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Improving the Shelf Life of Red Grapes Using Polyethylene Nanocomposite Packaging and Modified Atmosphere Techniques

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Abstract

Red ruby grapes are known for their rich anthocyanin content and nutritional and medicinal properties, but their high perishability limits postharvest shelf life. Current research highlights the potential of advanced packaging techniques, such as modified atmosphere packaging (MAP), and nanotechnology to enhance the quality and shelf life of fresh products. This study aims to investigate the combined use of these technologies to maintain the quality and increase the shelf life of red ruby grapes. This study evaluated the effectiveness of polyethylene packaging films containing silver nanoparticles and titanium dioxide with modified atmosphere packaging (50% CO_2 + 5% O_2 + 45% N_2). The experiments were conducted under three temperature conditions (25°C, 15°C, and 4°C) and over a 28-day storage period. Samples were assessed at five intervals (0, 7, 14, 21, and 28 days) for quality attributes and microbial loads. This approach was chosen to address the challenges of microbial growth and quality deterioration in grapes stored at different temperatures. The findings showed a continuous decrease in anthocyanin content and color intensity during the storage period, alongside an increase in soluble solids. Microbial analysis showed higher mold and yeast counts in grapes stored at 25°C and 15°C compared to those stored at 4°C. Packaging with MAP and nanocomposite films containing silver nanoparticles and titanium dioxide effectively preserved the quality of grapes, particularly at 4°C, where superior results were observed over the 28 days. This study demonstrates the integration of MAP and films containing nanoparticles to address the limitations of conventional grape storage methods. This approach offers practical solutions for the horticultural industry and contributes to the advancement of storage and preservation technologies.

Keywords: Modified atmosphere packaging, Nanosilver, Nanotitanium dioxide, Polyethylene, Ruby grape

Introduction

Grapes are among the most essential horticultural products, valued for their taste, nutritional properties, and economic importance. However, their high moisture content and susceptibility to fungal infections make them highly perishable and difficult to preserve after harvest. This is primarily due to respiration, transpiration, and other biochemical activities (Ngcobo *et al*., 2012). Additionally, fungal pathogens such as *Botrytis cinerea* (gray mold) and *Rhizopus stolonifer* are significantly contribue to grape decay, causing severe losses in both pre-and postharvest conditions (Teles, Benedetti, Gubler, & Crisosto, 2014). Preserving grape quality during storage is critical to minimizing waste and maintaining market value (Shin, Hai, Nock,

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Holliday, & Watkins, 2007). Grapes hold a unique position among horticultural products due to their widespread consumption, economic value, and sensitivity to post-harvest spoilage. Compared to other fruits, grapes are particularly challenging to preserve because of their high moisture content and susceptibility to fungal infections, which significantly impact both quality and marketability. Addressing these challenges is critical, not only to reduce economic losses but also to ensure the availability of high-quality produce for consumers.

Historically, sulfur dioxide (SO_2) was widely used to preserve grapes (Ahmed *et al*., 2018; Franck, Latorre, Torres, & Zoffoli, 2005; Sortino *et al.*, 2017). However, its corrosive effects on metals, as well as adverse impacts on grape flavor and toxicity concerns, have limited its acceptability. Regulatory bodies, including the U.S. Food and Drug Administration, have restricted its use, prompting the development of safer, more sustainable alternatives. In recent years, innovative packaging solutions such as MAP and nanoparticle-based films have gained attention for their potential to extend the shelf life of perishable commodities like grapes (Artés-Hernández, Aguayo, & Artés, 2004; Candir *et al*., 2012; Deng *et al*., 2019; Kumar, Boro, Ray, Mukherjee, & Dutta, 2019).

Antimicrobial packaging is a type of active packaging designed to inhibit microbial growth by incorporating antimicrobial agents into packaging films and utilizing active polymers. These systems effectively minimize or eliminate microbial activity in food by creating an environment hostile to microorganisms. When the packaging system is impregnated with antimicrobial properties, it effectively retards microbial growth by lengthening the lag phase and reducing the growth rate or lifespan of microorganisms (Alizadeh-Sani, Rhim, Azizi-Lalabadi, Hemmati-Dinarvand, & Ehsani, 2020; Kumar *et al.*, 2019).

One promising approach to preventing microbial growth in food packaging is the incorporation of nanotechnology into polymer films. Silver nanoparticles (SNPs) are particularly effective due to their antibacterial and antifungal properties. When incorporated into packaging films, SNPs have been shown to reduce bacterial growth by up to 98% within the first 24 hours compared to conventional packaging films (Joshaghanizade, Shahriari, Hoseini Ghiasvand, & Salehifar, 2024). The antimicrobial activity of SNPs stems from the release of positively charged silver ions upon decomposition, with nanoparticles typically ranging in size from 10 to 20 nm (Darab, Shahriari, & Mozafari, 2021). Titanium dioxide (TiO_2) is one of the most commonly used photo catalysts, exhibiting photocatalytic properties when activated by ultraviolet radiation. These properties make TiO_2 valuable in environmental applications, such as removing pollutants from air and water (Gelover, Gómez, Reyes, & Leal, 2006). TiO_2 is effective against both Gram-positive and Gram-negative bacteria, as well as viruses. Its antimicrobial efficiency depends on factors like particle size, light intensity, and wavelength, and typically requires concentrations ranging from 100 to 1000 ppm (Hajkova, Spatenka, Horsky, Horska, & Kolouch, 2007; Villatte *et al.*, 2015). Silver nanoparticles have been shown to enhance the photocatalytic activity of TiO_2 under visible light. For instance, incorporating 1% silver by weight into TiO_2 can significantly reduce the time needed to eliminate *Escherichia coli* (10^7 CFU/ml) from 65 minutes to 16 minutes under ultraviolet light exposure (Sarkar, Jana, Samanta, & Mostafa, 2007). The combination of silver and TiO_2 demonstrates exceptional photocatalytic performance, attributed to their synergistic optical activity and visible light reactivity. TiO_2 nanoparticles are widely used in large-scale applications, particularly for packaging films. This is due to their light color and resistance to ultraviolet radiation penetration. Additionally, nano-sized compounds like SiO_2 and TiO_2 are extensively applied in food coatings, offering innovative solutions for improving food preservation (Thiyagu, Gokilakrishnan, Uvaraja, Maridurai, & Prakash, 2022).

In food packaging, other methods beyond films incorporating silver nanoparticles (SNPs) and titanium dioxide (TiO_2) are also utilized. One widely recognized approach is modified atmosphere packaging (MAP), which has been employed for many years to preserve perishable food products and fruits by extending shelf life and maintaining quality (Ehsani, Shahriari, & Famil, 2018). The core principle of MAP involves reducing the oxygen content within the packaging environment. By decreasing oxygen levels from approximately 20% to near zero, MAP helps to stabilize the packaging atmosphere, thereby slowing down the growth of aerobic microorganisms and mitigating oxidation reactions (Pasha *et al.*, 2023). This process significantly extends the shelf life of food products. Typically, the removed oxygen is replaced with inert nitrogen gas, sometimes supplemented with carbon dioxide to achieve the desired atmosphere (Sobhani, Zamindar, & Aarabi Najvani, 2022).

The present study addresses grape spoilage by integrating the advantages of nanotechnology-based packaging and MAP. This strategy aims to extend the shelf life of grapes through the application of nanocomposite polyethylene (PE) films infused with silver nanoparticles (SNPs) and titanium dioxide (TiO_2), while simultaneously maintaining controlled atmospheric conditions using MAP. The antimicrobial properties of SNPs, coupled with the photocatalytic activity of TiO_2, work synergistically to inhibit microbial growth and oxidative reactions, which are the primary causes of spoilage. The main objective of this study is to evaluate the efficacy of nanocomposite PE films containing SNPs and TiO_2 when used under MAP conditions, examining the impact of varying nanoparticle concentrations and storage at three distinct temperatures (25°C, 15°C, and 4°C) over five storage periods (0, 7, 14, 21, and 28 days).

Materials and Methods

Materials

Ruby grapes were sourced from the gardens of Qazvin City, Iran. The grapes were screened for color and ripeness, ensuring that any unripe or damaged specimens were excluded. For the evaluation, 100 grams of intact grapes, free from blemishes or physical defects, were carefully weighed using an electronic balance (FX-300i, Japan). The grape packaging was designed to evaluate the effect of two different types of nanocomposite packaging (silver and titanium dioxide) in comparison to conventional grape packaging, as detailed below.

