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Original Article

Effect of Nanocomposite-Based Packaging on Postharvest Quality of Strawberry during Storage

Khabat Zandi[1], Weria Weisany*[2], Hasan Ahmadi[3], Irajh Bazargan[4], Lotfali Naseri[5]
[1]MSc Student of Horticultural Science, Department of Horticulture, Faculty of Agriculture, Urmia University.
[2] Young Researchers and Elite Club, Islamic Azad University, Sanandaj Branch, Iran.
[3]Research officer Agriculture and Natural Resources Research Center of Kurdistan Province, Iran.
[4]Manager of Nano Bespar Atick Company, Tehran
[5]Associate Professor, Department of Horticulture, Urmia University, Iran.
*Corresponding author Email: weria.wisany@gmail.com, weisany@tabrizu.ac.ir

ABSTRACT
Fruits and vegetables are living tissues subjected to quality changes after harvesting. The loss of strawberries can reach 40% during storage. In order to investigate the effects of postharvest application of nanocomposite packaging on shelf life and quality characteristics of strawberry fruit, a factorial experiment was conducted with two factors, including conventional polymer packaging (control) and nanocomposite in four types (nano-silver based on polyethylene, nano-silver based on polypropylene containing, nano-silicate based on polyethylene, nano-silicate based on polypropylene) and time of storage in four levels (at the beginning and 3, 7 and 10 days after storage) in a completely randomized design with four replications at agricultural College and School of Medical Sciences, Urmia University. The results showed that the over time of maintenance, total phenol content and fruit decay rate of fruits stored in conventional polymeric containers more than nanocomposite containers containing silver and silicate. While, by the use of nanocomposite containers containing silver and silicate increased the amount of ascorbic acid content in strawberry fruit. Ascorbic acid content of fruits significantly reduced with the passage of storage time. While strawberry fruit acidity significantly increased. Also, fruits stored in nano-silicate and nano-silicate based on polyethylene and polypropylene containers generally emitted lower levels of weight loss compounds than those stored in conventional polymer.
***Key words**: Nano-composites, Packaging, Strawberry, Total phenols, Vitamin C*

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INTRODUCTION

Strawberries are a good source of natural antioxidants [35, 36]. In addition to the usual nutrients, such as vitamins and minerals, strawberries are also rich in anthocyanins, flavonoids, and phenolic acids [17, 30]. Nowadays, consumption of fresh fruits and vegetables has attracted increasing attention due to their high nutritional values. Nevertheless, the major problem with fruits and vegetable is their perishable nature causing a great deal of troubles. At present, the most prevalent method of maintaining quality and controlling decay is rapid cooling after harvest and storage at low temperatures [15]. Thus, there is an urgent need to have alternative technologies to minimize the undesirable physicochemical and physiological changes of strawberries during storage. Many techniques have been studied in order to extend the shelf life of fresh produces for example, low temperature and high relative humidity, controlled and modified atmosphere packaging, etc. However, each has advantages and disadvantages, which later the predominating.

Recently, the application of the nanocomposite concept has been proven to be a promising option in order to improve above mentioned properties conveniently [11]. The use of protective coatings and suitable packaging by the food industry has become a topic of great interest because of their potentiality for increasing the shelf life of many food products [2, 13].

Nanotechnology has been touted as the next revolution in many industries, including food processing and packaging. Antimicrobially active packaging is a new generation of nano food

