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**ORIGINAL ARTICLE**

# Application of Novel Nano-biopackaging Based on Cassava Starch/Bovine Gelatin / Titanium oxide nanoparticle/Fennel Essential Oil to Improve Quality of the Raw Fresh Pistachio

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A R T I C L E I N F O

*Keywords:*

Antifungal;
*Aspergillus*;
Bionanocomposite film;
Pistachio kernel;
Sensory properties

A B S T R A C T

The aim of this research was to estimate the impacts of a combination of titanium oxide ($TiO_2$) nanoparticles and fennel essential oil (FEO) on the chemical and sensory properties of fresh raw Abbas Ali pistachio. The cassava starch/bovine gelatin biofilms with Nano-$TiO_2$ (1, 3, and 5% w/w), and essential oil (1, and 3% w/w) were fabricated by the casting technique. The sensory and chemical properties and the growth of *Aspergillus flavus* were evaluated during three weeks of storage at 4°C. After 21-day conservation, *Aspergillus flavus* count of the control specimen was the highest whereas bionanocomposite film containing FEO enabled lower amounts of *Aspergillus flavus* population. RP-HPLC analysis findings represented that packaging with starch/gelatin had a positive effect on the aflatoxin B1 content of pistachio, and the lowest amount of aflatoxin B1 was related to the biofilm containing 5% Nano-$TiO_2$/3% FEO. Sensory tests indicated that pistachios packaged with Nano-$TiO_2$/essential oil had a significant effect on taste and general acceptability, and the highest score of sensory properties was related to the pistachio sample packaged with starch/gelatin/5% Nano-$Tio_2$/3% FEO. Results showed that cassava starch/bovine gelatin film containing 5% Nano-$TiO_2$/3% FEO and control sample had significantly higher and lower moisture and carbohydrate soluble content than the treatments. At last, the findings demonstrate that cassava starch/bovine gelatin/5% Nano-$TiO_2$/3% FEO active film improved the chemical and sensory factors and had the positive effect on *Aspergillus flavus* population reduction of pistachio nuts; hence, it can be applied as biopackaging for fresh pistachio.

## Introduction

Pistachio nut is one of the agricultural products cultivated in different temperate regions such as Asia(Iran, Turkey, and Syria) Europe (Italy), and North America (USA)(Kazemi *et al*., 2020). Pistachio crop is a source rich in phenolic compounds,

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carbohydrates, dietary fiber, unsaturated fatty acids, and proteins (Babapour *et al*., 2021).

However, fresh pistachio is very susceptible to oxidation reactions and fungal contamination (Holakouie Naieni *et al*., 2020). The mentioned contamination in pistachio leads to the produce mycotoxins, which are critical compounds of various molds such as *Aspergillus flavus, Aspergillus tamarri, Aspergillus parasiticus*, *Aspergillus nomius*, and *Aspergillus bombycitts.* Aspergillus molds produce various aflatoxins for example $G_1$, $G_2$, $B_1$, and $B_2$. (Ortega-Beltran *et al*., 2019, Nobari *et al*., 2022). Recently, some searches focused to increase the shelf life of raw pistachio (Mousavi *et al*., 2015, Hashemi *et al*., 2021). On the other hand, agriculture production susceptible to different aflatoxin pollution are including pistachios, cotton seed, corn, spices, almonds, raisins, and peanuts (Holakouie Naieni *et al.*, 2020; Mahbobinejhad *et al.*, 2019). One insight in the mentioned challenge is edible film, which has been applied to several nuts (Kan *et al*., 2019, Khoshnoudi-Nia and Sedaghat, 2019).

Films are a thin layer of the biopolymer compound packaging food products (Hadadinejad *et al.*, 2018). The biodegradable film acts as a protection shield and maintains the different food production against unfavorable changes in sensory, microbial, and chemical properties (Moosavian *et al*., 2017). The ability of biodegradable film as a type of novel biopackaging to carry some additives including antifungal, nanofillers, antimicrobials, spices, and essential oil is being studied (Vanaei *et al*., 2014, Marvizadeh *et al*., 2021).

Nanoadditives improve antimicrobial, permeability, and antifungal properties of biofilms. Some nanoadditives such as ZnO or $TiO_2$ have antimicrobial and antifungal behavior and can also change the biopackaging characterizations to prevent water vapor and oxygen molecules penetration which provides good conditions for microbial and fungal contamination; as a result, scholars have increasingly focused on nano-biopackaging to food science (Mallakpour and Ramezanzade, 2020).

Kazemi *et al*. (2020) stated that the zinc oxide nanoparticles have antiaflatoxigenic and antifungal characterizations capability to control the growth of *A. flavus* mold and its aflatoxin B1. Mahdavi-Yekta *et al*. (2022) studied the effect of using different levels of silver nanoparticle and quinoa peptide in combination with polyethylene, on the aflatoxin of fresh pistachio during 30 storage days. They stated that Aflatoxin B1 of pistachios was significantly less than in other pistachios when using the polyethylene enriched with the 35% nanoparticle and quinoa peptide. Kamiab *et al*. (2017) stated that nano silver is more effective than silicon for reducing ethylene content.

Khajeh-Ali *et al*. (2022) represented that carboxymethylcellulose containing 2% *Astragalus* honey reduced the fungal counts and weight loss of pistachio. Also, higher sensory score were found in pistachio coated with carboxymethylcellulose containing honey. Pistachio kernel packaged with whey protein concentrate containing avishan-e Shirazi significantly reduced the fat oxidation of pistachio kernel and extended shelf-life of the final product (Javanmard and Ramazan, 2009).

Habibie *et al*. (2019) used ascorbic acid incorporated with walnut green husk extract for preserving the postharvest quality of cold storage fresh walnut kernels.

Fennel (*Foeniculum vulgare Miller*) among medical plants belonging to the *Umbelliferae* (*Apiaceae*) family is widely bred in Mediterranean countries(Belabdelli *et al*., 2020). Fennel is a good resource of antioxidant, antifungal, and antimicrobial compounds. Two types of fennel commercials are sweet (*F. vulgare* var. *dulce*) and bitter fennel (*F. vulgare* var. *vulgare*) estragole, *α*-pinene, *α*-phellandrene, and *o*-cymene have been found as the active compound in fennel essential oil (Abdellaoui *et al*., 2020). Various pharmacological roles have been identified to fennel essential oils including antibacterial activities, antioxidant, and antifungal (Badgujar *et al*., 2014).