Polyethylene Film Containing SNP/TiO_2

Low-density polyethylene (LDPE) granules (LH0075) were sourced from Fakour Nano Bespar Company, located in Shiraz, Iran. These granules possess a melt flow index of 2 g/10 min and a density of 0.921 g/cm^3. Titanium dioxide powder, boasting a purity of 99.5%, was acquired from Merck in Germany. According to the manufacturer (Merck), the titanium dioxide nanoparticles had a particle size of <100 nm as measured by BET and <50 nm as measured by XRD. Additionally, silver nanoparticles (SNPs) with purity of 99% and an average diameter of 35 nm were procured from Neutrino Company, China. The nanocomposite film was prepared by blending SNPs and titanium dioxide powder in ratios of 65:35 and 75:25, respectively. Before commencing the mixing process, all materials underwent 24 hours of humidification under vacuum conditions at 60°C. Subsequently, the three constituent materials were combined using the direct mixing method, with the final percentage of SNPs in 1 kg of nanocomposite determined within the mixer. Mixing was conducted at a rotor speed of 60 rpm and 170°C for 15 minutes. During this phase, the nanocomposite underwent mixing utilizing a twin-screw extruder (Cincinnati Milacron, Batavia, OH, USA), featuring a 55 mm extruder diameter and a screw length-to-diameter ratio of 30. The extruder operated at a spiral rotation speed of 100 rpm, with a thermal program incorporating four temperature zones set at 155°C, 160°C,

165°C, and 170°C, respectively. Nanocomposite films with a total nanoparticle loading of 2 wt% and thickness of 50 µm were prepared, with SNP and TiO_2 distributed as 1.30 wt% SNP + 0.70 wt% TiO_2 for the 65:35 formulation, and 1.50 wt% SNP + 0.50 wt% TiO_2 for the 75:25 formulation. The nanocomposite film was made according to the method reported by (Kubacka *et al.*, 2009; Zhang & Chen, 2009).

Scanning Electron Microscope (SEM) & Transmission Electron Microscope (TEM)

To investigate the effect of SNP on polyethylene films, surface analysis was performed using a Zeiss SEM (scanning electron microscope), model VP1430, Germany. The film samples, measuring 6x6 cm, were securely attached to the pins of the device using specialized techniques. A reflective layer consisting of gold was carefully deposited on the prepared samples using a Bal-Tec layering machine. In addition, to gain deeper insight into other relevant aspects, TEM (Transmission Electron Microscope) with an HMG400 model from Eindhoven, Netherlands was used. For TEM investigation, 6x6 cm film samples are coated with an ultra-thin carbon shield with a thickness between 20 and 40 nm. This shield is thin and electron transparent, ensuring accurate and insightful observations. The method employed is in line with previous reports as outlined in the cited articles (Youssef & Abdel-Aziz, 2013).

Fourier Transform Infrared Spectroscopy Analysis

Chemical structure recognition of the compounds and functional groups was carried out through Fourier Transform Infrared Spectroscopy (FTIR spectroscopy) under ambient conditions (Metak, Nabhani, & Connolly, 2015; Zielińska, Skwarek, Zaleska, Gazda, & Hupka, 2009). FT-IR spectra of the film were recorded within the wavelength range of 400-4500 cm^{-1}. The FTIR infrared spectroscopic analysis was conducted using an Avatar 320 device manufactured by Nicolet Company, USA.

Grape Packaging

Packaging films containing SNP and titanium dioxide with dimensions of 20x15 cm were used for grape packaging. The thickness of the film was 0.07 mm and each package contained 100±10 grams of grapes. A 2x3 cm sachet containing 20 grams of potassium permanganate as an ethylene absorbent and 20 grams of silica gel as moisture absorbent placedinside each package . The packages were thermally sealed using a MAP machine (A-200 PLC, Henkelman, Holland) with a gas pressure of 5.5 bar, and a gas mixture consisting of 50% carbon dioxide + 5% oxygen + 45% nitrogen at a speed of 28 $L.min^{-1}$. The control samples were placed in common polyethylene bags under normal atmospheric conditions, without vacuum or the addition of ethylene (potassium permanganate) or moisture (silica gel) absorbents. The packed grapes were stored for 28 days at three distinct temperatures: 4, 15, and 25 ^{o}C. A series of physical, chemical, and microbiological tests were performed on the grapes at regular intervals of 7 days, to assess their quality. Table shows the coded samples that were analyzed in this research.

Table 1- Specification of coded samples ratios of SNP to TiO_2

Sample code	Temperature (^{o}C)	(SNP + nanotitanium dioxide)
Conventional packaging or Control Samples (CO)		
COT4	4	-
COT15	15	-
COT25	25	-
Conventional Packaging with Silver Nanoparticles (SNP)		
C65T4	4	65:35
C65T15	15	65:35

C65T25	25	65:35
C75T4	4	75:25
C75T15	15	75:25
C75T25	25	75:25
Modified atmosphere packaging with SNP		
M65T4	4	65:35
M65T15	15	65:35
M65T25	25	65:35
M75T4	4	75:25
M75T15	15	75:25
M75T25	25	75:25

Headspace Gas Analysis

The O_2 and CO_2 percentages in the headspace were determined utilizing the Oxybaby gas analyzer model, manufactured by Wittgas in Germany. Approximately 8 mL of headspace gas was taken for analysis from the package (Antmann, Ares, Lema, & Lareo, 2008; Kargwal, Garg, Singh, Garg, & Kumar, 2020).

Microbial Analyses

Microbiological analyses, including standard plate counts and assessment of yeast and molds, were conducted following established protocols outlined in the American Public Health Association (APHA) guidelines of 1992 (Akhondzadeh Basti, 2006; Saxena, Bawa, & Srinivas Raju, 2008). Plate count agar (PCA) medium was employed to determine standard plate counts, while acidified potato dextrose agar (PDA) was utilized for yeast and mold counts. Colonies were then counted and expressed as log CFU/g of the sample. The inoculated PDA plates were incubated for 3 to 5 days at a 25°C, and the colony counts subsequently reported as Log CFU/g of the sample.

Color Measurement of Grapes

Grape color analysis was conducted using a Minolta Chromameter CR-400 (Minolta Co., Ltd., Osaka, Japan). The Hunter color scale was employed, and parameters including lightness (L) and chromaticity values for a (red-green) and b (yellow-blue) were recorded. The experiments were performed by placing the grape samples on a standard white plate to ensure consistent lighting. The samples were homogenized in a mixer grinder before color measurement (Candir *et al*., 2012).

Total Soluble Solids

Five grapes were handpicked from each cluster, pooled together, and finely ground to obtain a uniform sample. The concentration of total soluble solids (TSS) was assessed using a refractometer (REF108, China) at a consistent temperature of 27°C, with an accuracy of ±0.2%. The results were expressed as % Brix (Ayhan, Eştürk, & Taş, 2008).

Measurement of Anthocyanin Concentration

The quantification of anthocyanin concentration was conducted utilizing the differential pH method (Teng, Jiang, He, & Bai, 2020). In this method, initial grape samples were subjected to dewatering. Subsequently, 2 ml of grape juice was diluted to a final volume of 25 ml using a pH=1 buffer solution consisting of a 0.2 M potassium chloride and 0.2 M hydrochloric acid mixture. Simultaneously, another 2 ml of grape juice was similarly diluted to 25 ml but with a pH=4.5 buffer solution, composed of a mixture of 1 M sodium acetate and 1 M hydrochloric acid. The absorbance of the resultant solutions was measured at 510 nm employing a spectrophotometer (Model: (AA) PGLtd, Manufacturer: PG-Instruments, USA). The concentration of anthocyanin was subsequently determined using the following equation:

$$C = \frac{A \times MW \times DF \times 10^3}{\varepsilon \times L} \quad (1)$$

Where:

C = Anthocyanin concentration in mg/L ; $A = (Abs._{pH=1} - Abs._{pH=4.5})$

MW (molecular weight) = 484.82 g/mol for cyanidin-3-glucoside (CYD-3-Glu)

DF =1 (dilution factor); L = path length in cm; ε = 24825 molar extinction coefficient

Statistical Analyses

Data of physical and chemical parameters underwent an analysis of variance (ANOVA). To assess the significance of differences between treatments and storage time, a post-hoc analysis was conducted utilizing Duncan's test, and significance was determined at a threshold of $P<0.05$. All statistical analyses were performed using the SPSS software package, version 20, for Windows.

Results and Discussion

SEM & TEM

In Fig. 1, SEM images show two distinct nanocomposite samples obtained from polyethylene injected with SNP and TiO_2 in different ratios: 65:35 (left image) and 75:25 (right image). The films produced with a ratio of 75:25 of SNP to TiO_2 show homogeneous dispersion of SNP in the matrix.

Fig. 2 shows TEM images of polyethylene films containing different ratios of SNP to TiO_2 (65:35, left image; 75:25 right image). While differences are subtle, the film with a ratio of 75: 25 of SNP to TiO_2 has more uniform structure. Structures with a convex asymmetric state are observed, which is probably related to the time of polyethylene film formation.

