels) × 2 (temperature levels including 4°C and 25°C). 10 fruits were put in each packaging and packs were closed using thermal binding. Next, the samples were kept at 4 and 25°C and physical (weight loss), chemical (pH and soluble solids content), and mechanical (firmness and elasticity modulus) traits of strawberries were evaluated. The present study was conducted as factorial based on completely randomized design with three replications including two coating levels, three film levels, and two temperature levels to evaluate the effect of selected variables on the shelf life of strawberry fruits. For this purpose, nanocomposite films were prepared, their nanostructure was evaluated, and then fruits were packed with these films. Afterward, various physical, chemical, and mechanical traits were measured during the storage. Data were analyzed via SPSS v20 software and the results were discussed.

Weight loss was determined by weighing the strawberry before and during the storage period and the percentage of weight Loss was