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Evaluating an upward ventilation system for Short-term Storage of Pre-Treated Potato Tubers

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ABSTRACT

Potato is considered one of the main agricultural crops, and its proper storage plays a vital role in the human food supply chain. The method of storage has a significant impact on its quality. This study was conducted to design, construct, and evaluate an upward ventilation system using a blower to achieve better and shorter-term storage conditions for potatoes compared to traditional storage periods. The experiment included four different treatments: control, sprayed with water, CMC (carboxymethyl cellulose) coating, and CMC coating containing cinnamaldehyde essential oil. The study was carried out in a completely randomized design with three replications. The results of tissue firmness evaluation on the twelfth day showed that the moist treatment had the highest increase in elastic modulus, with a 56.80% rise. Moisture loss assessment on the twelfth day revealed that the moist treatment had the lowest moisture loss at 2.1%, which was significantly different from the other treatments. Additionally, the starch content analysis on the twelfth day indicated a 6.19% increase in the starch content of the control treatment, while the other treatments showed a reduction in starch content. The starch content in the CMC and moist treatments remained at the same level. Overall, the coated treatments especially CMC and moist demonstrated better performance in preserving the quality of potatoes compared to the control, and can be considered suitable options for improving the short-term storage quality of potatoes under storage conditions.

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INTRODUCTION

Agricultural products are metabolically active commodities that remain fresh but are highly perishable due to their high moisture content. From harvest to consumption, they suffer considerable quantitative and qualitative losses. It is estimated that more than 20–22% of the total fruit production is lost because of spoilage during the various stages of postharvest handling before reaching consumers (Gupta et al., 2015). Generally, agricultural products undergo numerous physical, chemical, and biological changes after harvest, each of which can render them unsuitable for consumption. Moisture loss, vitamin degradation, changes in taste and color, alterations in cellulose, pectin, and starch contents in certain crops, souring, wrinkling, and shriveling are among the most important postharvest deteriorations that reduce quality. Such changes ultimately lead to price reductions, resulting in severe economic losses for producers (Camire et al., 2009).

Potato is the most widely cultivated tuber crop in the world and ranks as the fourth most important food crop after rice, wheat, and maize. It is one of the key commercial crops and staple foods that play a vital role in global food security. In Iran, the per capita consumption exceeds 35 kg per year (Milczarek et al., 2017). Potatoes are classified as starchy foods, containing 9–25% starch, and are also rich in iron, phosphorus, protein, potassium, vitamins A, B, and C, and other minerals (Camire et al., 2009). More than 90% of potato production in Iran occurs in temperate and cold regions during spring and summer. Harvesting potatoes at any time of the year requires storage under controlled temperature conditions. Thus, cold storage is essential for maintaining potatoes for fresh consumption or processing (Milczarek et al., 2017).

Potato tubers have a postharvest dormancy period, the length of which depends on varietal differences and environmental factors such as storage conditions. Commercial potato cultivars grown for processing and industry usually have a shorter dormancy period, which often leads to quality issues such as weight and volume loss, moisture reduction, sugar and starch alterations, sweetening, sprouting, and toxicity. Therefore, providing proper storage conditions is necessary to minimize losses (Aksenova et al., 2013). To evaluate potato quality, different physical, visual, mechanical, and chemical indicators such as compression tests, moisture changes, and starch content are commonly used (Karim et al., 2007).

So far, no comprehensive guideline has been introduced for short-term storage of potatoes, which is required to maintain their quality until they reach consumers. Currently, it is frequently observed that a considerable portion of potatoes displayed in fruit and vegetable markets are shriveled and unsuitable for consumption, with weight loss being the major cause. Hence, it is necessary to develop measures to minimize such losses, ensuring that consumers receive higher-quality produce.

In recent years, edible coatings have emerged as modern and safe techniques that provide a temporary physical barrier on the surface of produce, reducing moisture evaporation, gas exchange, and degradative reactions, thereby maintaining their appearance and texture during storage (Singh & Packirisamy, 2022). Among them, carboxymethyl cellulose (CMC) has been widely applied in the food industry due to its natural origin, excellent film-forming properties, transparency, compatibility with food products, and moisture-retention capacity (Miteluț et al., 2021). Moreover, incorporating plant-based essential oils such as cinnamaldehyde into CMC coatings can enhance their antioxidant and antimicrobial activities, thereby significantly improving the effectiveness of edible films in preserving the physical and chemical quality of agricultural products (Bourtoom, 2008).

