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LASER IRRADIATION AND POMEGRANATE PEEL FOR PRESERVATION OF THE STRAWBERRY QUALITY

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KEY WORDS:
laser, coating, fruit waste, chitosan, shelf life

ABSTRACT
The present study is aimed to explore the influence of laser irradiation and coating with chitosan and pomegranate peel extract on the physico-chemical properties, weight loss, firmness, functional, microbiological, color, and sensory characteristics of strawberry for fifteen days of cold storage. Four treatments of strawberry were conducted with laser irradiation for 6 min. The second, third, and fourth groups were coated with chitosan, pomegranate peel extract (PPE), and mixture of chitosan and PPE at ratio 1:1. Compared to untreated strawberries, the exposure to laser radiation decreased the weight loss of strawberries by 43.44%. Also, the laser irradiation reduced the negative effect of storage on the total phenolic content, anthocyanin, ascorbic acid, and antioxidant ability of strawberry. The exposure of strawberry to laser irradiation reduced the counts of fungi and psychrotrophic bacteria and provided the positive effect on the color and sensory attributes. The coating with PPE and chitosan enhanced the positive effect of laser irradiation on the functional and quality properties of strawberry during its cold storage. It can be concluded that laser irradiation and coating with PPE may be applied as novel techniques for the preservation of strawberry properties during its storage period.

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ЛАЗЕРНОЕ ОБЛУЧЕНИЕ И КОЖУРА ГРАНАТА ДЛЯ СОХРАНЕНИЯ КАЧЕСТВА КЛУБНИКИ

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КЛЮЧЕВЫЕ СЛОВА:
лазерное облучение, покрытие, фруктовые отходы, хитозан, срок годности

АННОТАЦИЯ
Настоящее исследование направлено на изучение влияния лазерного облучения и нанесение покрытия из хитозана и экстракта кожуры граната на физико-химические свойства, потерю веса, упругость, функциональные, микробиологические, цветовые и органолептические характеристики ягод клубники в течение пятнадцати дней хранения в холодном режиме. Было проведены четыре обработки клубники лазерным облучением в течение 6 минут. Вторая, третья и четвертая группы были покрыты хитозаном, экстрактом кожуры граната (ЭКГ), и смесью хитозана и ЭКГ в соотношении 1:1. По сравнению с необработанной клубникой воздействие лазерного облучения снизило потерю веса клубники на 43,44%. Кроме того, лазерное облучение снизило отрицательное влияние хранения на общее содержание фенолов, антоцианов, аскорбиновой кислоты и антиоксидантные свойства клубники. Воздействие лазерного облучения на клубнику снизило количество грибков и психротрофных бактерий, и продемонстрировало положительное влияние на цвет и органолептические свойства. Покрытие ЭКГ и хитозаном усилило положительное влияние лазерного облучения на функциональные и качественные свойства клубники при ее хранении в холодных условиях. Можно сделать вывод, что лазерное облучение и покрытие ЭКГ могут применяться как новые технологии для сохранения свойств клубники в период ее хранения.

1. Introduction

The quality characteristics of vegetables, fruits, and food products through stages of their processing starting from postharvest to their marketing can be influenced by various essential and extraneous factors related to the kind of food. One of the most crucial factors that affect the quality of food products is packaging where it protects and prevents food from rapid damage and guarantees a high-quality food product for human consumption. Due to harmful impacts of synthetic packaging materials on the environment and food quality, and the increased health awareness of the consumers, the strive for edible, biodegradable, eco-friendly, and active packaging materials is growing [1,2].

Numerous types of biodegradable and eco-friendly materials including those based on proteins, polysaccharides, and lipids are applied for the development of edible food coating or films. One of these materials is chitosan which is acknowledged as a natural acidic soluble and nontoxic biopolymer. It is derived from chitin by deacetylation reaction, and it is utilized extensively in the pharmaceutical and food industries because of its convenient physic-chemical and functional properties. Using chitosan in preparation of edible coatings improves cohesiveness and adhesiveness, and provides a smooth surface for food products [3]. Fruits or vegetables byproducts are one of the most crucial of food wastes that present most considerable challenges which share contributes to about 50% of total food waste [4]. These byproducts comprise leaves, seeds, pulp, peels, stems, and bran which are discarded during various processing treatments of the final food products. These byproducts provide negative effects on the social and economic sectors and cause environmental pollution. Hence, the significance of finding an alternative use for these byproducts is very important [5]. Pomegranate peel is considered to be the main pomegranate waste as it represents about 48–50% waste material of the total pomegranate fruit. Several studies affirmed that pomegranate peel has greater biofunctions including antimicrobial and antioxidant activity compared to other parts of the pomegranate.

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These biofunctions may be attributed to their content of phenolic components, and tannins [6,7].