The presentation study, a novel packaging based on cassava starch/bovine gelatin/Nano-$TiO_2$/FEO was introduced for raw fresh pistachio. This packaging improves the product's sensory properties with minimized chemical characterization changes.

## Materials and Methods

### *Materials*

Cassava Starch powder, bovine gelatin glycerol and liquid sorbitol were purchased from Merck Co. (Darmstadt, Germany). Essential oil fennel was obtained from Nikoshimi Co. (Iran). Nano $TiO_2$ was purchased from NBIC Co (Oklahoma, USA). AbbasAli pistachio cultivar was obtained from the Damghan agriculture pistachio research station. Other chemicals material was purchased from Sigma Chemical Co (Burlington, USA).

### *Film preparation*

The cassava starch/bovine gelatin/Nano-$TiO_2$/fennel essential oil bionanocomposites were fabricated by utilizing the solvent casting technique. Firstly, the Nano-$TiO_2$ solution was fabricated by mixing the 1-2-3% of nanopowder with 100 mL of distilled water and kept under stirring for 24 h at 25°C and then homogenized by using an ultrasonic bath (sonic 6MX, James product Europe, Dorset, England). Afterward, the biocomposite dispersion was fabricated by dispersing the 4g of cassava starch and 0.4 g of bovine gelatin in 100 mL of Nano-$TiO_2$ solution and kept under stirring for 45 min at 87°C (Marvizadeh *et al*., 2016, Marvizadeh *et al*., 2014a).

To fabricate the bionanocomposite formulation, sorbitol and glycerol (40% w/w/%) were added to the bionanocomposite dispersion as plasticizers (Moosavian *et al*., 2017). During cooling stage of the bionanocomposite dispersion at 45°C, different levels of the essential oil (1%, and 3 w/w%) were added to the dispersion and homogenized for 40 min. At last, the film dispersion (90g) was cast into glass plates and dried for 1d at 25°C.

### *Pistachio sample packaging*

After preparing pistachio samples, healthy samples were separated from premature and perishable samples, and about 200 g of fresh raw pistachio fruit were applied in each test unit Fresh samples were packaged in the starch/gelatin/Nano-$TiO_2$ bionanocomposite films containing FEO and stored at 4 ± 1°C for 3 weeks, and the experiments were conducted on the fresh pistachio every week (Esfahani *et al*., 2020).

### *Moisture content*

The moisture content of the pistachio sample was measured utilization oven technique at 105°C for 4h and cooled in a desiccator. The moisture content was computed according to the following equation:

$$\text{Moisture content (\%)} = m_1 - m_2 / m_1 \times 100$$

where, $m_1$ is the weight(g) of pistachio before drying and $m_2$ is the weight (g) of pistachio after drying

### *Soluble carbohydrate*

The soluble carbohydrate contents were measured by the sulfuric acid-phenol method and according to Nezima and colleagues (Nzima *et al*., 1997) with slight modification. The absorbance of each of the solutions was read at a wavelength of 485 nm by a spectrophotometer (UV-1650PC, Shimadzu, Tokyo, Japan) and based on the standard curve and then the concentration of soluble carbohydrate of samples was calculated. The soluble carbohydrate content of pistachio was demonstrated as grams per hundred grams of dried matter.

### ***Aspergillus flavus* count and aflatoxin assay**

To count the *Aspergillus flavus* population, the surface culture technique, the potato dextrose agar, and the incubation for 4 days at 25°C were applied.

To prepare the specimens for *Aspergillus flavus* count experiment, about 25g of pistachio kernels on a magnetic stirrer (Heidolph, MR300 K, Schwabach, Germany) were added to 225mL of ringer solution at 25°C for 10 min (Babapour *et al*., 2022). The reverse-phase-high-efficiency liquid chromatography system (Hewlett-Packard, England) was utilized to evaluate the aflatoxin B1 in the pistachio samples (ISIRI, 2011).

### *Sensory properties*

The sensory characterization of fresh pistachio was measured by 10 panelists on the first and 21st days of the storage time. A 7-point hedonic scale (1 to 7, 1 = very bad and 7 = excellent) was applied. For each sample, five pistachio specimens were placed in glass containers and proposed to each panelist to measure sensory factors.

### Statistical analysis

Independent sample t-test and one-way ANOVA were conducted to compare means of sensory and chemical properties of pistachio kernel at $p<0.05$. Data from sensory and chemical evaluation were analyzed by SPSS statistics grad pack version 22 (IBM Co. Armonk, New York, U.S.A).

## Results

### *Moisture content*

As shown in Fig. 1. the findings demonstrate that the moisture content of the control specimen decreased (from 48.2 to 43.79%) after 3 weeks of storage. There was no significant difference in the level of moisture content between T4 and T2 treatments after 3 weeks of storage. Based on Fig.1. increasing the level of FEO and nanoadditive in the bionanocomposites, the moisture content of the fresh pistachios was better maintained, and the effect of nanoadditive was more than the essential oil. The lowest moisture content loss compared to the first value belonged to the active films containing 5% Nano-$TiO_2$/3% FEO. However, significant difference was found between the control sample and other treatments in terms of moisture content.