Considering the importance of maintaining potato quality during short-term storage, the present study aimed to design, construct, and evaluate an upward ventilation system equipped with a blower, combined with edible coatings, to reduce quality loss in potatoes. Four treatments control, sprayed with water, CMC coating, and

CMC coating with cinnamaldehyde essential oil were applied to the samples. Their effects on three quality indices, namely tissue firmness, moisture loss, and starch content, were examined during the storage period. The central research question is whether the application of edible coatings combined with a blower-based cooling system can improve the quality indices of potatoes during short-term storage.

MATERIALS AND METHODS

The initial design of the system was developed according to the experimental requirements using SolidWorks 2014 software. After reviewing the design and preparing the necessary components, the system was constructed, as shown in Figure 1. A plastic blower with a power of 22 W and dimensions of 12 × 12 cm was installed at the bottom of the system. The outlet air velocity of the blower above the metal mesh was measured using a digital anemometer, which recorded a value of 1.5 m/s. The blower remained in continuous operation throughout the experimental period.

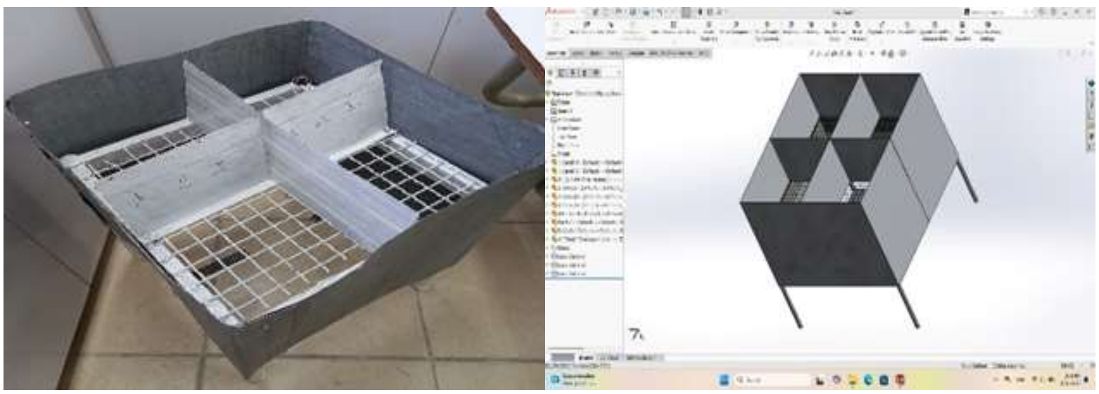

Figure 1. The initial design of the system and its constructed form

For the preparation of treatments, 15 kg of potatoes from a single and uniform cultivar were obtained from the fruit and vegetable market in Kerman, Iran. Healthy potatoes were selected and, as much as possible, cleaned of soil using a dry cloth without washing. The experimental treatments included control, sprayed with water, CMC coating, and CMC coating containing cinnamaldehyde essential oil. For each treatment, 2 kg of potatoes were separated. The control samples were transferred without any modification onto one section of the device, placed on a metal mesh. For the sprayed with water treatment, the potatoes were placed in a basket and sprayed each day with water twice a day.

To prepare the edible coating for the CMC treatment, 10 g of CMC was dissolved in 1 L of distilled water and hydrated at refrigeration temperature for 24 h. The solution was then stirred at 70 °C for 30 min using a magnetic stirrer at 1200 rpm. Subsequently, glycerol (50% w/w of CMC) was added as a plasticizer and citric acid (20% w/w of CMC) was incorporated into the solution. Stirring was continued for another 20 min at 70 °C (Abdollahi et al., 2019). After cooling, half of the solution was separated for preparing the CMC–cinnamaldehyde coating. The remaining solution was poured into a container, and the potato samples were immersed in it for 5 min. Afterwards, the samples were removed and placed on a plastic sheet for 5 min to allow the coating to dry and form a stable structure. The coated samples were then transferred to the third section of the device.

For the preparation of the CMC–cinnamaldehyde coating, the reserved half of the CMC solution was heated to 40 °C. Then, cinnamaldehyde essential oil (3000 mg/L) and Tween 80 (10% v/v of cinnamaldehyde) were added, and the mixture was homogenized at 10,000 rpm for 10 min using a homogenizer (Abdollahi et al., 2019). After cooling, the solution was poured into a container, and the potato samples were immersed in it for 5 min. Similar to the CMC treatment, the samples were removed and placed on a plastic sheet for 5 min to allow the coating to dry and achieve a stable structure. Finally, as illustrated in Figure 2, the samples were transferred to the fourth and last section of the device, where they were stored at room temperature for 12 days. Evaluations were carried out on days 1, 4, 8, and 12.