The disadvantages of traditional methods for protection of food safety and quality characteristics including destruction of bioactive molecules encourage the researchers to develop the modern techniques characterized by eco-friendly, easier to operate, non-noxious, economically efficient, more sustainable, accurate and faster [8]. Among the modern non-destructive methods, using laser irradiation is an effective, promising, and contactless method that features different positive properties compared to traditional methods [9]. Laser is described as a nonionizing radiation, consistent and monochromatic light. Laser irradiation motivates the bio-stimulation process in various microorganisms through its adsorption by their photoreceptors, inhibiting their growth [10]. The bio-stimulation impact of laser irradiation relies on time of exposure, wavelength, and intensity [11]. However, few studies have examined the positive impacts of laser irradiation on the fruit quality properties as a surface disinfection technique to extend shelf life.

Strawberry fruit is a type of berries that belongs to genus *Fragaria* in the *Rosaceae* family. It is a rich source of various nutritive and bioactive components including minerals, vitamins, and minor compounds such as folate, fatty acids, and dietary fibers. Proanthocyanidins, anthocyanins, flavanols, and ellagitannins are the main phenolic components in strawberry [12,13]. Regarding health effects, strawberry fruit has a valid preventative role against various diseases such as diabetes, cardiovascular, and cancer [14]. During storage, the elevated respiration rate and metabolic capacity stimulate a decline of the phenolic components; thus resulting in browning. Also, because of physiological impairment, mechanical damage, moisture loss, and fungal growth, comparatively high postharvest waste has occurred [15]. Therefore, this study was designed to investigate the effect of laser irradiation and coating with chitosan and pomegranate peel extract on the functional and quality properties of strawberry during its cold storage.

2. Materials and methods

Fresh strawberry samples were purchased from a local market in Egypt. Strawberries were selected regular in size, and free from fungal decay or mechanical damages. In the laboratory, strawberry samples were washed with tap water without any damage.

2.1. Chitosan and pomegranate peel extract (PPE) coating

Chitosan solution was prepared by mixing chitosan (0.5% w/v), ascorbic acid (1%), and water by stirring at 25 °C for 90 min until the chitosan powder was perfectly dissolved. The pomegranate peels were dehydrated at 40 °C, and then the dehydrated peels were milled to powder with particles able to pass through a 50-mesh sieve. About 200 g of pomegranate peel powder was extracted by ethanol 80% at a ratio of 1:20 (w/v) using a homogenizer for 30 min. The extract was filtered through a filter paper (Whatman No. 1). A rotary evaporator was used to concentrate the filtrate at 40 °C, and the concentrate was lyophilized and stored at 4 °C before coating application.

2.2. Laser irradiation treatment

Strawberry samples were divided into five groups, and the first group served as control group. The other four groups were treated by a helium-neon (HE-Ne) laser (Model of 05- LHP 151, Input current 220AC of Amp, manufactured in USA) at 632.8 nm for 6 min in a dark chamber. The distance between strawberry fruits and laser source accounted for 20 cm, and the light intensity downfall on strawberries surface was 1.3 W/cm^2. The third group was dipped into the coating solution of chitosan, while the fourth group was dipped into the coating solution of pomegranate peel extract 2%. The fifth group was dipped into the coating solution of mixture of chitosan and pomegranate peel extract at ratio 1:1. The dipping process was performed for 2 min and the excess of the immersion solutions was drained off for 5 min. After that, the strawberries were placed into polypropylene packages and thermally sealed by a stretch film before putting to storage at 4–6 °C and 80% RH. Strawberry treatments were analyzed at the first day of laser irradiation and coating, after 5, 10, and 15 days.

2.3. Physico-chemical properties

The strawberry fruits were grinded in a mixer and total soluble solids (TSS) of juice extracts were measured using a digital refractometer PR101 Palette, (Atago, Japan). Ten milliliters of juice were titrated with 0.1N NaOH in the presence of phenolphthalein as an indicator, and the titratable acidity (%) was determined as the percentage of citric acid.

2.4. Weight loss

The weight loss of strawberries was estimated as percentage of weight decrease according to Hammad et al. [16].

2.5. Firmness

The firmness of strawberry samples was determined by rate of force (Force Gauge Model M4–200, Electromatic Equipment Co., Inc., USA). The firmness was expressed in Newton (N) according to Zambrano-Zaragoza et al. [17].

2.6. Functional attributes

Antioxidant, total phenolic, total anthocyanins, and ascorbic acid values of strawberry samples were determined according to Elsayed et al. [18], AOAC [19], Tonutare et al. [20], respectively.

2.7. Microbiological examination

The counts of total molds and yeasts and psychrotrophic bacteria were enumerated using potato dextrose agar (PDA) and nutrient agar, respectively, by counting colony forming unit (Log CFU/g) after plating serial dilutions according to APHA [21].

2.8. Color analysis

The color of strawberries was determined by a chromameter Minolta CR-400 (Minolta. Inc., Tokyo, Japan) utilizing the CIE color properties L* (Lightness), +a* (Redness), chroma (C*), and hue angle as described by Pilon et al. [22].

2.9. Sensory evaluation

Ten panelists from the staff members of the Food science department, Faculty of Agriculture, Cairo University volunteered. A quality rating scorecard was used for the evaluation of treated strawberry for taste, odor, texture, and overall acceptability. Based on their preference and liking, panelists were required to classify the samples on a ten-point hedonic scale; 1 = unacceptable, and 10 = very much like.