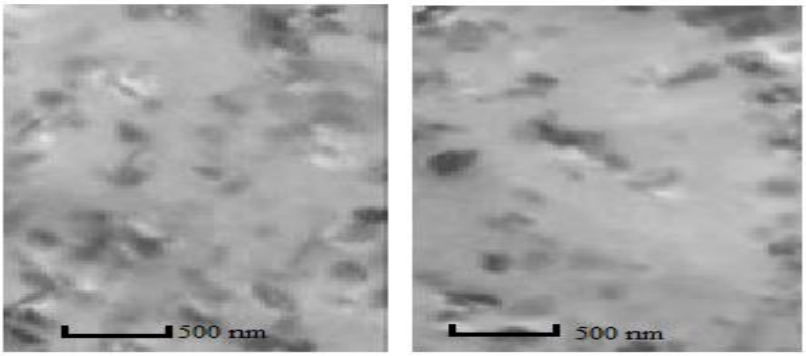


Fig. 1. SEM images of polyethylene films with different ratios of SNP to TiO_2, with the left image showing a 65:35 ratio and the right image showing a 75:25 ratio

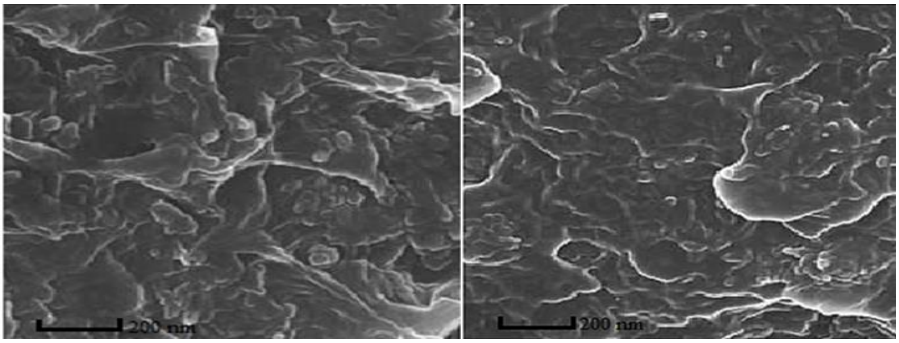


Fig. 2. TEM images of polyethylene films with different ratios of SNP to TiO_2, the left image showing a 65:35 ratio and the right image showing a 75:25 ratio

FTIR

Fig. 3 displays the FTIR spectra of polyethylene films with different SNP to TiO_2 ratios, specifically 65:35 and 75:25. In these spectra, distinctive absorption bands originating from the polyethylene film are evident, predominantly arising from the vibrations of carbon-carbon (C-C) and carbon-hydrogen (C-H) bonds. This spectral region, commonly termed the "CH stretching region," encompasses the vibrational modes of both C-C and C-H bonds. It is essential to underscore that the precise positions and intensities of the C-C and C-H bands can exhibit variations contingent on the unique properties and composition of the analyzed sample. Additionally, the presence of long-chain hydrocarbons within the prepared films is discernible in the spectrum. This observation is supported by the identification of peaks at frequencies of 1264, 1418, 1517, 1856, 2069, and 3373 cm^{-1}, primarily attributed to methylene deformation, carbon-hydrogen aromatic tension, carbon-carbon, and methylene displacement.

This observation suggests that there is no evidence of chemical bonding or substantial interaction between polyethylene and silver nanoparticles within the resulting structures. Instead, the silver nanoparticles are dispersed within the polyethylene matrix and on its surfaces, contributing to the antimicrobial properties of the polyethylene nanocomposite containing silver and titanium dioxide. Notably, rutile bands characteristic of titanium dioxide were not detected in the polyethylene film. This absence could be attributed to the high concentration of polyethylene, which may have masked the presence of other components at lower concentrations (León *et al.*, 2017). This phenomenon has been observed in other studies where the dominant polymer matrix conceals the characteristic peaks of embedded nanoparticles (Sarkar *et al.*, 2017).

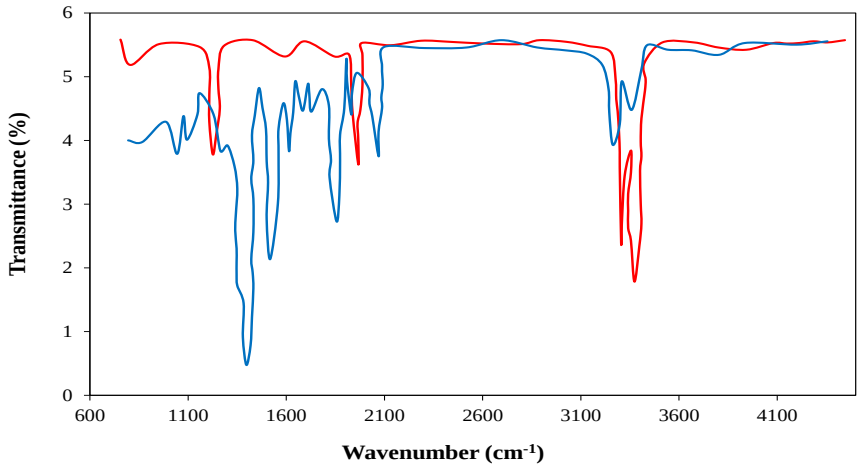


Fig. 3. FTIR spectra polyethylene films with different ratios of SNP to TiO_2; the red spectrum shows a 65:35 ratio and the blue spectrum shows a 75:25 ratio

Mold and Yeast Analysis

It should be noted that total mold and yeast counts provide a general indication of fungal activity and spoilage. Although grape spoilage is mainly caused by *Botrytis cinerea* and *Rhizopus stolonifer*, in this study only the overall mold and yeast counts were measured. The results of mold and yeast counts in various packaging samples can be found in Table 1. According to the findings, softening and moldy spoilage were observed in the control samples at 25°C after 7 days, and at 4°C and 15°C after 14 days. Consequently, mold and yeast counts were exclusively measured in the control sample at 25°C on first day, and at 4°C and 15°C only up to the seventh day of storage. As

the storage period extended, mold and yeast count in samples stored at 15°C and 25°C significantly increased ($P<0.05$). Consequently, mold and yeast counts were at their lowest on first day and reached their highest levels in all samples on the 28th day of storage ($P<0.05$). In contrast, at 4°C, mold and yeast counts decreased with prolonged storage, and on the seventh day, there was no significant difference compared to first day ($P>0.05$). At 4°C, the highest mold and yeast counts were observed on both first day and the seventh day, while the lowest counts were recorded in all samples on the 28th day of storage ($P<0.05$). Statistical analysis revealed no significant differences between samples in various packaging on first day ($P>0.05$). Mold and yeast counts were notably higher at 25°C compared to other samples during most storage periods, while at 4°C, they were significantly lower. An increase in the presence of SNP in packaging films corresponded to lower mold and yeast counts during most storage periods. The utilization of a modified atmosphere in packaging also led to decreased mold and yeast counts. By the end of the storage period, the C65T25 sample exhibited the highest mold and yeast counts (3.78 log CFU/g), while the M75T4 sample had the lowest counts (2.32 log CFU/g) ($P<0.05$). These findings are in agreement with those reported by Sobhani et al., where the application of nano-based packaging and modified atmosphere similarly resulted in lower microbial counts during storage (Sobhani *et al.*, 2022).

The findings suggest that integrating silver nanoparticles (SNPs) alongside titanium dioxide into packaging films yields positive outcomes in prolonging the storage time of grape samples. Proposed mechanisms associated with the antimicrobial properties of SNP and titanium dioxide in this context are primarily related to the release of silver ions at the film surface, which can interact with microbial cells and inhibit their growth (Efatian, Ahari, Shahbazzadeh, Nowruzi, & Yousefi, 2021). This effect is enhanced when combined with MAP, which reduces microbial proliferation through altering gas composition. Consistent with the findings of the present study, Danglu *et al.* (2020) demonstrated that polyethylene films incorporated with silver nanoparticles (SNPs) effectively reduced microbial growth and extended the shelf life of mushrooms during storage. Similarly, Mihaly Cozmuta *et al.* (2015) reported that coating wheat bread with SNPs significantly inhibited the growth of mold and yeast. A similar pattern of microbial behavior, akin to that observed for total mesophilic bacteria, was also noted in the case of molds and yeasts (Lok *et al.*, 2006).

On the other hand, the use of MAP also reduced the count of mold and yeast. The gases used in the modified atmosphere, such as carbon dioxide, have antimicrobial properties, and the mechanism is that they dissolve in the water in the food tissue and produce carbonic acid, which enters the cell membrane of the microorganism and enters the cell. It is then ionized and causes the death of microorganisms by disturbing the electrical balance inside the cell. Another reason is that samples packaged under a modified atmosphere show a lower level of mold and yeast compared to those in conventional packaging, mainly due to the antibacterial and antifungal effects of carbon dioxide. (Beigmohammadi *et al.*, 2016; He, Li, Fei, & Peng, 2021).