Figure 2. Placing treatment samples on the system

To evaluate tissue firmness, a compression test was conducted using a universal testing machine (Model MRT-1, Santam, Iran). The test was performed in triplicate for all treatments, and the stress–strain curves were plotted for each treatment on day 12.

For the determination of moisture loss, the samples from each treatment were peeled and cut into small strips. A 100 g portion of strips from each treatment was weighed using a digital scale and placed separately on aluminum foil. The strips were dried in an oven at 70 °C for 24 h. After drying, the samples were reweighed. Three replications were performed for each treatment, and the moisture content on a wet basis was calculated using Equation (1):

$$MC\% = \frac{M_i - M_f}{M_i} \times 100 \quad (1)$$

Where:

MC% = Moisture content (wet basis);

M_i = Initial mass of the sample before drying (g);

M_f = Final mass of the sample after drying (g).

Starch content of the samples was analyzed using the methodology described byMcCleary et al 2019. All tests were conducted under a completely randomized design (CRD) with four treatments and three replications, performed on days 1, 4, 8, and 12. The mean comparisons were carried out using Tukey’s test at a 5% significance level with the aid of Minitab software.

Starch measurement was carried out using a completely randomized design with four treatments and three replications on days 1, 4, 8, and 12. Mean comparisons were performed using Tukey’s test at a 5% significance level with the aid of Minitab software.

RESULTS AND DISCUSSION

Figure 3 illustrates the average stress–strain curves of the treatments on day 12. Based on the calculated modulus of elasticity, it was observed that the sprayed with water treatment showed the highest increase (56.80%) compared to the control treatment on day 1. This can be attributed to the daily water penetration and the resulting increase in cell turgor pressure. The results indicate that the sprayed with water treatment exhibited greater resistance to deformation and maintained a firmer texture than the other treatments. In contrast, the CMC-coated treatment (42.62%) and the CMC + cinnamaldehyde treatment (23.12%) showed relatively lower increases in the modulus of elasticity on the last day compared to the control on day 1. This reduction may be due to the interaction of the coating with the essential oil and a possible increase in enzymatic activity (Miteluț et al., 2021). A study by Gol et al. reported that edible coatings, depending on their composition, can either soften or help maintain the firmness of various products. The findings of the present research are consistent with these results, as both CMC and CMC + cinnamaldehyde coatings were effective in reducing modulus of elasticity and contributed to softer tissue texture (Gol et al., 2015).