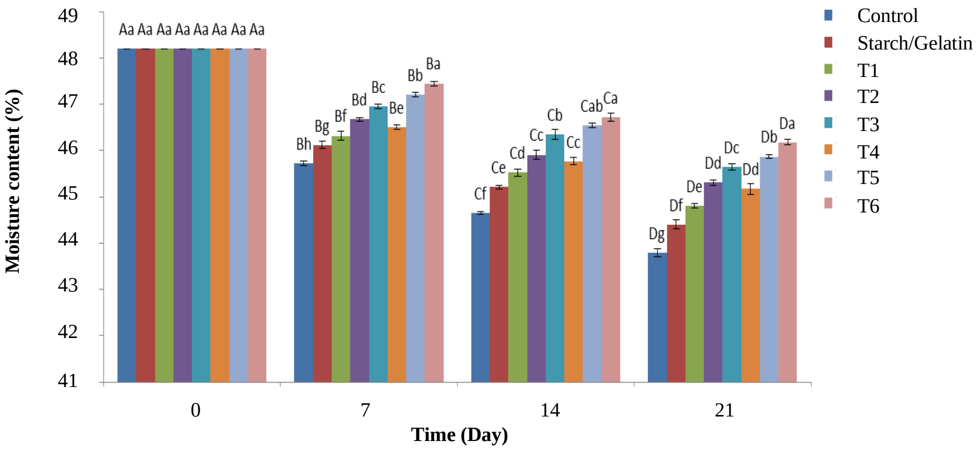



**Fig.1.** Moisture content of fresh pistachio Control: conventional packaging T1:1% $TiO_2$/1%FEO T2: 3% $TiO_2$/1%FEO T3: 5% $TiO_2$/1%FEO T4:1% $TiO_2$/1%FEO T5: 3% $TiO_2$/3%FEO T6: 5% $TiO_2$/3%FEO. Different small and capital letters indicate significant difference between means ± SD of different levels and one specimen during storage time respectively

### *Soluble carbohydrate*

Fig. 2. indicates the effect of different levels of Nano-$TiO_2$/FEO during 3 weeks of storage on fresh pistachio. The use of Nano-$TiO_2$/FEO had a significant impact on the soluble carbohydrate of pistachio ($p<0.05$). The findings indicated that the soluble carbohydrate of the sample had a reducing trend during storage period; there was no significant difference in the level of carbohydrate content between T1 and T4 samples on 21 days of storage. Regarding to Fig.2. increasing the level of FEO and

nanoadditive in the bionanocomposites, the carbohydrate soluble of the fresh pistachios was better maintained, and the effect of nanoadditive was more than the essential oil. The level of carbohydrate soluble in the starch/gelatin film decreased from 8.1 to 4.43% after 3 weeks of storage.

According to Fig. 2, it can be proved that in all samples, changes in carbohydrate soluble of pistachio packaged with 5% Nano-$TiO_2$/3% FEO are lower than control and starch/gelatin samples.

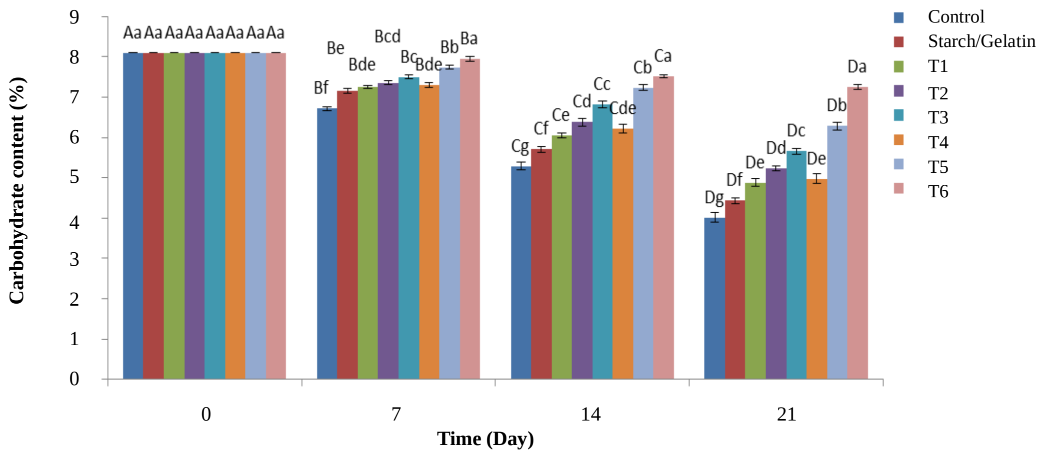



**Fig.2.** Carbohydrate content of fresh pistachio Control:conventional packaging T1:1% $TiO_2$/1%FEO T2: 3% $TiO_2$/1%FEO T3: 5% $TiO_2$/1%FEO T4:1% $TiO_2$/1%FEO T5: 3% $TiO_2$/3%FEO T6: 5% $TiO_2$/3%FEO. Different small and capital letters indicate significant difference between means±SD of different levels and one specimen during storage time respectively.

### *Aspergillus flavus* count and aflatoxin assay

The number of *A. flavus* in Abbas Ali pistachio during storage time is compared in Fig. 3. Regarding results, *Aspergillus flavus* population in different samples had an increment trend during storage period. Increasing the level of nanoadditive/FEO had desired effect on reducing the fungi population in the samples. There was no significant differences between T5 and T6 in terms of *Aspergillus flavus* count. The use of starch/gelatin films containing $TiO_2$/FEO significantly decrease the mold population in the pistachio samples.

Regarding the findings obtained from different samples, it is clear that increasing *Aspergillus flavus* count in the treatments that have been packaged with 5% Nano $TiO_2$/3% FEO bionanocomposite films, were lower than control specimens and starch/gelatin films.

As shown in Fig. 4. the findings indicate that the aflatoxin B1 content of the control specimen increased (from 0.65 to 6.2 ppb) after 3 weeks of storage. There was no significant difference in the aflatoxin B1 between T5 and T6 treatments after 3 weeks of storage. Based on Fig.4. increasing the level of FEO and nanoadditive in the bionanocomposites, the aflatoxin B1 of the fresh pistachios was decreased, and the effect of nanoadditive was more than the essential oil. Also, significant difference was found between the control sample and other treatments in terms of aflatoxin B1.

The lowest aflatoxin B1 compared to the first value belonged to the active films containing 5% Nano-$TiO_2$/3% FEO.