While the number of yeast and mold (log CFU/g) in different packaged samples such as C65T4 and M65T4, C65T15 and M65T15 at different storage time showed some variability, the combined use of nanomaterial-modified PE and MAP did exhibit an overall trend towards reduced microbial growth. Specifically, samples stored with MAP and higher SNP concentrations consistently showed lower counts of yeast and mold, indicating the efficacy of these packaging strategies in maintaining grape quality over time. These results underline the potential of SNP/TiO_2-modified films in enhancing food safety and extending shelf life.

Table 1- Changes in the number of yeast and mold (log CFU/g) in the different packaged samples at different storage times

Sample code	Storage day				
	0	7	14	21	28
COT4	3.12 ± 0.04^{Aa}	3.10 ± 0.02^{BCa}	-	-	-
COT15	3.11 ± 0.02^{Ab}	3.67 ± 0.02^{Aa}	-	-	-
COT25	3.15 ± 0.02^{Aa}	-	-	-	-
C65T25	3.15 ± 0.04^{Ad}	3.25 ± 0.02^{BCd}	3.34 ± 0.04^{Ac}	3.47 ± 0.07^{Ab}	3.78 ± 0.07^{Aa}
C75T25	3.12 ± 0.04^{Ac}	3.21 ± 0.01^{ABc}	3.27 ± 0.14^{ABc}	3.46 ± 0.02^{Ab}	3.63 ± 0.04^{ABa}
M65T25	3.16 ± 0.04^{Ac}	3.21 ± 0.01^{ABbc}	3.19 ± 0.06^{ABCb}	3.29 ± 0.05^{Bb}	3.54 ± 0.05^{BCa}
M75T25	3.13 ± 0.02^{Ac}	3.2 ± 0.01^{ABb}	3.17 ± 0.02^{BCb}	3.19 ± 0.08^{Bb}	3.45 ± 0.03^{BCa}
C65T15	3.13 ± 0.02^{Ac}	3.18 ± 0.03^{BCb}	3.21 ± 0.04^{ABCb}	3.25 ± 0.04^{Bb}	3.42 ± 0.08^{CDa}
C75T15	3.12 ± 0.02^{Ac}	3.18 ± 0.03^{BCb}	3.19 ± 0.04^{ABCb}	3.17 ± 0.01^{Bb}	3.24 ± 0.03^{DEa}
M65T15	3.11 ± 0.03^{Ac}	3.17 ± 0.04^{BCb}	3.18 ± 0.03^{ABCb}	3.2 ± 0.03^{Bb}	3.26 ± 0.03^{Ea}
M75T15	3.11 ± 0.02^{Ac}	3.17 ± 0.03^{BCb}	3.18 ± 0.03^{ABCb}	3.18 ± 0.06^{Bb}	3.21 ± 0.03^{Ea}
C65T4	3.15 ± 0.03^{Aa}	3.17 ± 0.03^{BCa}	3.11 ± 0.07^{BCb}	3 ± 0.13^{Cb}	2.73 ± 0.12^{Fc}
C75T4	3.15 ± 0.04^{Aa}	3.15 ± 0.04^{BCa}	2.94 ± 0.07^{DEbc}	2.86 ± 0.12^{Dc}	2.72 ± 0.18^{Fc}
M65T4	3.15 ± 0.04^{Aa}	3.14 ± 0.03^{BCa}	3.05 ± 0.1^{CDb}	2.68 ± 0.03^{Ec}	2.58 ± 0.02^{Gc}
M75T4	3.15 ± 0.04^{Aa}	3.12 ± 0.03^{BCa}	2.88 ± 0.09^{Eb}	2.51 ± 0.02^{Fc}	2.32 ± 0.07^{Hc}

Different uppercase letters in the same row and lowercase letters in the same column indicate significant differences ($p < 0.05$).

Anthocyanins Content

The red color of Ruby grapes is due to the presence of anthocyanins, a prominent group of pigments found in these delicious fruits. Among the multitude of phenolic compounds found in grapes, anthocyanins predominate, and cyanidin-3-O-glucoside appears as the most common among them. This particular compound plays an essential role in giving grapes strong antioxidant capabilities. Notably, anthocyanin pigments are very sensitive and prone to degradation, especially when exposed to storage conditions (Enaru, Drețcanu, Pop, Stănilă, & Diaconeasa, 2021). The results of anthocyanin levels under different temperature conditions in all packaging samples are presented in Fig. 4.

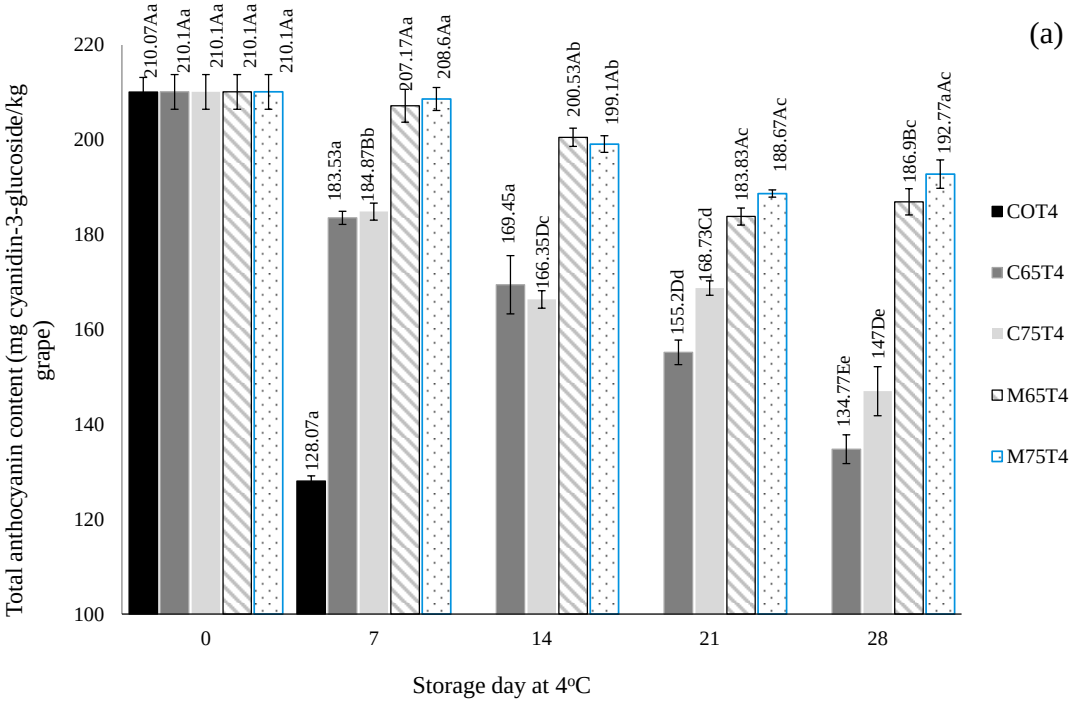
It is worth mentioning that the initial anthocyanin content in the red grapes investigated in this research was 210.07 mg of cyanidin 3-glucoside/kg of grape. However, it's crucial to recognize that the quantity of anthocyanin in grapes is influenced by a multitude of factors, including grape variety, soil composition, climate, geographical location, agricultural practices, latitude, growing season, storage conditions, and the use of growth regulators (Hernández-Jiménez, Gómez-Plaza, Martínez-Cutillas, & Kennedy, 2009; Lambri *et al.*, 2015; Theodorou *et al.*, 2019). Consequently, it can be asserted that the content of anthocyanin in red grapes is predominantly determined by the diversity in cultivars and species. In all samples, an evident decrease in anthocyanin content was observed as storage duration increased, regardless of the temperature namely, 4°C, 15°C, and 25°C. It should be noted that in the control sample stored at 25°C after 7 days and at 4 and 15°C after 14 days of storage, signs of softening and moldy spoilage were observed. Consequently, anthocyanin measurements were only conducted on the control sample at 25°C on the first day, and for control samples stored at 4°C and 15°C, assessments were limited to the first 7 days. As storage days progressed, a significant decline in anthocyanin levels was consistently observed across all packaging samples ($P<0.05$). The highest amount of anthocyanin was recorded on the first day, while a significant decline was observed throughout the storage period. The lowest amount of anthocyanin was detected in the control sample stored at 25°C on the 28th day of storage. Statistical analysis showed that the anthocyanin values on the first day did not exhibit significant differences ($P > 0.05$).