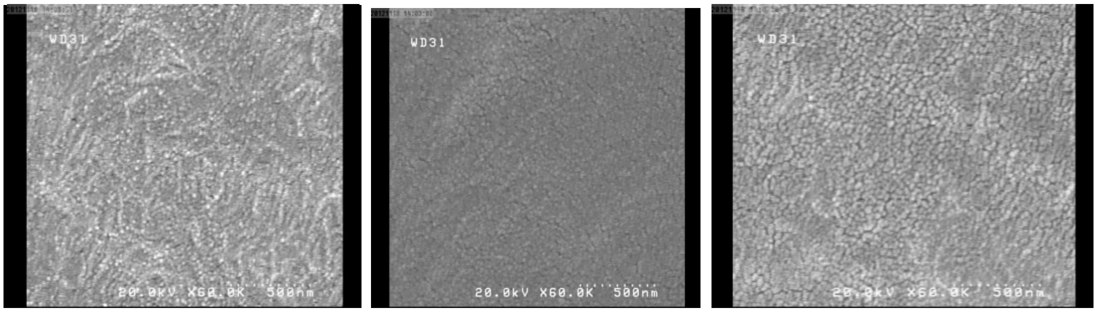
packaging based on metal nanocomposites which are made by incorporating metal nanoparticles into polymer films [7]. The most common nanocomposites used as antimicrobial films for food packaging are based on silver, which is well known for its strong toxicity to a wide range of microorganisms [23], Silver ions have also attracted the interests of several researchers, because of their photoactivity of semiconductor photocatalysis nanocrystallites and antibacterial activity. Silver nanocomposites have been produced by several researchers, and their antimicrobial effectivity has usually been reported. Damm et al [9], comparing efficacy of polyamide 6/silver-nano- and microcomposites, reported that nanocomposites with a low silver content presented a better increased efficacy against Escherichia coli than microcomposites with a much higher silver content. Fuji apples with nano-SiOx/chitosan keeping fresh agents had better preservation quality [22]. Green tea with nano-packing had better maintenance of vitamin C, chlorophyll, polyphenols, and amino acid compared with normal packing [19].
Microbial growth rate in orange juice were significantly reduced as a result of using packaging material containing silver and ZnO nanoparticles, which prolonged the shelf life of fresh orange juice up to 28 days without any negative effects on sensorial parameters [10]. It is well known that silver in various chemical forms has strong toxicity to a wide range of microorganisms [23]. In particular, silver nanoparticles have been shown to be a promising antimicrobial material [32].
Silver has antibacterial, anti-mold and anti-fungal properties inherently. Using these containers, during first 24 hours growth of bacteria has been reduced 98% in comparison with regular containers. Besides, nano silver leads to absorption and decomposition of ethylene [18]. Yang et al [38] showed that there is a significant difference in the amount of acids between nano containers and regular polymer ones for preserving strawberry during storage life. In addition, strawberry available in nano containers achieve more market-friendly compared to regular polymer containers. This is due to the fact that nano containers hold more humidity and also less oxygen enter and leave [38]. Since clay layers constitute a barrier to gases and water, forcing them to follow a tortuous path, the introduction of nanoclays into polymer biostructures has been shown to greatly improve barrier properties [1], minimizing one of the main limitations of biopolymer films. Indeed, many studies have reported the effectiveness of nanoclays in decreasing oxygen [5, 6, 21, 24, 25] and water vapor permeabilities [20, 24, 25]. To well understand the effect of this novel nanocomposite-based packaging material, the quantitative and qualitative characterization, antibacterial effect of the nanocomposite were conducted as well.

MATERIALS AND METHODS

In order to investigate the effects of postharvest application of nanocomposite packaging on shelf life and quality characteristics of strawberry fruit, a factorial experiment was conducted with two factors, including conventional polymer packaging (control) and nanocomposite in four types (nano-silver based on polyethylene, nano-silver based on polypropylene, nano-silicate based on polyethylene, nano-silicate based on polypropylene) and time of storage in four levels (at the beginning and 3, 7 and 10 days after storage) in a completely randomized design with four replications at agricultural College and School of Medical Sciences, Urmia University.
The strawberry fruits were harvested at the trade repining stage, shipped to the laboratory and up to the treatment and kept at the temperature of 4°C. Then, in 4 different combinations of nano-silver, nano-silicate clay and conventional polymer containers were considered as control samples, and were transferred to fridge (0.5°C and 90%- 95% relative humidity). FDA law states that nano-silver should be restricted in terms of consumption and its delivery rate. Besides, in short-term it should be near to 100 pbb, and in long-term around 1420 pbb. Therefore, we thought that seems necessary to create a barrier against passing oxygen and water. In fact, in this method, polymer nano-silica was designed and produced (ANSC-PE_4 and ANSC-PP_2) which belongs to Nano Bespar Aytech Company (Tehran, Iran).

Morphological investigations of nanocomposite-based packaging materials

Scanning electron microscopy (SEM) was applied for the investigation of the nanocomposite-based packaging. Goldwas deposited on the cryogenic fracture surfaces of the samples. The SEM measurements were made on a scanning electron microscope (S-3000N, Hitachi High- Technologies Corporation, Japan) at an accelerating voltage of 20 kV (Figure 1).



C B A

Figure 1. SEM micrographs for the polypropylene and polyethylene nanocomposites containing A: nano silver, B: typical polymer C: nano-silicate.