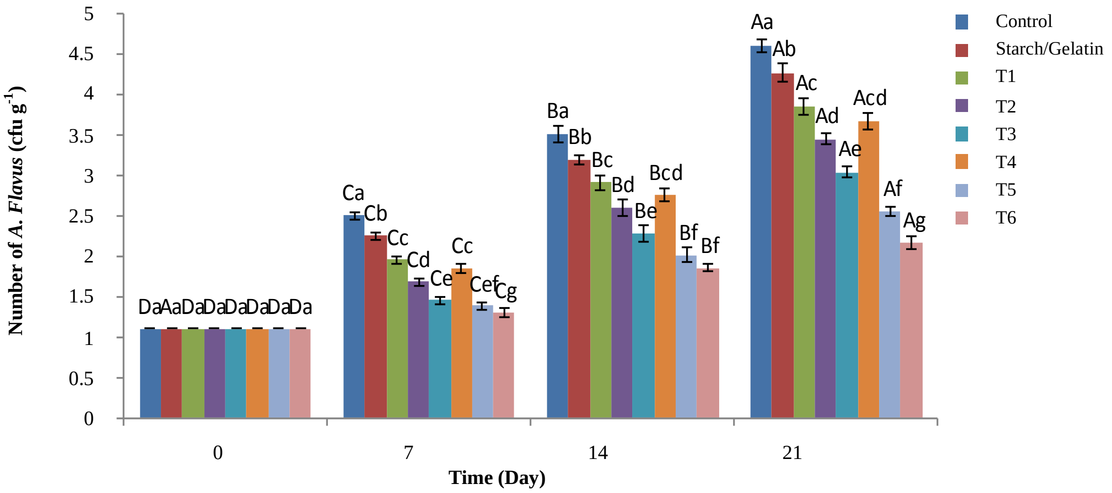



**Fig.3.** Number of *A.flavus* of fresh pistachio Control: conventional packaging T1:1% $TiO_2$/1%FEO T2: 3% $TiO_2$/1%FEO T3: 5% $TiO_2$/1%FEO T4:1% $TiO_2$/1%FEO T5: 3% $TiO_2$/3%FEO T6: 5% $TiO_2$/3%FEO. Different small and capital letters indicate significant difference between means±SD of different levels and one specimen during storage time respectively.

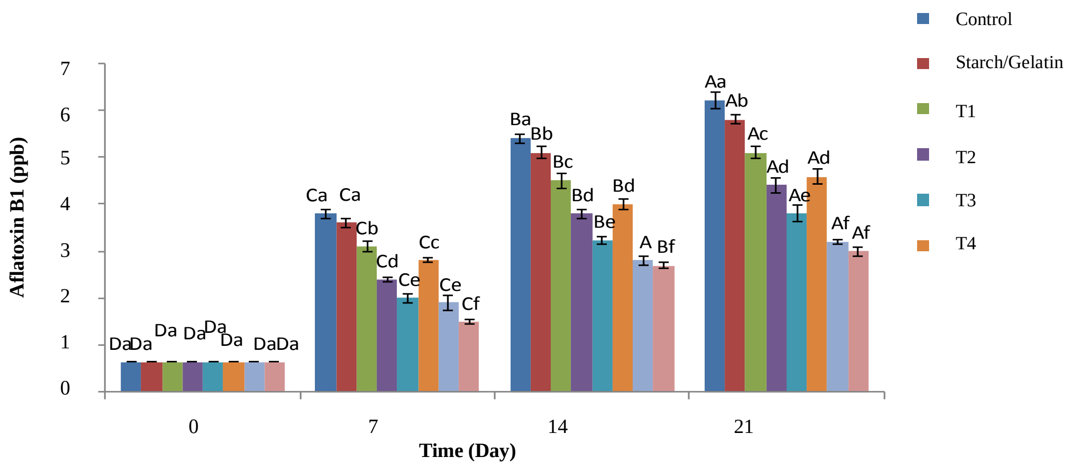



**Fig.4.** Aflatoxin B1 content of fresh pistachio Control: conventional packaging T1:1% $TiO_2$/1%FEO T2: 3% $TiO_2$/1%FEO T3: 5% $TiO_2$/1%FEO T4:1% $TiO_2$/1%FEO T5: 3% $TiO_2$/3%FEO T6: 5% $TiO_2$/3%FEO. Different small and capital letters indicate significant difference between means±SD of different levels and one specimen during storage time respectively.

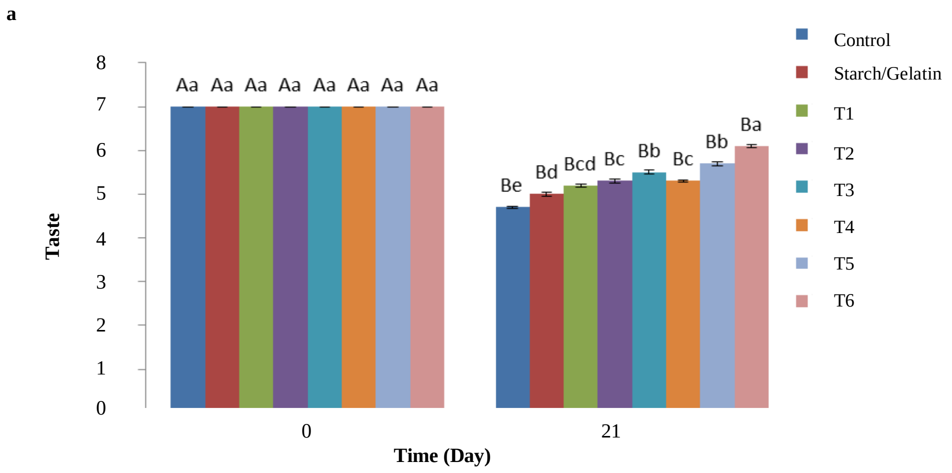
### *Sensory properties*

The average data of taste and general acceptability of different specimens of Abbas Ali pistachio are shown in Fig. 5.

On the 1st day, all specimens obtained perfect sensory scores, and there was no significant difference between the fresh samples. The changes in the sensory factors in samples packaged with $TiO_2$/FEO biodegradable films and in samples packaged with starch/gelatin films and conventional packaging were a decreasing trend until the end of conserve period.

Increasing the amounts of nanoadditive/essential oil in the packaging resulted in better maintenance of the sensory quality of fresh samples during storage time. In this study, the lowest changes in sensory factors between bionanocomposite films were observed.

According to the findings obtained taste and general acceptability score in fresh pistachio that has been packaged with starch/gelatin films containing 5% Nano-$TiO_2$/3% FEO were higher than the control sample and starch/gelatin.