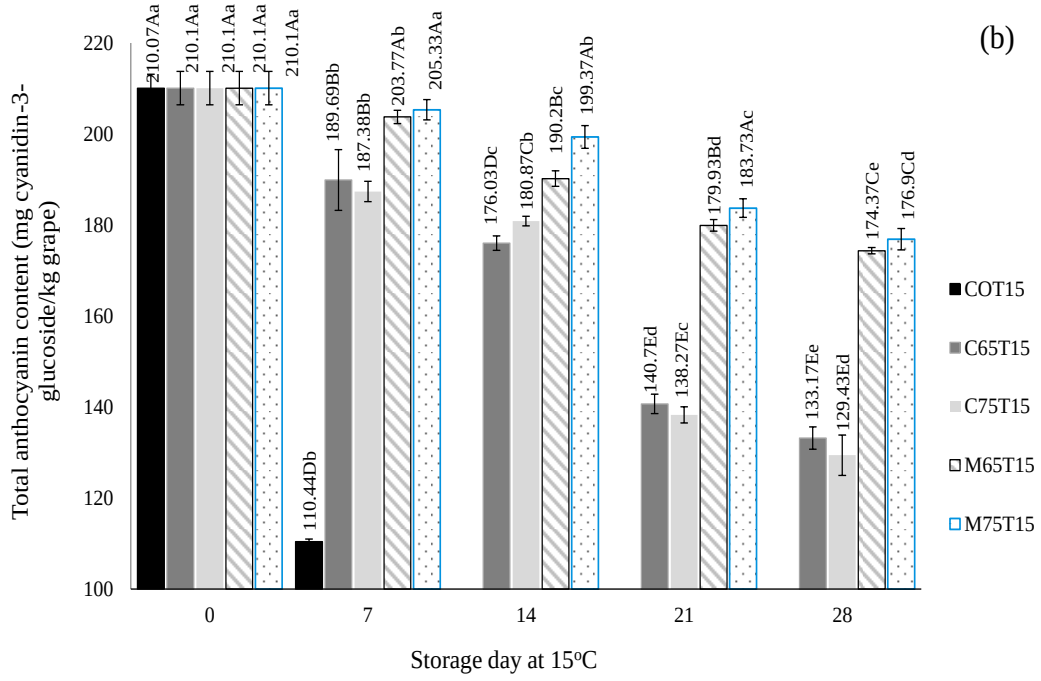
The observation of anthocyanin content at various temperatures during storage reveals intriguing patterns. Notably, at 25°C, anthocyanin content consistently remained lower than in the other packaging samples throughout most of the storage period. Conversely, at 4°C, anthocyanin content exhibited a noticeable increase. This trend aligns with published research, which has illuminated temperature as a pivotal influencer on anthocyanin accumulation in fruits, both pre-and post-harvest. Elevating the storage temperature is found to hinder the build-up of anthocyanin pigments in fruits. In simpler terms, temperature increments during the growth phase result in heightened respiration and carbohydrate consumption, subsequently leading to a decrease in the available sugar required for anthocyanin formation (Marszałek, Woźniak, Kruszewski, & Skąpska, 2017; Muche, Speers, & Rupasinghe, 2018).

In investigating the effect of packaging type on the preservation of anthocyanin content of grapes, it was observed that packaging films with higher SNP led to a relatively slower decrease in anthocyanin content during the storage period. The use of MAP also showed the ability to maintain the anthocyanin content in the samples. Ultimately, upon the conclusion of the storage period, the sample labeled as C65T25 exhibited the lowest anthocyanin content (111.14 mg of cyanidin 3-glucoside/ kg of grape) at 25°C, while the sample labeled as M75T4 displayed the highest anthocyanin content (192.77 mg of cyanidin 3-glucoside/kg of grape) at 4°C. It's worth mentioning that the initial anthocyanin content in the red grapes investigated in this research was 210.07 mg of cyanidin 3-glucoside/ kg of grape. This value exhibited an 8.2% reduction after 28 days of storage in the M75T4 packaging. Therefore, the results indicated that the use of 75% SNPs in the packaging film along with the use of MAP has a good ability to maintain the content of anthocyanin after 28 days at 4°C.

The use of SNPs in packaging film and the use of MAP have advantages over conventional packaging in maintaining grape anthocyanin content during storage for several reasons: a) SNPs integrated into the packaging film create a more effective barrier against the penetration of oxygen and moisture. This limits the exposure of the grapes to external factors that can lead to the degradation of anthocyanins. In conventional packaging, which may not have the same inhibitory properties, grapes are more vulnerable to environmental elements that can accelerate anthocyanin degradation (Rajakannu, Shankar, Perumal, Subramanian, & Dhakshinamoorthy, 2015). MAP allows for the regulation of internal gas composition, often by reducing oxygen levels. This controlled atmosphere can slow down the rate of grape respiration. Slower respiration means that fewer metabolic processes, including anthocyanin degradation, occur during storage. Standard packaging lacks this level of control, leading to higher respiration rates and faster anthocyanin loss (Enaru *et al.*, 2021). MAP, along with SNPs, can inhibit microorganism growth and delay enzymatic spoilage. Microorganisms and enzymes can help degrade anthocyanins. These packaging methods help preserve anthocyanins for longer by reducing their activity.

In summary, the use of SNPs in packaging films along with MAP provides a more controlled and protective environment for grapes during storage. This results in reduced respiration, reduced exposure to oxygen and moisture, and inhibition of degradation factors, all of which collectively help preserve the grape's anthocyanin content for longer than conventional packaging.


(a)
Total anthocyanin content (mg cyanidin-3-glucoside/kg grape)
220
200
180
160
140
120
100
210.07Aa
210.1Aa
210.1Aa
210.1Aa
210.1Aa
183.53a
184.87Bb
207.17Aa
208.6Aa
128.07a
169.45a
166.35Dc
200.53Ab
199.1Ab
155.2Dd
168.73Cd
183.83Ac
188.67Ac
134.77Ee
147De
186.9Bc
192.77aAc
0
7
14
21
28
Storage day at 4ºC
COT4
C65T4
C75T4
M65T4
M75T4


(b)
Total anthocyanin content (mg cyanidin-3-glucoside/kg grape)
220
200
180
160
140
120
100
210.07Aa
210.1Aa
210.1Aa
210.1Aa
210.1Aa
189.69Bb
187.38Bb
203.77Ab
205.33Aa
110.44Db
176.03Dc
180.87Cb
190.2Bc
199.37Ab
140.7Ed
138.27Ec
179.93Bd
183.73Ac
133.17Ee
129.43Ed
174.37Ce
176.9Cd
0
7
14
21
28
Storage day at 15ºC
COT15
C65T15
C75T15
M65T15
M75T15

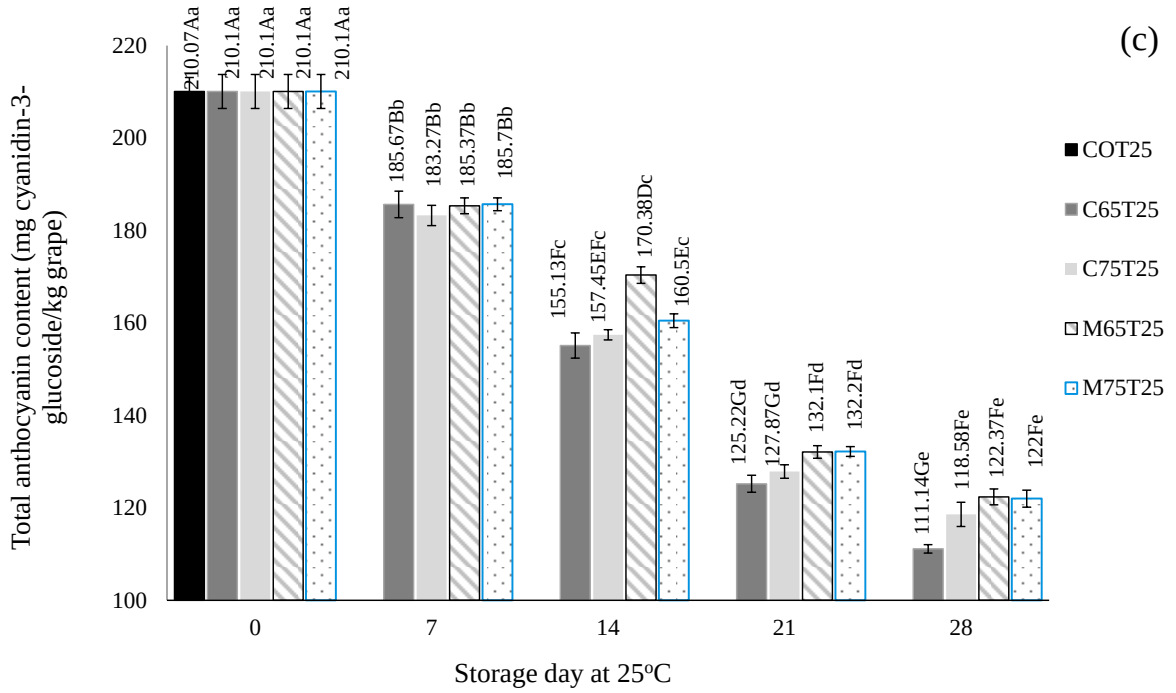


Fig. 4.The results of anthocyanin levels in different temperature conditions and different types of packaging (a) 4°C; (b) 15°C; (c) 25°C. Error bars represent the standard deviation

Total Soluble Solids

The results concerning the total soluble solids (TSS) content of grapes in various packaging types at three different temperatures (4°C, 15°C, and 25°C) are illustrated in Fig. 5. It's worth noting that in the control sample stored at 25°C for 7 days and at 4°C and 15°C for 14 days, evident signs of softening and moldy spoilage were observed, rendering the measurement of TSS content in these samples unfeasible. According to the experimental data in Fig. 5, with the increase in storage day, a significant increase in the content of TSS was observed in all samples in different packaging methods ($P<0.05$). The lowest soluble solids content was recorded on first day, while the highest content was observed on the 28th day of storage. Notably, statistical analysis revealed no significant differences among the samples on first day ($P>0.05$). The increasing trend of TSS in grapes during storage in this study was in good agreement with the report by Sobhani et al. during storage of cherry tomatoes (Sobhani *et al.*, 2022).