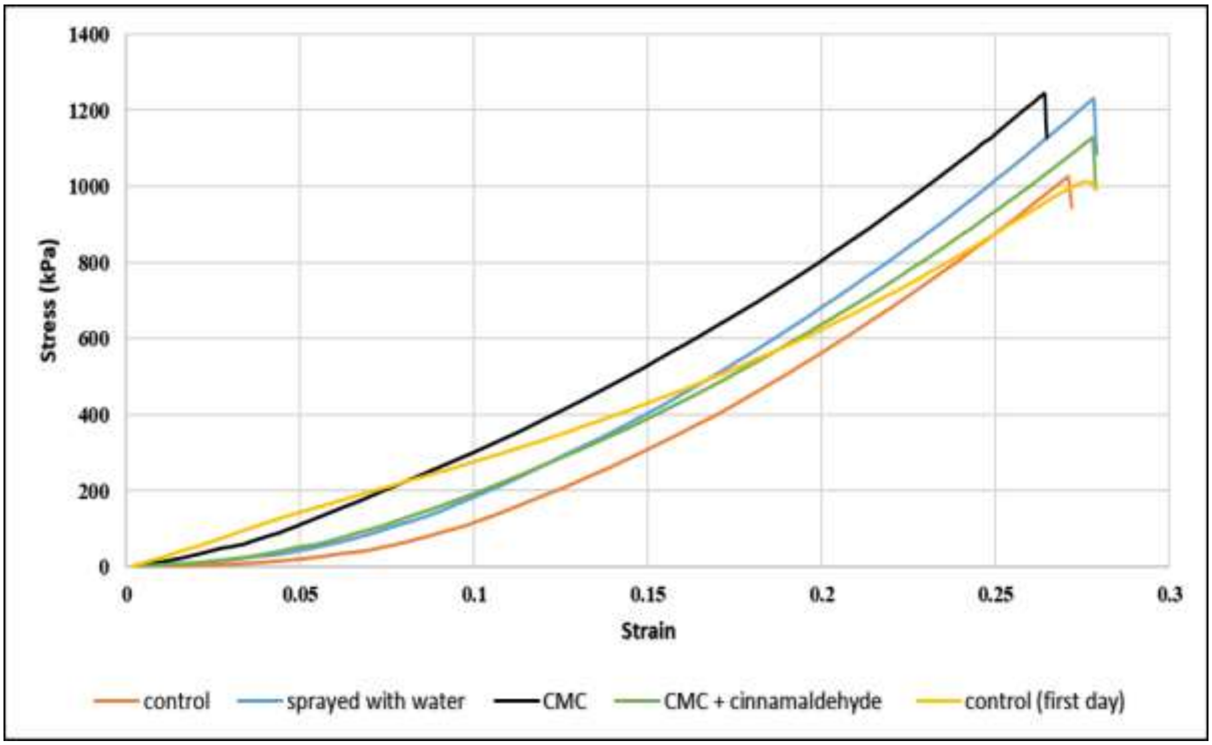

Figure 3. Average stress-strain diagrams on the 12th day of potato samples in the system with different treatments

According to the statistical analysis of moisture loss data presented in Table 1, the effects of treatment and time on moisture content were significant at the 1% level ($P < 0.01$), whereas the interaction between treatment and time was not significant ($P > 0.01$). Figure 4 shows that on day 12, the lowest moisture loss relative to day 1 was observed in the sprayed with water treatment (2.1%), while the highest loss occurred in the control treatment (6.5%). This pattern indicates the positive effect of complete immersion in maintaining internal water content, although other types of coatings also somewhat improved moisture retention compared to the control. A study by Pleșoianu and Nour reported that coatings enriched with plant extracts were effective in preserving moisture and preventing evaporation and wrinkling of mushroom skin. The findings of the present study are consistent with this, showing that the sprayed with water treatment performed well in maintaining moisture (Pleșoianu & Nour, 2022). The CMC coating with essential oil also showed lower moisture loss than the control, likely due to the formation of a protective layer that limited mass transfer. Similar results regarding the effectiveness of edible coatings in moisture retention have been observed in previous studies (Emragi et al., 2022; Zhang et al., 2017).

Table 1. Analysis of variance results for the effect of different treatments in the system on the moisture content (wet basis) of potato samples during 12 days of storage

Source	DF	Adj MS
Treatment	3	12.608**
Time	3	47.774**
Treatment*Time	9	2.510^{ns}
Error	32	1.169
Total	47	-

^{ns}: not significant, *: significant at p<0.05 and **: significant at p<0.01

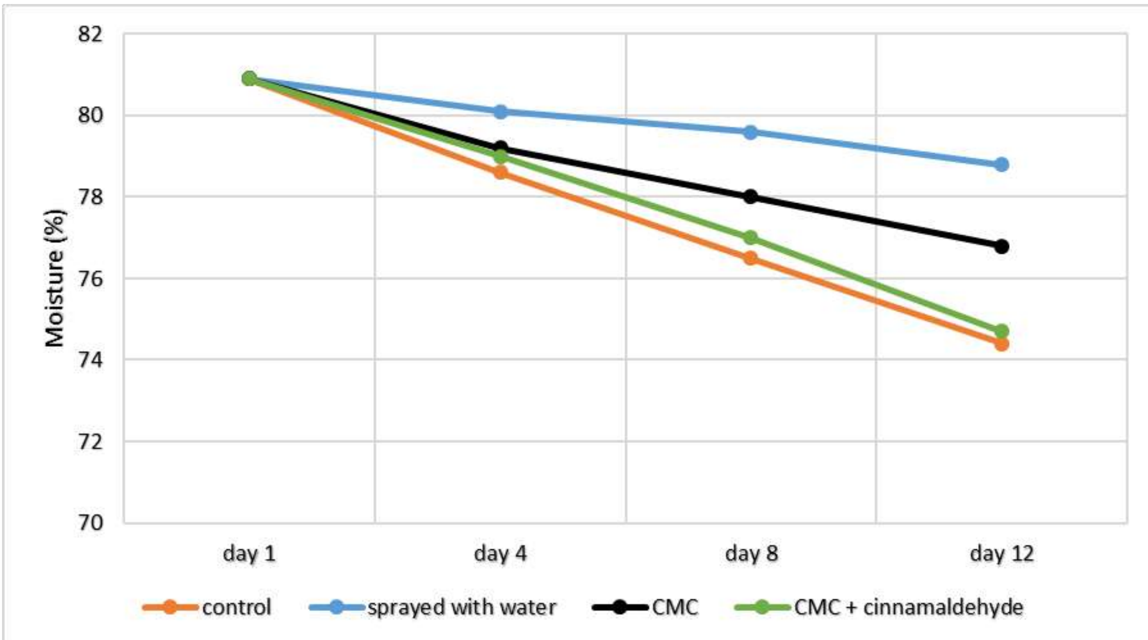

Figure 4. Moisture content (wet basis) of potato samples in the system under different treatment during 12 days of storage