2.10. Statistical analysis

All parameters were analyzed in three replications for each parameter. Results were expressed as the mean ± standard deviation (SD). Statistical analysis was performed using XLSTAT software (USA). Significant differences ($p < 0.05$) between means were determined by Tukey's test.

3. Results and discussion

3.1. Physico-chemical properties

At harvest, total soluble solids (TSS) ranged from 11.80 ± 0.75 to 12.50 ± 0.70 without significant variation, while acidity was approximately 0.65% (Table 1). After 15 days of cold storage, TSS values significantly decreased in control sample, while it significantly increased in treated group 2 (strawberry treated with laser irradiation for 6 min), 3 (strawberry treated with laser irradiation for 6 min and coated with chitosan), 4 (strawberry treated with laser irradiation and coated with pomegranate peel extract (PPE), and 5 (strawberry treated with laser irradiation

Table 1. **Total soluble solids (TSS) and acidity (%) of strawberry treated with laser irradiation and coated with chitosan and pomegranate peel extract**

Таблица 1. **Общее содержание растворимых сухих веществ (TSS) и кислотность (%) клубники, обработанной лазерным излучением и покрытой хитозаном и экстрактом кожуры граната**

Treatments	TSS (Means ± SD)			
	Storage period (Day)			
	0	5	10	15
Treatment 1	12.5 ± 0.70^{cde}	8.50 ± 0.40^{h}	9.20 ± 0.32^{gh}	10.1 ± 0.28^{fg}
Treatment 2	11.8 ± 0.75^{de}	9.60 ± 1.31^{gh}	13.3 ± 0.50^{bc}	15.0 ± 0.90^{a}
Treatment 3	12.4 ± 0.64^{cde}	9.90 ± 0.70^{fg}	11.2 ± 0.33^{ef}	14.0 ± 0.80^{ab}
Treatment 4	12.3 ± 0.65^{cde}	11.5 ± 0.51^{e}	11.7 ± 0.57^{de}	13.2 ± 0.62^{bc}
Treatment 5	12.1 ± 0.50^{cde}	11.9 ± 0.95^{de}	12.8 ± 0.966^{bcd}	12.1 ± 0.22^{cde}
Treatments	Acidity (Means ± SD)			
	Storage period (Day)			
	0	5	10	15
Treatment 1	0.62 ± 0.03^{e}	0.95 ± 0.03^{de}	1.74 ± 0.05^{c}	3.25 ± 0.56^{a}
Treatment 2	0.65 ± 0.01^{e}	0.86 ± 0.04^{de}	0.92 ± 0.05^{de}	2.17 ± 0.20^{b}
Treatment 3	0.66 ± 0.02^{e}	0.83 ± 0.02^{de}	0.90 ± 0.01^{de}	1.10 ± 0.1^{d}
Treatment 4	0.65 ± 0.01^{e}	0.71 ± 0.01^{de}	0.80 ± 0.01^{de}	0.87 ± 0.02^{de}
Treatment 5	0.64 ± 0.005^{e}	0.68 ± 0.005^{de}	0.72 ± 0.005^{de}	0.77 ± 0.02^{de}

Means with different superscript letters differ significantly.

Treatment 1: untreated strawberry; treatment 2: strawberry irradiated with laser; treatment 3: strawberry irradiated with laser and coated with chitosan; treatment 4: strawberry irradiated with laser and coated with pomegranate peel extract, and treatment 5: strawberry irradiated with laser and coated with chitosan + pomegranate peel extract.

and coated with chitosan and PPE). These results are in agreement with Tanada-Palmu et al. [23]. who reported that the increase of TSS may be due to loss of excessive water from strawberries. Also, Hernández-Muñoz et al. [24] attributed the increase in TSS to the solubilization of the cell wall polyuronides and hemicelluloses in ripe strawberry. Regarding titratable acidity (TA) of strawberry, there was a significant increase in all treatments except treatments 3 and 4 where TA values were not affected by storage period. The increase in TA value may be attributed to the loss of water content where TA is estimated as a proportion of citric acid of fresh strawberry. Our results are in agreement with those of Ali et al. [25].