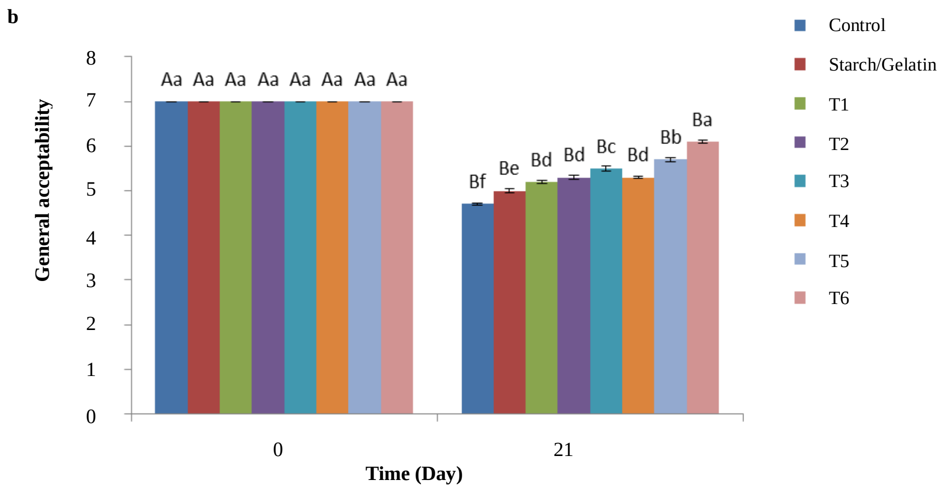




**Fig.5.** Taste(a) and general acceptability(b)of fresh pistachio Control: conventional packaging T1:1% $TiO_2$/1%FEO T2: 3% $TiO_2$/1%FEO T3: 5% $TiO_2$/1%FEO T4:1% $TiO_2$/1%FEO T5: 3% $TiO_2$/3%FEO T6: 5% $TiO_2$/3%FEO. Different small and capital letters indicate significant difference between means±SD of different levels and one specimen during storage time respectively.

## Discussion

Moisture content is one of the effective indexes in extended shelf life and improving quality of nuts(Farooq *et al*., 2021).

Bionanocomposite films act as a gas shield against oxygen and water vapor molecules to the nuts and decreasing of the oxidation reaction (Marvizadeh *et al*., 2014b, Marvizadeh *et al*., 2017). The bionanocomposite films, not only have the effect of moisture content in the pistachio, but also they have prevented weight loss (Barikloo and Ahmadi, 2018). Hydrophobic additives of Nano-$TiO_2$ and FEO acted as a strong barrier against water vapor molecules migration by increasing the barrier characterizations of the starch/gelatin films against moisture (Babapour *et al*., 2022). The increase in barrier properties after the incorporation of nanoadditive may be attributed to the effects of Nano-$TiO_2$ on tortuous pathways. Hence, this phenomenon is attributed to the addition of nanofillers in the tortuous pathway structure for moisture to pass through (Marvizadeh *et al*., 2017, Fallah *et al*., 2022). The decrease in water vapor molecules travel due to the incorporation of FEO is probably because of it's hydrophobic nature and can increase the barrier characterizations of films by increasing the portion of hydrophobic properties (Bof *et al*., 2021).

Based on Fig. 1. Starch/gelatin film containing 3%FEO/5%Nano-$TiO_2$ had higher moisture content (46.18%) than other samples and neat samples. The neat sample indicated the lower moisture content (43.79%), which is in agreement with the findings of Babapour *et al*. (2022). They reported that starch film containing 3%FEO/5%Nano-ZnO increases the moisture content of pistachio to 46.8%, compared to control specimens (45.3%). The impact of edible coating based on chitosan containing walnut leaf extract on the moisture content of pistachio has been demonstrated in another study (Jafari and Javadi, 2020). The authors reported that, the moisture content of the pistachio packaged (3% chitosan containing 3% walnut leaf extract) was enhanced from 3.12% to 4.99% by increasing of chitosan/walnut leaf extract concentration from 1.5% to 3%. These findings of moisture content were in consistent with another study of Maghsodlo (2011) that showed the moisture content of pistachio was enhanced significantly upon increasing chitosan concentration. Also, Nur Hanani *et al*. (2012) reported that the films based on 4% pork, beef, and fish gelatin were good barriers against water vapor.

The carbohydrate soluble of fresh pistachios maintaned due to the application of nanopackaging can be related to the decreasing of oxygen transmission of the biofilms. Due to the addition of nanoadditive, reducing the permeability of oxygen molecules into fresh pistachios, the respiration rate of the pistachio nano-packaged decreases, and the decomposition of nutrient compounds for example carbohydrates also decreases (Nasiri *et al*., 2022). In other words, nanofillers present in the biodegradable films decreased the respiration rate of nuts and maintain the carbohydrate soluble content of nuts by decreasing the transmission of water vapor and oxygen (Barikloo and Ahmadi, 2018).

Recently, The impact of film containing Nano-ZnO/essential oil based on starch on the carbohydrate soluble of pistachio has been represented in another study (Babapour *et al*., 2022). They reported that, the carbohydrate soluble of the pistachio packaged with potato starch containing 5% Nano-ZnO/2% FEO was enhanced from 6.8% to 8.4% by increasing of nanoadditive concentration from 1% to 5%. The use of aloveragel for fresh pistachio also has stated improvements in carbohydrate content (Ahmadi *et al*., 2014).

These findings were in accordance with another research which indicated that after coating with 1.5% alginate, the soluble sugar of the pistachio packaged represented the highest soluble sugar compared to the neat specimen (Shakerardekani *et al*., 2021). In another study on fresh pistachio packaged with 1.5% carboxymethyl cellulose and 0.4% Zataria mulrifolra essential oil, it was illustrated that carbohydrate soluble was the highest amount (7.8%) in comparison with the control sample during 32 days of storage (Hashemi *et al*., 2018).

Pistachio nuts can be attacked by molds, such as *Aspergillus flavus*, which produce different mycotoxins, particularly aflatoxin $B_1$. There are various indices, which can influence mold growth, for example, a relative humidity increase, moisture content of pistachio, and favorable temperature and presence of oxygen and water vapor in the packaging, The coating inhibits mold growth by reducing moisture and oxygen penetration (Boghori *et al*., 2020). The starch films containing FEO (Pirsa and Asdagh, 2019) and Nano-$TiO_2$ (Nassiri and Mohammadi, 2013) have strong barrier characterizations against gases molecules and reduce the rate of growth of mold by reducing water vapor and oxygen transmission. Also, both FEO (Long *et al*., 2022) and Nano-$TiO_2$ (Esfahani *et al*., 2020) have antimicrobial properties and prevent the increase of mold population and other microorganisms.