Overall quality

Fruits per treatment were used for each quality evaluation. Samples from each treatment were evaluated subjectively on the initial day and on days 3, 7, and 10 during storage. Overall quality was evaluated on a 1 to 5 scale according to the overall condition of the fruit, where 1=unacceptable, 2=bad, 3=acceptable, 4=good, and 5=excellent. Results were expressed as an overall quality index [4].

Total phenolic compound analysis

The amount of total phenolic content (TP) was determined as described by Waterhouse [37]. Sample extracts were prepared by diluting 1:10. To proceed with the Folin-Ciocalteu method, 0.5 mL of sample extract followed by the addition of 0.25 mL of Folin-Ciocalteu reagent (2.0 N) and 2.5 mL sodium carbonate solution 0.1 M. The blank was prepared using the same chemical reagents excluding the extract. The flasks were mixed well and left in the dark, at room temperature ($25^{\circ}C$) for 60 minutes, then the absorbance was read at λ=750 nm. UV/VIS spectrophotometer Secoman S750i and 1 cm quartz cells were used for all absorbance measurements.

Fruit decay rate

At each iteration, for evaluating the fruit decay rate just 15 fruit samples were used. All fruits according to their decay were classified into 4 categories: 1. Fruits without decay. 2. Fruits with decay less than one-third of the fruit surface. 3. Fruits with decay between one-third and two-thirds of the fruit surface. 4. Fruits with decay more than two-third of fruit surface. Index of decay was expressed by the following formula [40].

$$\text{Decay index} = \frac{\Sigma(\text{rank} \times \text{quantity})}{4 \times 15} \times 100$$

Measurement of weight loss

After packing, strawberries were weighed at the beginning of the experiment and thereafter 3, 7 and 10 days during the storage period. Weight loss was expressed as the percentage loss of the initial total weight.

Juice pH measurement

Originally machine model digital pH meter (CG 824) was calibrated with buffers 4 and 7, and then the juice pH measurements were performed with a device named.

Measurement of ascorbic acid (vitamin C)

Ascorbic acid in asparagus was determined according to AOAC official method [3]. In brief, a 5 g sample of asparagus was blended with 50 mL of metaphosphoricacetic acid solution to extract ascorbic acid. The mixture was centrifuged (at 4000-g for 5min), and then the supernatant was taken and transferred to a volumetric flask. It was rapidly titrated with indophenols solution until light distinct rose pink color persisted for more than 5 s.

Statistical analysis

Analysis of variance was performed using SAS version 9.1 (SAS Institute Inc., Cary, NC, USA). The data were presented as the means for each treatment. Means were compared using the LSD test at the 5% probability level.

RESULTS AND DISCUSSION

Overall quality

As shown in figure 2, at 1 and 3 days after of storage, there were no significant differences among of packaging containers in terms of overall quality of strawberry fruits. Overall quality of strawberry was improved using nano-composite containers containing silicate and silver and at 3 and 7 days after of storage (Figure 2). The results showed that there were no significant differences between nano-composite containers containing silicate and silver in terms of overall quality (Figure 2). One of the main indices used to determine fruit quality and post-harvest shelf life is the rate and extent of firmness loss during storage. According to the research by Manning [26] fruit softening is due to the degradation of cell wall components, mainly pectins, by the action of specific enzymes, such as polygalacturonase. Li et al [22] indicated that nano-packing material had a quite beneficial effect on physicochemical and sensory quality compared with normal packing material.