3.2. Weight loss and firmness

As shown in Figure 1, uncoated strawberry (control treatment) had the highest weight loss of 77.67% after 15 days of storage. The strawberry samples exposed to laser irradiation for 6 min then coated with chitosan and PPE reliably exhibited the lowest weight loss value (14.85%). The laser irradiation for 6 min and coating with pomegranate peel extract was more effective in preventing weight loss and significant decreasing weight loss by 27.56% compared to that of strawberry coated with chitosan. As expected, the firmness of strawberry samples had the opposite trend. During storage period, the firmness of all treated samples was significantly higher than the control samples (Figure 1). At the end of storage period, the strawberry samples of control treatment lost around 67.53% of their firmness compared to 19.68% for strawberry exposed to laser irradiation for 6 min then coated with chitosan and PPE. Meanwhile, the loss of firmness in strawberry samples treated by laser irradiation then coated with PPE was the lowest, followed by the loss of firmness in strawberry samples treated by laser irradiation then coated with chitosan which recorded 33.31 and 41.55%, respectively. Ali et al. [25] found that treated strawberry samples with 6 min of laser irradiation showed a significant reduction in weight loss compared to untreated strawberries. Also, they observed that the treated samples of strawberries with laser irradiation preserved firmness until the fifth day of storage period, whilst control group strawberries became softer and fully ripe. Saeed et al. [26] found the similar results through coating of tomatoes with pomegranate peel extract and chitosan, in which study they observed that the coated samples featured lower weight loss and higher firmness than uncoated samples. Our results may be attributed that the coating reduced the moisture loss and respiration process. Kumar et al. [2] revealed that the combination of higher concentration of pomegranate peel extract in chitosan film retains significant amount of moisture, and that may be attributed to molecular interactions and modifications in the hygroscopic characteristic of the chitosan compound.

3.3. Functional properties

In this study the effect of laser irradiation and coating with chitosan or PPE on the total phenolic, ascorbic acid, anthocyanin content, and antioxidant activity of strawberry samples during cold storage was investigated and the results are shown in Figure 2. Compared to control

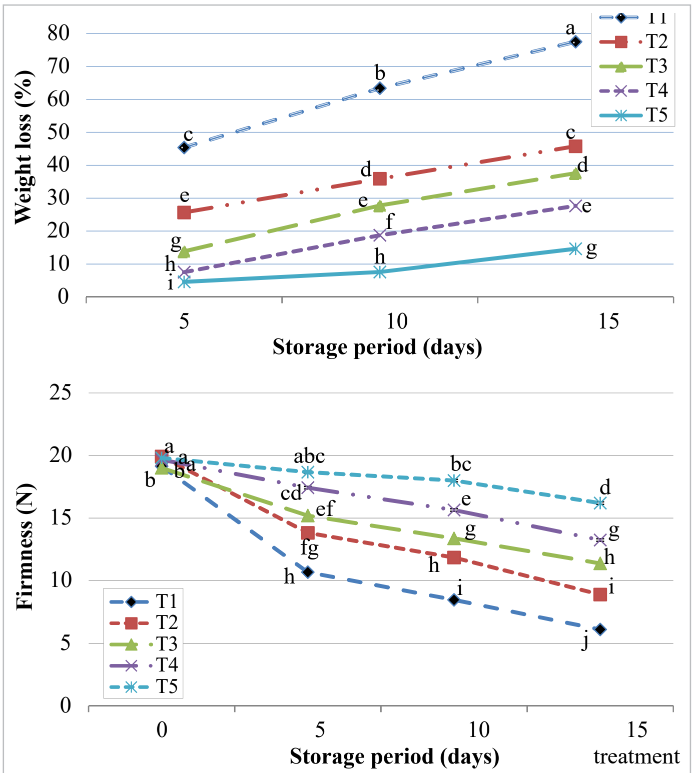

Figure 1. **Weight loss and firmness of strawberry treated with laser irradiation and coated with chitosan and pomegranate peel extract. Treatment 1: untreated strawberry; 2: strawberry irradiated with laser; treatment 3: strawberry irradiated with laser and coated with chitosan; treatment 4: strawberry irradiated with laser and coated with pomegranate peel extract, and treatment 5: strawberry irradiated with laser and coated with chitosan + pomegranate peel extract**

Рисунок 1. **Потеря веса и твердость клубники, обработанной лазерным излучением и покрытой хитозаном и экстрактом кожуры граната. Обработка 1: необработанная клубника; обработка 2: клубника, облученная лазером; обработка 3: клубника, облученная лазером и покрытая хитозаном; обработка 4: клубника, облученная лазером и покрытая экстрактом кожуры граната; обработка 5: клубника, облученная лазером и покрытая хитозаном + экстракт кожуры граната**