In the presented study, the *A. flavus* count of pistachio increased from 1.1 log CFU/g (first day) to 4.6 and 2.17 (last day) for the control sample and starch/gelatin containing 5% Nano-$TiO_2$/3%FEO a respectively (Fig. 3). The packaging with 5% nanoadditive/3% essential oil was the most effective in inhibiting *A. flavus* mold growth were considered a critical factor of pistachio sample. Total *A. flavus* count of pistachio was evaluated by Babapour *et al*. (2022). They represented that the *A. flavus* count ($15^{th}$ day) of samples range from 1.67 and 3.31 log CFU/g in starch/3% FEO/5% Nano-ZnO-coated specimens and neat group, respectively. Tavakolipour *et al*. (2020) stated the desired effect of packaging containing antibacterial activity with the incorporation of Shirazi thyme extract into whey protein concentrate-packaged. The packaged with Shirazi thyme extract decreased the *Aspergillus flavus* growth of pistachio kernels during storage. These findings were in good consistent with the study of Kazemi *et al*. (2020) who found the antifungal properties of cinnamon essential oil/Nano-ZnO against *A. flavus*. Ramedani and Farokhi (2015), studied the effect of different levels of Nano-clay embedded in CMC/PVA film on inhibition of mold growth on walnut kernels, and their research indicated that this film prevented mold growth and as the amounts of nanoadditives increased, their antifungal properties increased, too.

Based on Fig. 4. cassava starch/bovine gelatin film containing 3%FEO/5%Nano-$TiO_2$ had lower aflatoxin B1 (3ppb) than other samples and neat samples after 3 weeks of storage. The neat group indicated the higher aflatoxin B1 (6.2 ppb), which is in agreement with the findings of Babapour *et al*. (2022). They stated that potato starch film containing 3%FEO/5%Nano-ZnO decreases the aflatoxin B1 content of pistachio to 2.5 ppb, compared to control specimens (5.1 ppb). Moslehi *et al*. (2021) studied the amount of aflatoxin B1 of pistachio; according to the group, 2% methylcellulose indicated extremely low aflatoxin content (0.91 µg/kg).

According to Fig. 4. the amount of aflatoxin B1 of all samples increased during storage, and the increase in the neat group was highlighted. The aflatoxin content of pistachios was the highest on the last day of storage, as Tavakolipour *et al*. (2020). They stated that the amount of aflatoxin B1 of pistachio kernel sample is 5.6 ppb in active packaging containing Shirazi thyme extract, and the packaging with extract shows lower contamination compared with the neat specimens.

Sensory properties were performed according to 7-point hedonic scale using 10 panelists. The sensory properties of pistachio include an important index in studying packaged fresh pistachio and are affected by the photochemical and chemical reaction of bioactive compounds. Also, Nano $TiO_2$/FEO can affect the properties, for example, general acceptability and taste. The findings of the sensory properties indicated that the use of biofilms containing FEO/Nano $TiO_2$ by barrier properties against penetration of oxygen molecules into the fresh pistachio prevented oxidation reactions and improved taste of final product.

The neat specimens reached 4.9 on day 21. However, the average data of taste of starch/gelatin film containing 5%Nano/3% FEO was 5.9 during 21-day storage (Fig. 4a). Taste factor of sensory properties in pistachio decreased with increased storage time, as Kazemi *et al*. (2020). They represented that the factor mentioned (last day) of pistachio samples are 3 and 0.5 in active packaging containing cinnamon essential oil/Nano ZnO and neat samples, respectively, and the packaging with nanoadditive/essential oil shows higher sensory quality compared with the neat specimens. In another research, the sensory results indicated significant difference between control samples and pistachio packaged with potato starch/Nano ZnO/FEO(Babapour *et al*., 2022). Hashemi *et al*. (2021) observed the effect of alginate containing Shirazi thyme essential oil on the sensory properties of pistachio. The findings indicated a significant change in sensory factors of the pistachio with different levels of alginate film. Maghsoudlou *et al*. (2012) also stated the insignificant change in using chitosan on the sensory properties of fresh pistachios.

## Conclusions

In this study, fungal spoilage, sensory, and chemical properties of packaged pistachios were controlled during 3 weeks of storage. The findings indicated that the cassava starch/bovine gelatin/Nano-$TiO_2$/FEO had a favorable effect on fungal and aflatoxin B1 contamination. The experimental results show that the biofilm containing nanoadditive/essential oil maintained the chemical composition of fresh pistachio compared with starch/gelatin film and control samples. The findings in the presentation study prove that applying active film to raw pistachio can improve sensory factors, such as taste, and general acceptability.

Due to the lowest changes in soluble carbohydrate, moisture content, least fungal and aflatoxin B1 contamination, and the high score of sensory factors during 3 weeks of storage, were found in the active packaged fresh pistachio in the biofilm with 3% FEO/5% Nano $TiO_2$, therefore, this specimen was selected as best biopackaging.

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**Conflict of interests**

The authors declare that there is no conflict of interest.

**References**

Abdellaoui M, Bouhlali EDT, Derouch M, El-Rhaffari L (2020) Essential oil and chemical composition of wild and cultivated fennel (*Foeniculum vulgare* Mill.): A comparative study. South African Journal of Botany. 135, 93-100.

Ahmadi Z, Mirdehghan S, Hokmabadi H, Shamshiri M (2014) Nano packaging and edible coating used for improvement of shelf life and quality of individual fresh pistachio nuts. Journal of Horticultural Science. 27(4), 367-374.

Babapour H, Jalali H, Mohammadi Nafchi A (2021) The synergistic effects of zinc oxide nanoparticles and fennel essential oil on physicochemical, mechanical, and antibacterial properties of potato starch films. Food Science & Nutrition. 9, 3893-3905.

Babapour H, Jalali H, Mohammadi Nafchi, A, Jokar, M (2022) Effects of Active Packaging Based on Potato Starch/Nano Zinc Oxide/Fennel (Foeniculum vulgare Miller) Essential Oil on Fresh Pistachio during Cold Storage. Journal of Nuts. 13, 105-123.