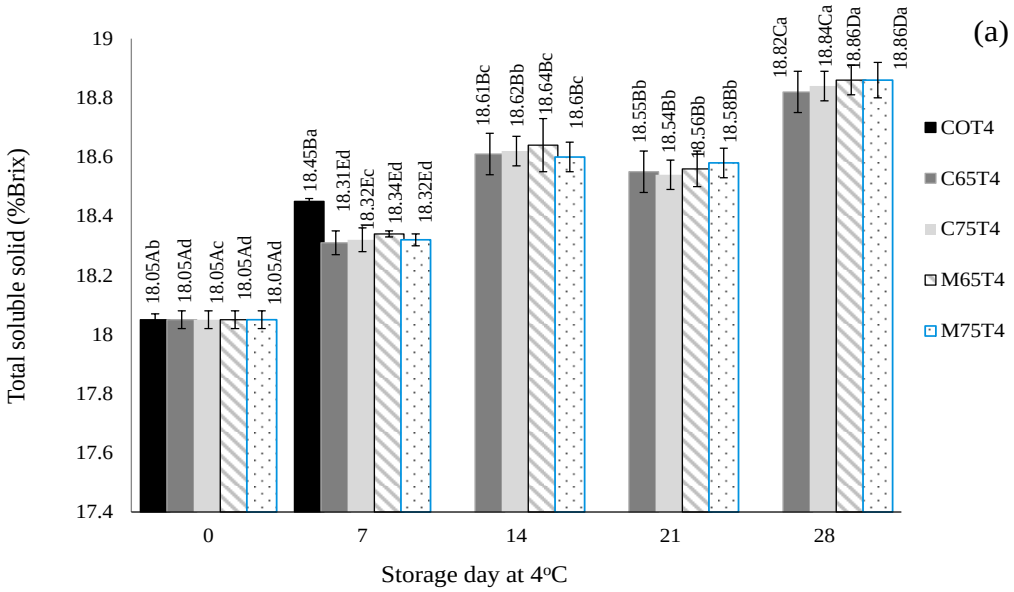
Due to the increase in soluble solid content in grape samples with increasing days of storage, the reason can be explained as follows. As grapes continue to ripen even after harvest, the sugar content in grapes can increase. This sugar accumulation is a natural part of fruit development and is driven by enzymatic processes. The longer the grapes are stored, the more time there is for these processes to continue, resulting in higher soluble solids content. During storage, some of the water in the grapes can evaporate or transpire, especially if the storage conditions are dry or the storage temperature is increased. This loss of water without a corresponding loss of solutes (sugars, acids, and other compounds) causes the remaining liquid to thicken and increase the soluble solids content (Hudina, Stampar, Orazem, Petkovsek, & Veberic, 2012; Khorram, Ramezanian, & Hosseini, 2017).

In this current research, the percentage of SNP during the days of storage did not show a significant effect on the content of soluble solids. However, the use of MAP effectively reduced the rate of change in soluble solids content. As a result, on the last day of storage, the lowest amount of soluble solids was recorded in samples M65T4 (18.37%) and

M75T4 (18.36%), and no significant difference was observed between them (P>0.05).

Finally, MAP was shown to be effective in stabilizing the soluble solids content during grape storage because it allows control of the storage environment, especially the gas composition surrounding the grapes. This respiration control helps maintain quality and prevent loss of soluble solids content. Here, we have interpreted how MAP achieves this as follows: One of our primary goals in choosing MAP was to reduce the oxygen content in the packaging. Therefore, by reducing the oxygen level and maintaining the reduced oxygen atmosphere, the rate of grape respiration can be reduced. On the other hand, by increasing the concentration of CO_2 and decreasing the concentration of oxygen, the respiration of grapes can be inhibited in packaging and the enzymatic processes that break down carbohydrates can be slowed down. This helps maintain the soluble solids content and increases the shelf life of the grapes. MAP can help maintain optimal humidity levels for grape storage. Moisture control is important because excessive moisture loss can lead to dehydration of grapes and increased soluble solids contents, while excessive moisture can promote mold growth and spoilage. MAP helps maintain the ideal balance and preserve the quality of the grapes (Pasha *et al.*, 2023).

Overall, as previous research has shown, MAP is an effective way to create an optimal storage environment for fruits, preventing loss of soluble solids by controlling gas composition, humidity, and exposure to factors that can destroy the fruit. This results in longer shelf life, better fruit quality, and reduced risk of economic loss for producers and distributors (Sabır, Selçuk, & Unal, 2020).



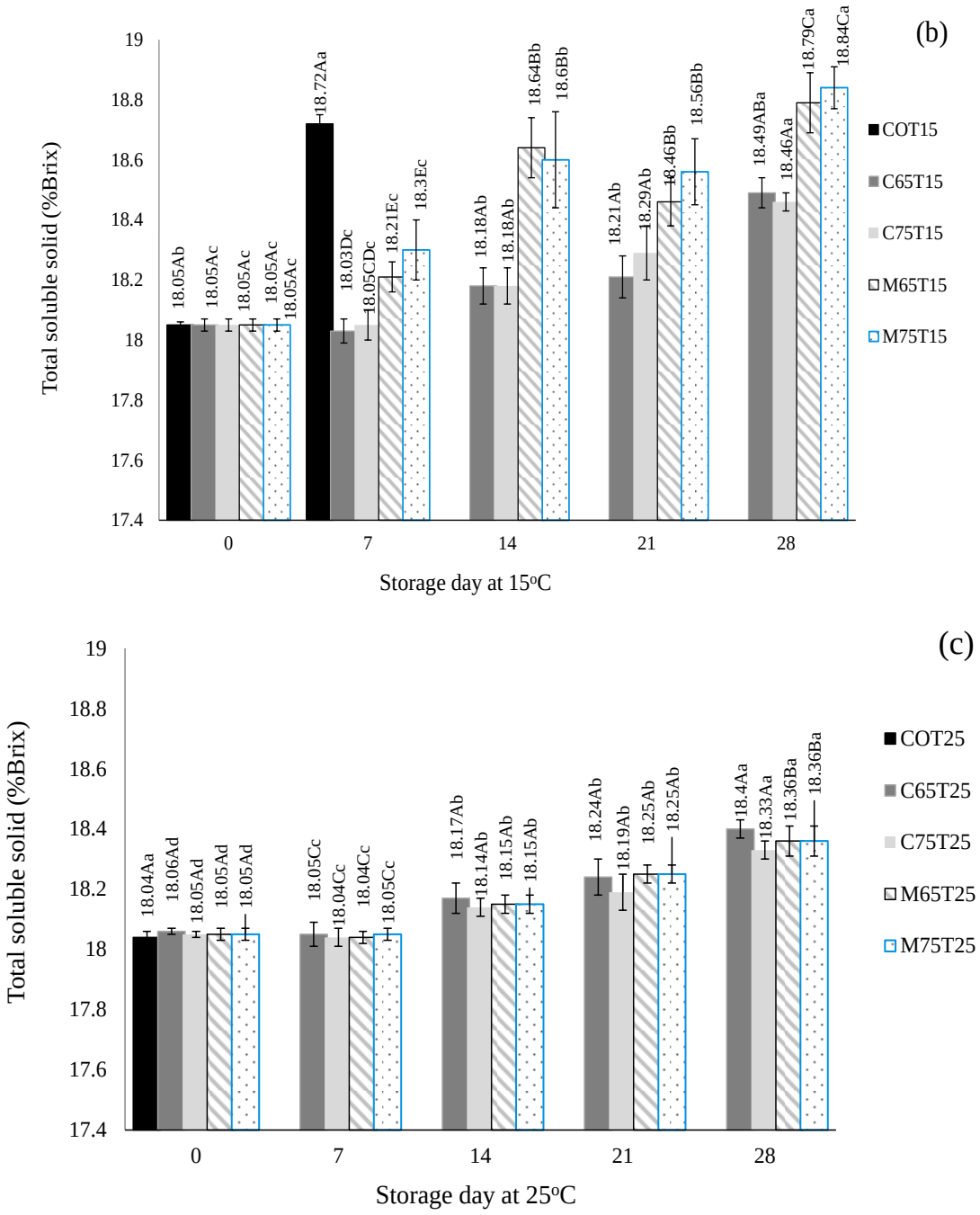


Fig. 5. The results of soluble solids content in different temperature conditions and different types of packaging (a) 4°C; (b) 15°C; (c) 25°C. Error bars represent the standard deviation