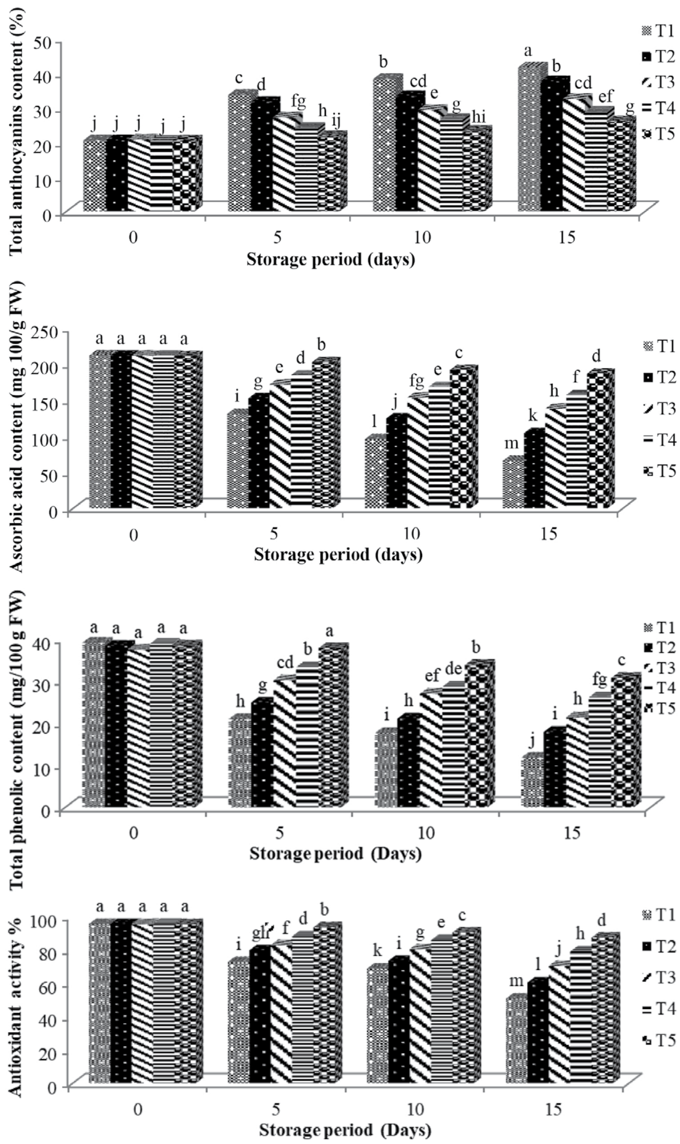

Figure 2. **Functional profile of strawberry treated with laser irradiation and coated with chitosan and pomegranate peel extract. Treatment 1: untreated strawberry; treatment 2: strawberry irradiated with laser; treatment 3: strawberry irradiated with laser and coated with chitosan; treatment 4: strawberry irradiated with laser and coated with pomegranate peel extract, and treatment 5: strawberry irradiated with laser and coated with chitosan + pomegranate peel extract**

Рисунок 2. **Функциональный профиль клубники, обработанной лазерным излучением и покрытой хитозаном и экстрактом кожуры граната. Обработка 1: необработанная клубника; обработка 2: клубника, облученная лазером; обработка 3: клубника, облученная лазером и покрытая хитозаном; обработка 4: клубника, облученная лазером и покрытая экстрактом кожуры граната; обработка 5: клубника, облученная лазером и покрытая хитозаном + экстракт кожуры граната** treatment, laser irradiation for 6 min provided a significant positive effect on the total phenolic, ascorbic acid content, and antioxidant properties of strawberry in treatment 2, particularly after 15 days of storage. The level of anthocyanin significantly increased in all treatments during the storage period; pointing out that the strawberry became duskier as maturation advanced. Our results are in relevance to those of Taha et al. [27] who found that the exposure of *Sequoia sempervirens* shoots to laser irradiation for 5 min led to increase the total content of phenolic compounds, tannins, and DPPH radical scavenging capacity compared to untreated shoots. Ali et al. [25] reported that laser irradiation could have a secondary impact on the anthocyanin cumulation in strawberry fruits, whilst the major effect was provided by the storage time and temperature. They also found that the ascorbic acid level of the strawberry treated by laser light for 3 min was significantly greater than both strawberry samples treated by laser for 6 and 12 min. Cordenunsi et al. [28] observed that laser irradiation did not expose the strawberry to heat through process and did not influence on the ascorbic acid content. In another study, Pirvu et al. [29] observed that the exposure of the aqueous extract of *Plantago lanceolata* L. leaves to laser irradiation enhanced the antioxidant activity comparing with control sample. Salyaev et al. [30] attributed the effect of laser to stimulate morphogenetic processes in plant fractions or tissues inducing metabolic changes and these changes lead to generate various antioxidant components. Maraei et al. [31] found that the antioxidant capacity of gamma-irradiation treated and untreated strawberry samples enhanced during the cold storage (9 days). They attributed these results to the destructive behavior of gamma irradiation and oxidation that may fracture the chemical bonds of polyphenol components, thus deblocking low molecular weight soluble phenol components with antioxidant properties.