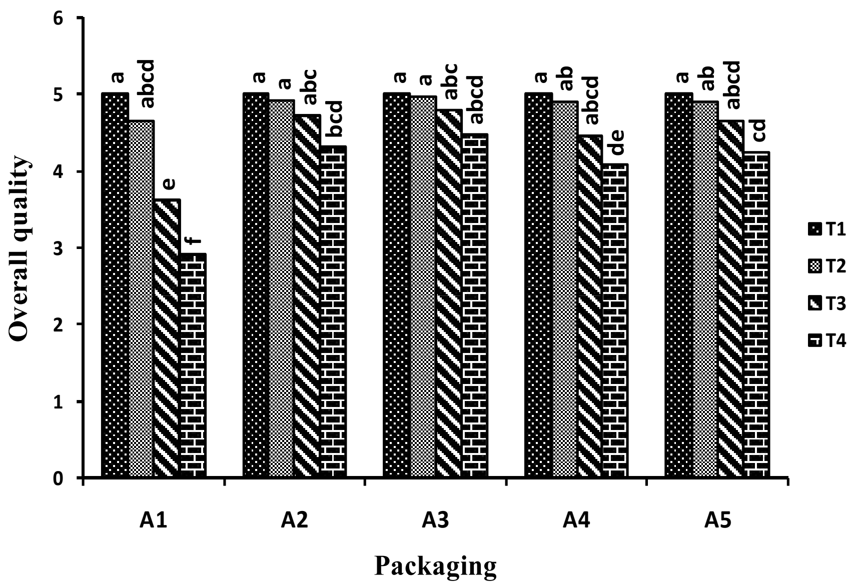


Figure 2- Interaction effect of containers of packaging and time of storage on overall quality of strawberry fruits: A1: conventional polymer, A2: nano-silver based on polypropylene, A3: nano-silver based on polyethylene: A4: nano-silicate based on polyethylene A5: nano-silicate based on polypropylene. T1: at the beginning of storage, T2: 3 days after storage, T3: 7 days after storage and T4: 10 days after storage. Means with the same letter for each stage are not significantly different (P≤0.05).

Total phenolic compounds

As shown in figure 4, at the 3 day after storage, total phenol content was significantly increased in strawberry fruits by the use of silver and silicate containing nanocomposite polymer compared to conventional containers. Also, result showed that at the 7 and 10 days after of storage, nanosilicate based on polypropylene containers reduced the total phenolic content of strawberry fruits (Figure 4). Yang et al [38] demonstrated that in strawberry fruits packaged in nano-silver containers phenol compounds would go through less reduction. In addition, Qiuhui Hu et al [28] showed that polyphenols oxidize activity in nano-composite packages or oxidation amount of poly phenols by these enzymes decrease significantly in fruits placed in nano containers. The increase of the total phenolic compounds could be a response to the oxidative stress caused by high oxygen concentrations [14].

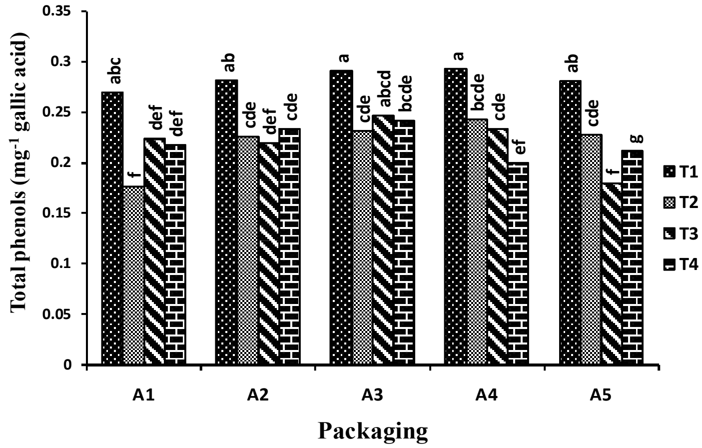


Figure 3 - Interaction effect of containers of packaging and time of storage on total phenols of strawberry fruits: A1: conventional polymer, A2: nano-silver based on polypropylene, A3: nano-silver based on polyethylene: A4: nano-silicate based on polyethylene A5: nano-silicate based on polypropylene. T1: at the beginning of storage, T2: 3 days after storage, T3: 7 days after storage and T4: 10 days after storage. Means with the same letter for each stage are not significantly different ($P \leq 0.05$).

Fruit decay rate

Fruit decay, resulting from mold, such as Penicillium, is an important cause of a short shelf-life [16]. Over time, the rate of decay of stored fruits in the conventional polymer containers was more than fruits stored in nanocomposite packaging containing silicate and silver (Figure 4). This lower decay rate might be attributed to the relative higher barrier property of nano-packing materials against O_2 and H_2O than the normal packing, which kept the fruit under an internal atmosphere and low-moisture surroundings, thus not favoring the growth of fungi [38]. Between of silicate and silver nanocomposite packaging, the lowest percentage of related to polypropylene containers based on nano-silver. Zhao et al [39] reported that nano-silver displayed the strongest inhibitive effect upon *Penicillium funiculosum*. Antibacterial property of Nano-silver particle is due to the fact that with growth surface, silver particles interfere in cell's normal affairs such as respiration and substance transfer. Besides, silver ions penetrate into the inside of the cell, and by sticking to base binding of DNA make it to compact form. This action prohibits the reproduction capability from cell which leads to death of cell bacteria. Indeed, nano particles attack the respiration and reproduction chain of the cell that finally cell's death is resulted [29]. Damm et al [8] reported much more antimicrobial effect for silver nano-composite compared to other nano-composites.