The Color Index of Grapes

The research findings, as outlined in Tables 3, 4, and 5, highlight a consistent decreasing trend in the L, a, and b indices over the storage period. In the control sample at 25°C, softening and moldy spoilage occurred after 7 days, while at 4°C and 15°C, these issues emerged after 14 days. Consequently, the color indices in the control sample at 25°C were only observed on the first day, whereas at 4°C and 15°C were observed on the seventh day. Notably, at 25°C, the L, a, and b indices consistently exhibited lower values than those of other samples throughout most storage period. Conversely, at 4°C, these indices were significantly higher than those at 15 and 25°C.

Examining the L index specifically (Table 2), a decline was observed during the storage period, attributed to the grape's chlorophyll content. Notably, neither the SNP concentration nor the type of packaging demonstrated a statistically significant effect on the L color index throughout the storage days ($p>0.05$). However, at 4°C, MAP exhibited a positive impact on the L color index. Coded samples M65T4 and M75T4 showed the highest L color index values at the end of the storage period, recording 37.81 and 37.84, respectively.

The results regarding the color index b, presented in Table 3**,** revealed a significant decrease in all treatments with an increase in storage days ($P<0.05$). The highest values belonged to the first day, while the lowest values were noted across all samples on the 28th day. At 25°C, the values of color index b were significantly lower than other samples during most storage times, whereas at 4°C, they were notably higher. In samples at 25°C, SNP concentration and packaging type had no significant effect on the color index b ($P>0.05$), but at 4 and 15°C, due to increasing SNP concentration and using MAP, leads to decreasing trend of index b. The M75T4 sample exhibited the highest values of color index b (1.92) at the end of the storage period ($P < 0.05$).

Similarly, results of the color index a in different samples (Table 4) showed a significant decrease with increasing storage days ($P<0.05$). The highest values were observed on the first day, while the lowest index occurred on the 28th day across all samples. No significant differences were found between samples on the first day ($P>0.05$). As the SNP concentration increased at different storage temperatures and times, the decrease in color index “a” became less pronounced. The use of MAP also reduced the variation of color index a. It is worth mentioning that the lowest value of color index was observed in the C65T25 sample (7.01) and the highest value was observed in the M75T4 sample (7.74) at the end of the storage time ($P<0.05$).

In the concluding remarks of this section, it became evident that a significant correlation exists between the color index values and the onset of grape browning. The accumulation of pigmented compounds, such as melanin, contributing to the browning of tissues, results in a diminished brightness of grape color. Anthocyanin, the principal pigment in grapes, appears to undergo degradative change during the storage period at various temperatures, showcasing a connection with alterations in color indicators (Muche *et al.*, 2018).

The quantity of anthocyanin compounds in grapes is intricately linked to its antioxidant activity. Notably, by the end of the storage period, there is a noticeable decrease in the concentration of anthocyanin compounds. This reduction is attributed to the oxidation reactions that transpire within the pigments during the storage period. The influence of enzymatic browning reactions on the color of grapes is noteworthy, contributing to a reduction in the transparency of grape samples (Pantelidis, Vasilakakis, Manganaris, & Diamantidis, 2007). Additionally, it is crucial to acknowledge the works referenced, which likely provide further insights into the broader context of the discussed phenomena (Moon, Kwon, Lee, & Kim, 2020).

Table 2- Rate of color index (L) in different packages of grapes

Sample code	Storage day				
	0	7	14	21	28
COT4	45.12 ± 0.04^{Aa}	34.91 ± 0.81^{Db}	-	-	-
COT15	45.14 ± 0.05^{Aa}	36.66 ± 0.86^{Eb}	-	-	-
COT25	45.13 ± 0.06^{Aa}	-	-	-	-
C65T25	45.12 ± 0.07^{Aa}	40.01 ± 0.11^{BCb}	37.60 ± 0.14^{Cc}	34.96 ± 0.01^{Ed}	33.21 ± 0.13^{De}
C75T25	45.11 ± 0.02^{Aa}	40.05 ± 0.09^{Cb}	37.58 ± 0.18^{Cc}	34.94 ± 0.08^{Ed}	33.27 ± 0.17^{De}
M65T25	45.11 ± 0.04^{Aa}	40.05 ± 0.09^{Cb}	37.63 ± 0.14^{Cc}	34.95 ± 0.09^{Ed}	33.25 ± 0.18^{De}
M75T25	45.12 ± 0.07^{Aa}	40.03 ± 0.12^{Cb}	37.55 ± 0.16^{Cc}	34.98 ± 0.11^{Ed}	33.21 ± 0.13^{De}

C65T15	45.12±0.07^{Aa}	42.18±0.18^{Bb}	39.56±0.26^{Bc}	36.79±0.17^{Cd}	35.32±0.17^{Cc}
C75T15	45.11±0.04^{Aa}	42.22±0.16^{Bb}	39.60±0.33^{Bc}	35.81±0.22^{Dd}	35.29±0.14^{Cc}
M65T15	45.12±0.03^{Aa}	42.19±0.15^{Bb}	39.53±0.53^{Bc}	36.74±0.34^{Cd}	35.25±0.14^{Cc}
M75T15	45.11±0.02^{Aa}	42.20±0.14^{Bb}	39.56±0.56^{Bc}	36.78±0.24^{Cd}	35.22±0.12^{Cc}
C65T4	45.11±0.05^{Aa}	44.84±0.29^{Aa}	42.14±0.14^{Bb}	39.17±0.19^{Bc}	36.79±0.26^{Bd}
C75T4	45.12±0.03^{Aa}	44.86±0.32^{Aa}	42.16±0.16^{Bb}	39.20±0.15^{Bc}	36.85±0.27^{Bd}
M65T4	45.12±0.03^{Aa}	44.90±0.33^{Aa}	43.18±0.18^{Ab}	40.20±0.15^{Ac}	37.81±0.23^{Ad}
M75T4	45.11±0.02^{Aa}	44.88±0.32^{Aa}	43.17±0.17^{Ab}	40.25±0.16^{Ac}	37.84±0.31^{Ad}

Different uppercase letters in the same row and lowercase letters in the same column indicate significant differences ($p < 0.05$).

Table 3- Rate of color index (b) in different packages of grapes

Sample code	Storage day				
	0	7	14	21	28
COT4	2.33±0.08^{Aa}	1.67±0.08^{Bb}	-	-	-
COT15	2.35±0.06^{Aa}	1.39±0.05^{Cb}	-	-	-
COT25	2.38±0.06^{Aa}	-	-	-	-
C65T25	2.37±0.02^{Aa}	2.18±0.08^{Ab}	1.83±0.10^{Bc}	1.63±0.15^{Bcd}	1.33±0.09^{Ee}
C75T25	2.37±0.02^{Aa}	2.20±0.06^{Aa}	1.85±0.25^{Bb}	1.66±0.17^{BCc}	1.34±0.11^{Ed}
M65T25	2.37±0.02^{Aa}	2.13±0.12^{Ab}	1.75±0.14^{Cc}	1.57±0.09^{BCd}	1.34±0.07^{Ee}
M75T25	2.37±0.02^{Aa}	2.11±0.08^{Ab}	1.72±0.16	1.58±0.15^{BCcd}	1.38±0.11^{ECcd}
C65T15	2.37±0.02^{Aa}	2.22±0.07^{Aa}	1.87±0.07^{Bb}	1.60±0.05^{BCc}	1.38±0.11^{Ed}
C75T15	2.37±0.02^{Aa}	2.11±0.08^{Ab}	1.86±0.06^{Bc}	1.54±0.05^{Cd}	1.43±0.07^{De}
M65T15	2.37±0.02^{Aa}	2.09±0.08^{Ab}	1.66±0.25^{Dc}	1.51±0.07^{Cc}	1.52±0.08^{CDd}
M75T15	2.37±0.02^{Aa}	2.25±0.08^{Ab}	2.18±0.13^{Abc}	1.99±0.12^{Ac}	1.81±0.05^{Bd}
C65T4	2.37±0.02^{Aa}	2.19±0.06^{Ab}	2.12±0.05^{Ab}	1.94±0.15^{Ac}	1.77±0.05^{Cd}
C75T4	2.37±0.02^{Aa}	2.16±0.10^{Aab}	2.09±0.20^{Ab}	1.75±0.08^{Bc}	1.86±0.05^{Bd}
M65T4	2.37±0.02^{Aa}	2.15±0.07^{Ab}	2.12±0.10^{Abc}	1.96±0.07^{Ac}	1.86±0.07^{Bd}
M75T4	2.37±0.02^{Aa}	2.11±0.08^{Ab}	2.02±0.07^{Ac}	1.95±0.07^{Acd}	1.92±0.07^{Ad}

Different uppercase letters in the same row and lowercase letters in the same column indicate significant differences ($p < 0.05$).