Regarding the effect of coating materials on strawberry, it was noted that there were no significant differences in the total content of phenolic compounds, anthocyanin, ascorbic acid, and antioxidant activity values among all strawberry treatments at day 1 of cold storage (Figure 2). A decline trend in total content of phenolic compounds, ascorbic acid, and antioxidant activity was observed in all treatments during cold storage period, but anthocyanin showed opposite trend. After 15 days of storage, the strawberry of treatment 5 significantly showed the highest values of total phenolic, ascorbic acid, and antioxidant activity compared to the other treatments. However, the strawberry in treatment 5 significantly exhibited the lowest anthocyanin content. Our results revealed a good positive correlation between the content of ascorbic acid ($r = 0.99$) or total phenols ($r = 0.89$) and the antioxidant activity. These results were attributed to the coating with pomegranate peel that contains high content of phenolic compounds, particularly ellagitannins. Tannins are known as high molecular weight phenolic components that exhibit noteworthy antioxidant capacity [32]. Furthermore, Kaderides et al. [33] reported that the major phenolic component in pomegranate peel is punicalagin, which rates about 70% of the ellagitannins, and accounts approximately for 76.5% of total phenolic compounds. Cruz-Valenzuela et al. [34] reported that pomegranate peel extract had high DPPH radical scavenging activity (86.12%). Opara et al. [35] observed that the Egyptian pomegranate peel had higher vitamin C content (80 mg/100 g) than that of pomegranate aril (58 mg/100 g). The greater vitamin C level in fruit peels corresponds with the studies of other researchers, who confirmed higher antioxidant activity in various fruit peels than in other fruit parts [36,37]. Pomegranate is a rich source of anthocyanins that act as antioxidants through radical scavenging, metal chelating, hydrogen donors, and singlet O_2 quenching [38,39]. In this respect, Kumar et al. [2] made chitosan-based edible film enriched with pomegranate peel extract and found that the total phenolic and antioxidant activity ranged between 5.75–32.41 mg/g and 23.13–76.54%, respectively, depending on the volume fraction of pomegranate peel extract. Moreover, our findings revealed a positive correlation between weight loss and the level of anthocyanin content and this result is in agreement with the result of Darwish et al. [40].

3.4. Microbiological examination

Results in Table 2 present that the exposure to laser irradiation led to a decline in the count of fungi in strawberry of treatment 2 at day 1 and after 15 days of cold storage. Strawberry samples in the treatments 3, 4, and 5 were free from fungi on day 1 of storage. A growing trend in fungi count on the strawberry surface was noted during storage period. The increase in fungi count was recorded in uncoated strawberry samples, and the growth rate of fungi was not great in the coated strawberry samples. At the beginning of storage, psychrotrophic bacteria did not appear in the strawberries of all treatments. However, the count of psychrotrophic bacteria increased gradually in all treatments except treatment 5. After 15 days of storage, the strawberry of treatment 5 significantly demonstrated the lowest count of psychrotrophic bacteria compared to other treatments. In this regard, Saeed et al. [26] observed that the pomegranate peel extract and chitosan were successfully utilized for coating of tomato as antifungal agents. Azam et al. [41] attributed these results to the bioactive components in pomegranate peel oil that inhibit the growth of fungi and bacteria. Hence, the coated strawberries contained lower bacteria and fungi counts than the uncoated strawberries. Nazeam et al. [42] reported that phloretin and coutaric acid gained from pomegranate peels showed strong antimicrobial activity, particularly against *Staphylococcus epidermidis*, and punigratane featured the most essential antibacterial impact on *Micrococcus kristinae*. Nazeam et al. [42] and Charalampia and Koutelidakis [43] pointed out that pomegranate extracts are powerful inhibitors of *Bacillus cereus, Bacillus subtilis, Bacillus coagulans, Listeria monocytogenes, Enterobacter aerogenes, Pseudomonas aeruginosa, Escherichia coli, Salmonella typhimurium, Staphylococcus aureus, Trichoderma reesei, Aspergillus niger, Rhizopus oryzae, Penicillium citrinum*, and *Mucor indicus*. They attributed that to the high content of tannins, flavonoids, and phenolic components in pomegranate peels.

Table 2. **Psychrotrophic bacteria and fungi counts (log CFU/g) on the strawberry treated with laser irradiation and coated with chitosan and pomegranate peel extract**

Таблица 2. **Количество психротрофных бактерий и грибов ((log КОЕ/г) на клубнике, обработанной лазерным излучением и покрытой хитозаном и экстрактом кожуры граната**

Treatments	**Psychrotrophic bacteria (means ± SD)**			
	Storage period (day)			
	0	**5**	**10**	**15**
Treatment 1	ND	3.71 ± 0.49^{c}	4.14 ± 0.32^{b}	5.05 ± 0.06^{a}
Treatment 2	ND	2.48 ± 0.38^{e}	2.99 ± 0.37^{d}	3.83 ± 0.50^{bc}
Treatment 3	ND	ND	2.17 ± 0.27^{ef}	2.89 ± 0.22^{d}
Treatment 4	ND	ND	1.83 ± 0.05^{fg}	1.98 ± 0.01^{f}
Treatment 5	ND	ND	ND	1.49 ± 0.02^{g}
Treatments	Fungi counts (log CFU/g)			
	Storage period (day)			
	0	5	10	15
Treatment 1	2.26 ± 0.46^{cd}	2.61 ± 0.46^{c}	3.38 ± 0.39^{b}	4.38 ± 0.48^{a}
Treatment 2	1.70 ± 0.32^{efg}	1.84 ± 0.09^{ef}	2.39 ± 0.30^{cd}	3.68 ± 0.18^{b}
Treatment 3	ND	1.56 ± 0.27^{fg}	1.85 ± 0.20^{ef}	2.07 ± 0.40^{de}
Treatment 4	ND	1.33 ± 0.18^{gh}	1.58 ± 0.09^{fg}	1.85 ± 0.08^{ef}
Treatment 5	ND	ND	ND	1.09 ± 0.23^{h}

Means with different superscript letters differ significantly.
Treatment 1: untreated strawberry; treatment 2: strawberry irradiated with laser; treatment 3: strawberry irradiated with laser and coated with chitosan; treatment 4: strawberry irradiated with laser and coated with pomegranate peel extract, and treatment 5: strawberry irradiated with laser and coated with chitosan + pomegranate peel extract.