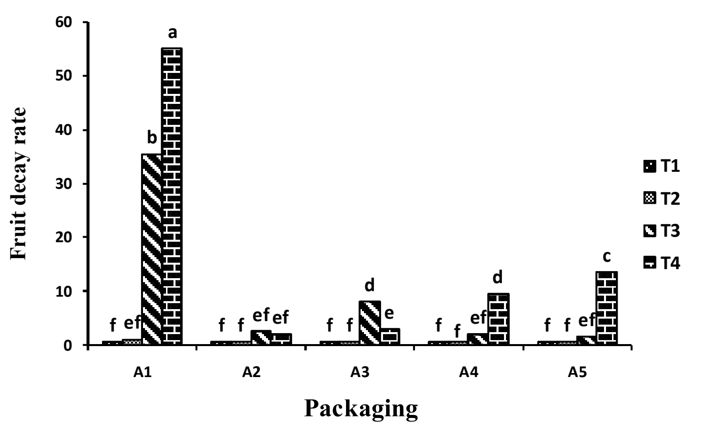


Figure 4- Interaction effect of containers of packaging and time of storage on fruit decay rate of strawberry fruits: A1: conventional polymer, A2: nano-silver based on polypropylene, A3: nano-silver based on polyethylene: A4: nano-silicate based on polyethylene A5: nano-silicate based on polypropylene. T1: at the beginning of storage, T2: 3 days after storage, T3: 7 days after storage and T4: 10 days after storage. Means with the same letter for each stage are not significantly different ($P \leq 0.05$).

Weight Loss

Nano-silicate beads on polyethylene and nano-silicate based on polypropylene containers have less weight loss compared with conventional polymer containers, hence the fruits were kept in the containers have more weight (Figure 5). Also, results showed that in terms of weight loss of strawberry fruits, there were no significant difference between nano silver based on polypropylene and nano silver based on polyethylene. This result indicated that the nano-packing had a greater effect in preventing weight loss of fruit, which could be attributed to its better barrier properties against H_2O [22]. Kiwi fruit and grapefruit package insert polymer nano-loss less weight than a conventional package within 42 days of storage [28].

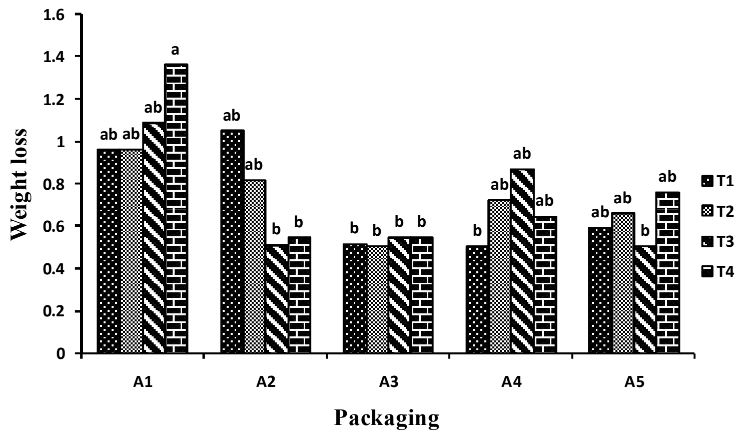


Figure 5- Interaction effect of containers of packaging and time of storage on weight loss of strawberry fruits: A1: conventional polymer, A2: nano-silver based on polypropylene, A3: nano-silver based on polyethylene: A4: nano-silicate based on polyethylene A5: nano-silicate based on polypropylene. T1: at the beginning of storage, T2: 3 days after storage, T3: 7 days after storage and T4: 10 days after storage. Means with the same letter for each stage are not significantly different (P≤0.05).

Acidity (pH)

Over time of storage of one to three days, acidity of strawberry fruit significantly was decreased (Figure 6). Strawberry fruit acidity was increased with increasing storage time of three to 7 days. It seems that decomposition of cell wall in days of 7 causes to this irregular pattern. Our results confirmed other study results by day 9 [34]. Ayala-Zavala et al [4] reported that pH values increased during storage period in strawberry fruit. The increase in pH values seems to be normal during the postharvest life of strawberry fruit.