Table 4- Rate of the color index (a) in different packages of grapes

Sample code	Storage day				
	0	7	14	21	28
COT4	8.26±0.08^{Aa}	7.11±0.1^{Bb}	-	-	-
COT15	8.32±0.07 ^{Aa}	6.8±0.04^{Bb}	-	-	-
COT25	8.28±0.09 ^{Aa}	-	-	-	-
C65T25	8.31±0.09 ^{Aa}	8.19±0.12^{Aa}	7.64±0.07^{Db}	7.31±0.07^{Fc}	7.01±0.08^{Fd}
C75T25	8.31±0.09 ^{Aa}	8.17±0.17^{Aa}	7.66±0.09^{Db}	7.31±0.06^{Fc}	7.10±0.05^{Ed}
M65T25	8.31±0.09 ^{Aa}	8.08±0.05^{Ab}	7.80±0.05^{CDc}	7.49±0.04^{DEd}	7.13±0.02^{Ee}
M75T25	8.31±0.09 ^{Aa}	8.05±0.22^{Aa}	7.68±0.13^{Db}	7.39±0.06^{DEFc}	7.21±0.07^{Dc}
C65T15	8.31±0.09 ^{Aa}	8.21±0.10^{Aa}	7.76±0.06^{CDb}	7.46±0.07^{DEc}	7.28±0.09^{Dc}
C75T15	8.31±0.09 ^{Aa}	8.14±0.16^{Aa}	7.77±0.15^{CDb}	7.33±0.07^{EFc}	7.20±0.06^{Dc}
M65T15	8.31±0.09 ^{Aa}	8.18±0.06^{Aa}	7.91±0.10^{BCb}	7.60±0.05^{CDc}	7.47±0.06^{Cc}
M75T15	8.31±0.09 ^{Aa}	8.05±0.06^{Aa}	7.95±0.08^{Bb}	7.67±0.04^{BCc}	7.54±0.04^{Cc}
C65T4	8.31±0.09 ^{Aa}	8.06±0.25^{Aa}	7.65±0.09^{Cb}	7.40±0.07^{DEFc}	7.10±0.06^{Ed}
C75T4	8.31±0.09 ^{Aa}	8.02±0.14^{Ab}	7.67±0.06^{Cc}	7.30±0.09^{Fd}	7.16±0.05^{DEe}
M65T4	8.31±0.09 ^{Aa}	8.16±0.16^{Aa}	7.93±0.10^{Bb}	7.77±0.04^{ABc}	7.67±0.03^{Bd}
M75T4	8.31±0.09 ^{Aa}	8.20±0.06^{Aa}	8.01±0.06^{Ab}	7.88±0.03^{Ac}	7.74±0.05^{Ad}

Different uppercase letters in the same row and lowercase letters in the same column indicate significant differences ($p < 0.05$).

Conclusion

In this study, we aimed to evaluate the effect of MAP and silver/titanium dioxide

nanocomposite films (with ratios of 35:65 or 25:75) under different storage conditions (25°C, 15°C, and 4°C) and durations (0, 7, 14, 21, and 28 days) regarding the chemical and microbial characteristics of grapes. Our findings show that the use of nanocomposite films containing silver/titanium dioxide particles and MAP techniques during the storage of red ruby grapes led to significant improvements compared to the control samples.

A key result of this research emphasizes the effectiveness of using a MAP along with silver/titanium dioxide nanocomposite films (75:25 ratio) and keeping grapes at 4°C. This combination showed reduced mold formation and improved overall color retention. Overall, our research emphasizes the potential of modified atmosphere packaging and low-density polyethylene films with silver/titanium dioxide particles as effective antifungal measures for grape storage, thereby increasing food safety standards. In addition, their implementation promises significant benefits in terms of long-term durability and cost-effectiveness. This study was limited to a single grape variety and specific storage conditions, which may affect the generalizability of the results. Future research could explore the effects of these packaging strategies on different grape cultivars and other perishable fruits. Additionally, investigating the long-term environmental impact, potential migration of nanoparticles into fruits, and consumer safety aspects would provide valuable insights for practical applications. Further studies could also optimize nanocomposite formulations and MAP gas compositions to enhance storage efficiency and shelf life.

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Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest for the research, authorship, and/or publication of this article.

Author Contributions

Anahita Norouzi Tafreshi: conducted the experiments, collected and processed the data, and prepared a draft of the manuscript. **Shahla Shahriari:** supervised and designed the experiments, interpreted the data, contributed to the writing of the original draft, and revised the manuscript. **Toktam Mostaghim:** co-supervisor on this project; provided general guidance throughout the development of the work.

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مقاله پژوهشی

جلد ۲۱، شماره ٦، بهمن- اسفند ١٤٠٤، ص.

بهبود ماندگاری انگور قرمز با استفاده از بسته‌بندی نانوکامپوزیتی پلی‌اتیلن و فناوری اتمسفر اصلاح‌شده

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چکیده

انگورهای یاقوتی قرمز به‌دلیل محتوای غنی آنتوسیانین و خواص تغذیه‌ای و دارویی شناخته شده‌اند، اما فسادپذیری بسیار بالا آنها ماندگاری‌شان را محدود می‌کند. تحقیقات نشان می‌دهد تکنیک‌های پیشرفته بسته‌بندی، مانند بسته‌بندی با اتمسفر اصلاح‌شده (MAP) و فناوری نانو می‌تواند کیفیت و ماندگاری این محصولات تازه را افزایش دهند. هدف این مطالعه بررسی استفاده ترکیبی از این فناوری‌ها برای حفظ کیفیت و افزایش ماندگاری انگورهای یاقوتی است. این مطالعه اثربخشی فیلم‌های بسته‌بندی پلی‌اتیلن حاوی نانوذرات نقره و دی‌اکسید تیتانیوم را در ترکیب با بسته‌بندی با اتمسفر اصلاح‌شده ($50\% CO_2 + 5\% O_2 + 45\% N_2$) ارزیابی کرد. آزمایش‌ها تحت سه شرایط دمایی (۲۵ درجه سلسیوس، ۱۵ درجه سلسیوس و ۴ درجه سلسیوس) در یک دوره نگهداری ۲۸ روزه انجام شد. نمونه‌ها در پنج بازه زمانی (۰، ۷، ۱۴، ۲۱ و ۲۸ روز) از نظر ویژگی‌های کیفی و بار میکروبی ارزیابی شدند. این رویکرد به هدف بررسی رشد میکروبی و کاهش کیفیت در انگورهای نگهداری شده در دماهای مختلف انتخاب شد. یافته‌ها نشان‌دهنده کاهش مداوم محتوای آنتوسیانین و شدت رنگ در طول دوره نگهداری، در کنار افزایش مواد جامد محلول بود. بررسی رشد میکروبی، تعداد کپک و مخمر بیشتری را در انگورهای نگهداری شده در دمای ۲۵ و ۱۵ درجه سلسیوس در مقایسه با انگورهای نگهداری شده در دمای ۴ درجه سلسیوس نشان داد. بسته‌بندی با اتمسفر اصلاح‌شده و فیلم‌های نانوکامپوزیتی حاوی نانوذرات نقره و دی‌اکسید تیتانیوم به‌طور مؤثری کیفیت انگور را به‌ویژه در دمای ۴ درجه سلسیوس حفظ کرد، که در طول ۲۸ روز نتایج بهتری مشاهده شد. این مطالعه، پتانسیل استفاده هم زمان بسته‌بندی با اتمسفر اصلاح‌شده و فیلم‌های با نانوذرات را برای رفع محدودیت‌های روش‌های سنتی نگهداری انگور نشان می‌دهد. این دستاورد جدید، راه‌حل‌های عملی برای صنعت باغبانی ارائه می‌دهد و راه را برای بهبود فناوری‌های ذخیره‌سازی و نگهداری هموار می‌کند.

واژه‌های کلیدی: انگور یاقوتی، بسته‌بندی با اتمسفر اصلاح‌شده، پلی‌اتیلن، نانوذرات نقره، نانودی‌اکسید تیتانیوم

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