According to the statistical analysis of starch content data presented in Table 2, the effects of treatment, time, and their interaction on starch content were significant at the 1% level (P < 0.01). Figure 5 shows that on day 12, the sprayed with water treatment experienced the greatest reduction in starch content (21.67%) compared to day 1. This finding is consistent with the study by Frederick et al., which reported that higher moisture levels can enhance enzymatic activity, leading to increased starch degradation (Frederick et al., 1973). In a study conducted on native starch coatings in avocado, it was observed that such coatings, while preserving texture, also resulted in a reduction of starch content. These results indicate that starch-based coatings, particularly those with high vapor permeability, can accelerate enzymatic reactions (Choque-Quispe et al., 2022).

Table 2. Analysis of variance results for the effect of different treatments in the system on the starch content of potato samples during 12 days of storage

Source	DF	Adj MS
Treatment	3	111.445**
Time	3	724.632**
Treatment*Time	9	350.451**
Error	32	0.872
Total	47	-

^{ns}: not significant, *: significant at p<0.05 and **: significant at p<0.01

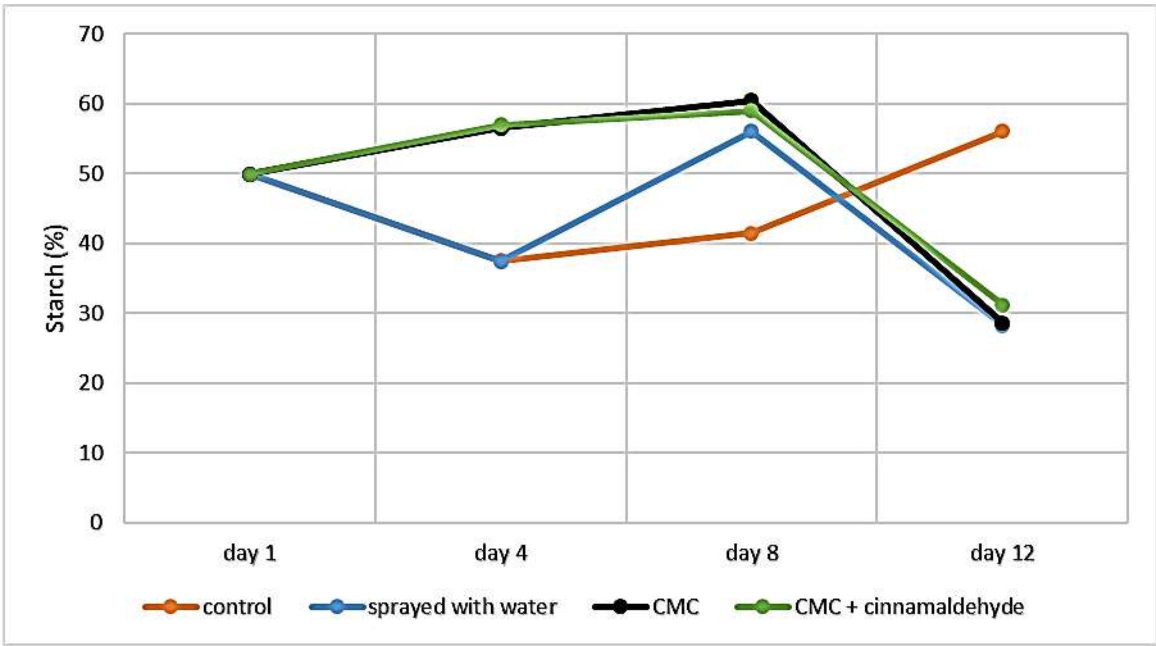

Figure 5. Starch content of potato samples in the system under different treatment during 12 days of storage

CONCLUSIONS

The results of this study demonstrated that the sprayed with water treatment exhibited the greatest increase in modulus of elasticity, indicating a firmer texture and greater resistance to deformation. In terms of moisture retention, the sprayed with water treatment also performed the best, highlighting the positive effect of complete immersion on preserving internal water content. Regarding starch content, the control treatment showed a significant increase, while the other treatments experienced a reduction in starch levels, which can contribute to improved sensory attributes such as crispness and tenderness. Overall, coated treatments, particularly CMC coating and the sprayed with water, showed superior performance in maintaining tissue quality and reducing starch content compared to the control. These findings suggest that the combination of an upward ventilation system and edible coatings can effectively preserve the physicochemical quality of potatoes during short-term storage.

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