3.5. Color attributes

The effect of laser irradiation, and coating with chitosan and PPE on strawberry color properties during storage period is shown in Figure 3. The L* values indicate the grade of strawberry shine, while positive +a* values denote to redness. Hue (h°) values point out the visible spectrum color, whilst Chroma (C*) values refer to the purity or intensity of hue related to neutral gray. There were no significant differences among all treatments in all color characteristics at the beginning of storage period. During storage period, the L*, +a*, and h° values of all treatments significantly decreased, but C* values showed the opposite trend. After 15 days of storage period, strawberry in treatment 5 reliably demonstrated the highest values of L*, +a*, and h°, and the lowest value of C* compared to other treatments. Low values of L* refer to more intense color and storage effect, but high values indicate less tincture accumulation and less storage effect [44]. Positive a* values are referred to the anthocyanin content of strawberry [45]. Ali et al. [25] reported that low exposure period of laser irradiation prevented darkening of strawberry, while value of chroma remained the same.

3.6. Sensory evaluation

Using laser irradiation and coating with fruit or vegetable waste-based materials for preservation of fruits or vegetables quality may change their sensory properties that might lead to a deterioration in their acceptability for the consumers. Hence, it was important to monitor the changes in taste, odor, texture, and overall acceptability of strawberry as a result of laser irradiation and coating with chitosan and PPE (Figure 4). Storage

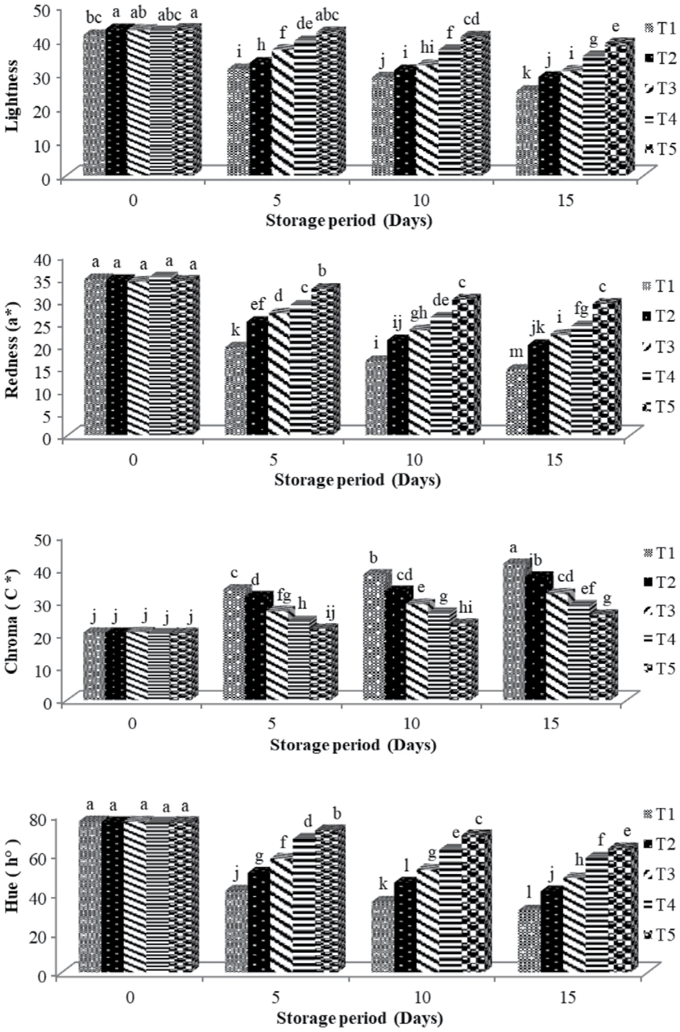

Figure 3. **Color characteristics of strawberry treated with laser irradiation and coated with chitosan and pomegranate peel extract. Treatment 1: untreated strawberry; treatment 2: strawberry irradiated with laser; treatment 3: strawberry irradiated with laser and coated with chitosan; treatment 4: strawberry irradiated with laser and coated with pomegranate peel extract, and treatment 5: strawberry irradiated with laser and coated with chitosan + pomegranate peel extract**