Badgujar SB, Patel VV, Bandivdekar AH (2014) *Foeniculum vulgare* Mill: A Review of Its Botany, Phytochemistry, Pharmacology, Contemporary Application, and Toxicology. BioMed Research International. 842674.

Barikloo H, Aamadi E (2018) Shelf life extension of strawberry by temperatures conditioning, chitosan coating, modified atmosphere, and clay and silica nanocomposite packaging. Scientia Horticulturae. 240, 496-508.

Belabdelli F, Piras A, Bekhti N, Falconieri D, Belmokhtar Z, Merad Y (2020) Chemical Composition and Antifungal Activity of Foeniculum vulgare Mill. Chemistry Africa. 3, 323-328.

Bof MJ, Locaso DE, García MA (2021) Corn Starch-Chitosan Proportion Affects Biodegradable Film Performance for Food Packaging Purposes. Starch - Stärke. 73, 2000104.

Boghori P, LATIFI Z, Ebrahmi P, Mohamadi Kartalaei N, Dehghan L (2020) Effect of whey protein concentrate-Shiraz thyme (*Zataria multiflora*) essential oil coating on the shelf life of peanut. Journal of Advanced Pharmacy Education & Research. 10(4), 131-138

Esfahani A, Ehsani, MR, Mizani M, Mohammadi Nafchi A (2020) Application of Bio-Nanocomposite Films Based on Nano-$TiO_2$ and Cinnamon Essential Oil to Improve the Physiochemical, Sensory, and Microbial

Properties of Fresh Pistachio. Journal of Nuts. 11, 195-212.

Fallah N, Marvizadeh, MM, Jahangiri R, Zeinalzadeh A, Mohammadi Nafchi A (2022) High-Barrier and Light–protective Bionanocomposite Film Based on Rye Starch/nanorod-ZnO for Food Packaging Applications. Journal of Chemical Health Risks. (In press)

Farooq M, Azadfar E, Rusu A, Trif M, Poushi MK, Wang Y (2021) Improving the Shelf Life of Peeled Fresh Almond Kernels by Edible Coating with Mastic Gum. Coatings. 11, 618.

Habibie A, Yazdani N, Saba MK, Vahdati K (2019) Ascorbic acid incorporated with walnut green husk extract for preserving the postharvest quality of cold storage fresh walnut kernels. Scientia Horticulturae. 245, 193-199.

Hadadinejad M, Ghasemi K, Mohammadi AA (2018) Effect of storage temperature and packaging material on shelf life of thornless blackberry. International Journal of Horticultural Science and Technology. 5(2), 265-275.

Hashemi M, Dastjerdi AM, Shakerardekani A, Mirdehghan SH (2021) Effect of alginate coating enriched with Shirazi thyme essential oil on quality of the fresh pistachio (*Pistacia vera* L.). Journal of Food Science and Technology. 58, 34-43.

Hashemi M, Mirzaaaleian Dastjerdi A, Shakerardekani A, Mirdehghan SH (2018) Effect of carboxymethyl cellulose edible coating enriched with Zataria multifloraessential oil on the quality and shelf-life of fresh pistachio (*Pistacia vera* L.) fruit. Pistachio and Health Journal. 1, 6-12.

Holakouie Naieni K, Ghods B, Ghorbani R, Bagheri B, Abdolshahi A (2020) Aflatoxin Contamination of Pistachio and Aflatoxicose: Knowledge, Attitude, and Practices of People in Damghan City, Iran. Journal of Nuts. 11, 91-99.

ISIRI 2011. Human and Livestock Feeding-Measurement of group B and G aflatoxins by high-efficiency liquid chromatography and immune-affinity purification-test method No. 6872, First Review. [In Persian].

Jafari FJ, Javadi A (2020) The Effect of Chitosan Coating Incorporated with Walnut Leaf Extract on Shelf Life of Pistachio. Journal of Food Research. 30, 221-232.

Javanmard M, RamzanY (2009) Application of edible coatings incorporated Avishan-e Shirazi (*Zataria multiflora*) alcoholic extract for inhibition of Aspergillus flavus growth on the pistachio kernel. Journal of Medicinal Plants. 8, 61-167.

Kamiab F, Shahmoradzadeh Fahreji S, Zamani Bahramabadi E (2017) Antimicrobial and physiological effects of silver and silicon nanoparticles on vase life of Lisianthus (*Eustoma grandiflora* cv. Echo) flowers. International Journal of Horticultural Science and Technology. 4(1), 135-144.

Kan J, Liu J, Yong H, Liu Y, Qin Y, Liu J (2019) Development of active packaging based on chitosan-gelatin blend films functionalized with Chinese hawthorn (Crataegus pinnatifida) fruit extract. International Journal of Biological Macromolecules. 140, 384-392.

Kazemi MM, Hashemi-Moghaddam H, Mohammadi Nafchi A, Ajodnifar H (2020) Application of modified packaging and nano ZnO for extending the shelf life of fresh pistachio. Journal of Food Process Engineering, 43, e13548.

Khajeh-Ali S, Shahidi F, Sedaghat N (2022) Evaluation of the effect of carboxy methyl cellulose edible coating containing Astragalus honey (Astragalus gossypinus) on the shelf-life of pistachio kernel. Food Control. 139, 109094.

Khoshnoudi-Nia S, Sedaghat N (2019) Effect of active edible coating and temperature on quality properties of roasted pistachio nuts during storage. Journal of Food Processing and Preservation. 43, e14121.

Long H, Bi Y, Pu L, Xu W, Xue H, Fu G, Prusky D (2022) Preparation of chitosan/fennel seed essential oil/starch sodium octenyl succinate composite films for apple fruit preservation. Food Science and Technology (LWT). 167, 113826.

Maghsodlo A, Maghsodlo Y, Khamiri Y, Ghorbani M (2011) The effect of chitosan coating in preventing fungal activity and moisture absorption in kernel pistachio. The first national congress of new agricultural sciences and technologies. Zanjan, Iran.

Maghsoudlou A, Maghsoudlou Y, Khomeiri M, Ghorbani M (2012) Evaluation of anti-fungal activity of chitosan and its effect on the moisture absorption and organoleptic characteristics of pistachio nuts. Research and Innovation in Food Science and Technology. 1, 87-98.