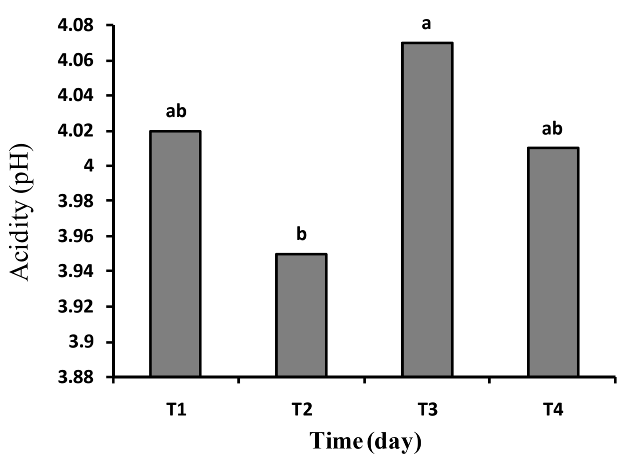


Figure 6- Effect of storage time on the acidity (pH) of strawberry fruit: T1: at the beginning of storage, T2: 3 days after storage, T3: 7 days after storage and T4: 10 days after storage. Means with the same letter for each stage are not significantly different (P≤0.05).

Vitamin C

The results showed that ascorbic acid content of strawberry fruits was increased using nano-silver based on polypropylene and nano-silver based on polyethylene containers compared to conventional polymers containers (Figure 7). Over time of storage, fruit ascorbic acid content significantly decreased (Figure 8). This overall ascorbic acid reduction might be due to the nonbarrier properties of packaging against oxygen [12] and the duration of storage time [27]. The reason for ascorbic acid can be associated with free radicals [31]. Due to increasing in oxidative metabolism, active oxygen types increase which can impose damage on biological membranes. For tackling damage on active oxygen types, plants activate their antioxidant systems. Some of these systems include ascorbate peroxidase or non-enzymatic systems like ascorbic acid (Vitamin C) or alpha-tocopherol (Vitamin E). Antioxidants themselves by giving away the electron to active oxygen types are oxidized, and subsidy their oxidization power and damage [33]. Emamifar et al [10] showed that silver nano composites containers have preserved more ascorbic acidin fresh orange juice compared to regular polymer ones.

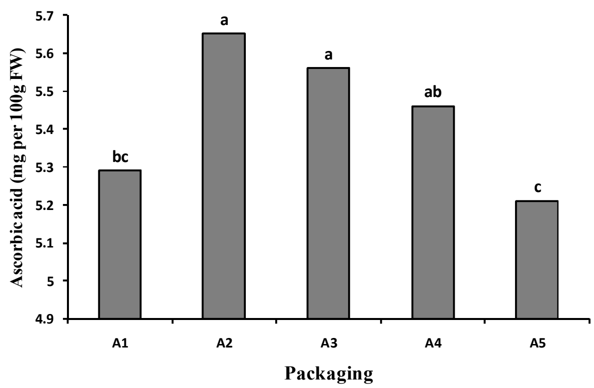


Figure 7- Effect of containers of packaging and time of storage on ascorbic acid of strawberry fruits: A1: conventional polymer, A2: nano-silver based on polypropylene, A3: nano-silver based on polyethylene: A4: nano-silicate based on polyethylene A5: nano-silicate based on polypropylene. Means with the same letter for each stage are not significantly different (P≤0.05).

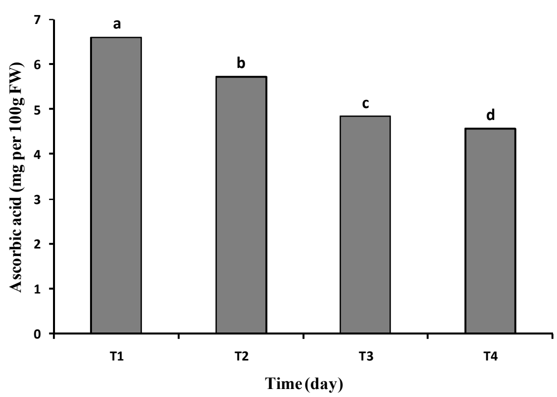


Figure 8- Effect of storage time on ascorbic acid of strawberry fruit: T1: at the beginning of storage, T2: 3 days after storage, T3: 7 days after storage and T4: 10 days after storage. Means with the same letter for each stage are not significantly different (P≤0.05).

CONCLUSION

The results showed that the nano-packing material had quite beneficial effects on physicochemical and physiological quality compared with conventional packing material. Furthermore, these nano-packing materials have the advantages of simple processing and industrial feasibility in contrast with other storages. Therefore, the nano-packing may provide an attractive alternative to improve the preservation qualities of strawberry during storage. Moreover, further research will be needed to explore the exact nano-packing mechanism during storage to facilitate the application of nano-technology over a broader range in the future.

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