Рисунок 3. **Цветовые характеристики клубники, обработанной лазерным излучением и покрытой хитозаном и экстрактом кожуры граната. Обработка 1: необработанная клубника; обработка 2: клубника, облученная лазером; обработка 3: клубника, облученная лазером и покрытая хитозаном; обработка 4: клубника, облученная лазером и покрытая экстрактом кожуры граната; обработка 5: клубника, облученная лазером и покрытая хитозаном + экстракт кожуры граната**

period provides negative effects on the sensory properties of strawberry fruits, particularly in the control treatment. Laser irradiation for 6 min protected the strawberry fruits somewhat from the effect of storage period. Furthermore, the coating with PPE or chitosan and PPE greatly mitigated the negative effect of storage period on the sensory characteristics of strawberry fruits. These findings are in consistency with the above strawberry properties, especially the weight loss and color. In this regard,

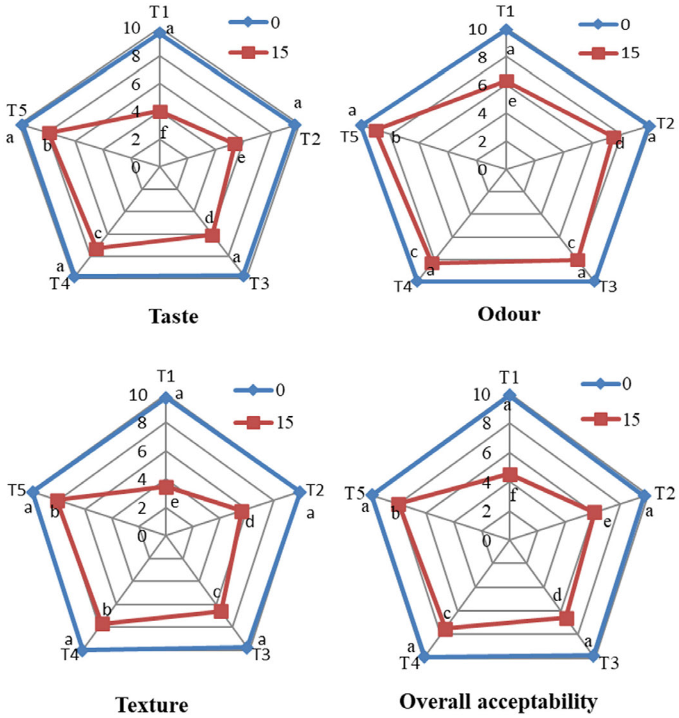

Figure 4. **Sensory attributes of strawberry treated with laser irradiation and coated with chitosan and pomegranate peel extract. Treatment 1: untreated strawberry; treatment 2: strawberry irradiated with laser; treatment 3: strawberry irradiated with laser and coated with chitosan; treatment 4: strawberry irradiated with laser and coated with pomegranate peel extract, and treatment 5: strawberry irradiated with laser and coated with chitosan + pomegranate peel extract**

Рисунок 4. **Сенсорные характеристики клубники, обработанной лазерным излучением и покрытой хитозаном и экстрактом кожуры граната. Обработка 1: необработанная клубника; обработка 2: клубника, облученная лазером; обработка 3: клубника, облученная лазером и покрытая хитозаном; обработка 4: клубника, облученная лазером и покрытая экстрактом кожуры граната; обработка 5: клубника, облученная лазером и покрытая хитозаном + экстракт кожуры граната**

Jiang et al. [47] reported that the coating of blueberries with chitosan did not affect negatively the flavor attribute. Alqahtani et al. [48] found that the dipping of Barhi date fruits in PPE preserved sensory characteristics during storage period.

4. Conclusion

During cold storage period, the ability of laser irradiation and coating with chitosan and pomegranate peel extract (PPE) to hinder the negative changes in quality characteristics of strawberry fruits was researched. The exposure to laser irradiation at 632.8 nm following by coating with chitosan and PPE enhanced the shelf-life of strawberry by decreasing the weight loss and preventing the undesirable changes in color, microbial growth, and sensory properties. Also, treated strawberry fruits exhibited the highest values of total content of phenolic compounds, ascorbic acid, and antioxidants. However, further studies are required to illustrate the impact of laser irradiation on the functional and quality characteristics of various vegetables and fruits. Moreover, this research will urge the researchers and food producers to utilize laser irradiation and coating the fruit and vegetables with waste-based coating materials for preservation fruits quality characteristics during their storage.

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Contribution	**Критерии авторства**
Authors equally relevant to the writing of the manuscript, and equally responsible for plagiarism. **Nesren Elsayed:** Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools, or data. **Hany Elkashef:** Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper. **Shaimaa R. Ali:** Conceived and designed the experiments; Performed the experiments.	Авторы в равных долях имеют отношение к написанию рукописи и одинаково несут ответственность за плагиат. **Эльсайед Нерсен:** Разработал и проектировал эксперименты; Проводил эксперименты; Анализировал и интерпретировал данные; Предоставлял реагенты, материалы, инструменты анализа или данные. **Элькашиф Хейни:** Разработал и проектировал эксперименты; Анализировал и интерпретировал данные; Написал статью. **Али Шаймаа Раби:** Разработал и спланировал эксперименты; Провел их.
Conflict of interest	**Конфликт интересов**
The authors declare no conflict of interest.	Авторы заявляют об отсутствии конфликта интересов.