Mahbobinejhad Z, Aminian H, Ebrahimi L, Vahdati K. (2019) Reduction of aflatoxin production by exposing *Aspergillus flavus* to $CO_2$. Journal of Crop Protection. 8(4), 441-448.

Mahdavi-Yekta M, Karimi-Dehkordi M, Hadian Z, Salehi A, Deylami S, Rezaei M, Mosavi Khaneghah A (2022) Silver nanoparticles and quinoa peptide enriched nanocomposite films for the detoxification of aflatoxins in pistachio. International Journal of Environmental Analytical Chemistry. 1-14.

Mallakpour S, Ramezanzade V (2020) Green fabrication of chitosan/tragacanth gum bionanocomposite films having $TiO_2$@Ag hybrid for bioactivity and antibacterial applications. International Journal of Biological Macromolecules. 162, 512-522.

Marvizadeh MM, Mohammadi Nafchi A Jokar M (2014a) Improved Physicochemical Properties of Tapioca Starch/ Bovine Gelatin Biodegradable Films with Zinc Oxide Nanorod. Journal of Chemical Health Risks. 4(4) 25 -31.

Marvizadeh MM, Mohammadi Nafch A, Jokar M (2014b) Preparation and Characterization of Novel Bionanocomposite Based on Tapioca Starch/Gelatin/Nanorod-rich ZnO: Towards Finding Antimicrobial Coating for Nuts. Journal of Nuts. 05, 39-47.

Marvizadeh MM, Mohammadi Nafchi AR, Jokar M (2016) Obtaining and Characterization of Bionanocomposite Film Based on Tapioca Starch/Bovine Gelatin/Nanorod Zinc Oxide. Food Structure Design. Akdeniz university, Turkey, 160.

Marvizadeh MM, Oladzadabbasabadi N, Mohammadi Nafchi A, Jokar M (2017) Preparation and characterization of bionanocomposite film based on tapioca starch/bovine gelatin/nanorod zinc oxide. International Journal of Biological Macromolecules. 99, 1-7.

Marvizadeh MM, Tajik A, Moosavian V, Oladzadabbasabadi N, Mohammadi Nafchi A (2021) Fabrication of Cassava Starch/Mentha piperita Essential Oil Biodegradable Film with Enhanced Antibacterial Properties. Journal of Chemical Health Risks. 11, 23-29.

Moosavian V, Marvizadeh MM, Mohammadi Nafchi A (2017) Biodegradable Films Based on Cassava Starch/Mentha piperita Essence: Fabrication, Characterization and Properties. Journal of Chemical Health Risks. 7, 239-245.

Moslehi Z, Mohammadi Nafchi A, Moslehi M, Jafarzadeh S (2021) Aflatoxin, microbial contamination, sensory attributes, and morphological analysis of pistachio nut coated with methylcellulose. Food Science & Nutrition. 9, 2576-2584.

Mosavi FP, Pour HH, Nasab AH, Rajabalipour AA, Barouni M (2015) Investigation Into Shelf Life of Fresh Dates and Pistachios in a

Package Modified With Nano-Silver. Global Journal of Health Science. 8, 134-44.

Nasiri SL, Azizi MH, Movahedi F, Rahimifard N, Tavakolipour H (2022) Potential perspectives of CMC-PET/ZnO bilayer nanocomposite films to improve the shelf life of mushroom (*Agaricus bisporus*). Journal of Food Measurement and Characterization. 16, 849-856.

Nassiri R, Mohammadi Nafchi A (2013) Antimicrobial and barrier properties of bovine gelatin films reinforced by nano $TiO_2$. Journal of Chemical Health Risks. 3(3) 21-28.

Nobari A, Marvizadeh MM, Sadeghi T, Rezaei-SavadKouhi N, Mohammadi Nafchi A (2022) Flavonoid and Anthocyanin Pigments Characterization of Pistachio Nut (Pistacia vera) as a Function of Cultivar. Journal of Nuts, Journal of Nuts. 13(4), 313-322. doi: 10.22034/jon.2022.1965310.1191

Nur Hanini ZA, Roos YH, Kerry J P (2012) Use of beef, pork and fish gelatin sources in the manufacture of films and assessment of their composition and mechanical properties. Food Hydrocolloids. 29, 144-151.

Nzima MD, Martin GC, Nishijima C (1997) Seasonal Changes in Total Nonstructural Carbohydrates within Branches and Roots of Naturally "Off" and "On"Kerman'Pistachio Trees. Journal of the American Society for Horticultural Science. 122, 856-862.

Ortega-Beltran A, Moral J, Picot A, Puckett RD, Cotty PJ, Michilides TJ (2019) Atoxigenic Aspergillus flavus Isolates Endemic to Almond, Fig, and Pistachio Orchards in California with Potential to Reduce Aflatoxin Contamination in these Crops. Plant Disease. 103, 905-912.

Pirsa S, Asdagh A (2019) Investigation the physical, antioxidant and mechanical properties of active pectin film containing Peppermint and Fennel essential oil. Iranian Journal of Biosystems Engineering. 50, 129-143.

Ramedani N, Farokhi Z (2015) Evaluation of moisture absorption and permeability to water vapor cellulose nanocomposites and its effect on moisture, mold and yeast packed with walnuts. Biological Forum Research Trend. 7(2), 94 -102

Shakerardekani A, Hashemi M, Shahedi M, Mirzaalian Dastjerdi A (2021) Enhancing the quality of fresh pistachio fruit using sodium alginate enriched with thyme essential oil. Journal of Agricultural Science and Technology. 23, 65-82.

Tavakolipour H, Kalbasi-Ashtari A,Mokhtarian M (2020) Effects of coating pistachio kernels with mixtures of whey protein and selected herbal plant extracts on growth inhibition of Aspergillus flavus and prevention of aflatoxin during storage. Journal of Food Safety. 40, e12711.

Vanaei M, Sedaghat N, Abbaspour H, Kaviani M, Azarbad HR (2014) Novel edible coating based on Aloe Vera Gel to Maintain pistachio Quality. International Journal of Scientific Engineering and Technology. 3, 1016-1019.