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Scientific Research

Investigating the effect of edible chitosan coating and process conditions on drying time and quality of dried melon slices using Taguchi design

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ABSTRACT

Edible coatings are biological materials that can be applied as a thin layer on fresh fruits and vegetables to enhance their quality during the drying process. In this research, we conducted drying tests and evaluated the quality of melon slices under the influence of chitosan pretreatment and process conditions to obtain the drying characteristics of melon slices. Melon slices of varying thicknesses (0.5, 0.75, 1, and 1.25 cm) were immersed in chitosan solutions (at concentrations of 0.5, 1, 1.5, and 2%) and then were dried in a hot air oven at four different temperature levels (65, 70, 75, and 80 °C). Using the Taguchi design, we investigated how the independent variables (coating concentration, temperature, and slice thickness) affected the dependent variables, including drying time, shrinkage, water reabsorption ratio, and texture hardness. The drying results revealed that process temperature had the most significant effect on drying time (61.87%), while slice thickness had the least impact (10.72%). As coating concentration and slice thickness increased, the rehydration ratio and shrinkage of the dried slices decreased, but both increased with rising temperature. Coating concentration had the greatest influence on these two factors, while slice thickness had the smallest. Additionally, increasing the concentration of chitosan pretreatment led to a firmer texture in the samples.

1.Introduction

The inclusion of fruits and vegetables in a healthy diet is essential, as there is a direct relationship between their consumption and reduced risk of various diseases. These effects are attributed to the bioactive compounds present in these products [1]. However, due to their high sensitivity to chemical and microbial changes, many efforts have been made to find processes that ensure extended shelf life [2].

Drying is a widely used method to increase shelf life by reducing moisture content. It offers significant advantages such as high nutrient concentration due to water loss, greater stability at room temperature, prevention of microbial activity, protection against enzymatic and oxidative degradation, ease of transport and storage, and reduction of post-harvest waste. However, during drying, quality and sensory properties (shape, size, color, texture, aroma, and taste), as well as nutritional value, change [3]. Almost all drying methods—such as hot air drying, microwave drying, vacuum drying, or combinations—can result in degradation or quality loss, especially for heat-sensitive fruits and vegetables. Therefore, developing alternative pretreatment methods is necessary to preserve bioactive compounds [4].

Recent studies have shown that applying edible coatings to fruit and vegetable chips before drying, which form a thin layer acting as a selective barrier against moisture, CO_2, and O_2, improves the nutritional and physicochemical quality of dried products [5]. Edible coatings are eco-friendly and can be consumed as part of the product, enhancing shelf life by protecting against physical, chemical, and microbial damage [6]. Plant and animal proteins, lipids, and polysaccharides are the most common biological sources of edible coatings. Chitosan is a high molecular weight polysaccharide derived from shrimp shell exoskeletons. Due to its desirable properties such as biocompatibility, biodegradability, and antimicrobial activity, it is widely used for coating fruits and vegetables [7]. Chitosan, alone or in combination with other coatings, has been used to create active edible packaging for various fruits and vegetables including tomatoes, plums, bananas, and strawberries [8]. Additionally, chitosan has been successfully used as a pretreatment for drying fruits and vegetables such as apricots, blueberries, and basil leaves [9-11].

Melon (Cantalupensis Group) is a fruit with a short shelf life and is typically consumed fresh. Its postharvest shelf life under ambient or refrigerated conditions is limited to one or two weeks, making marketing difficult [12]. Therefore, many studies have aimed at extending its shelf life [13-15].

Among the evaluated methods, drying has proven more effective than chemical additives in extending melon's shelf life. Dried melon, rich in antioxidants, vitamins, and minerals, is considered a healthy snack. Its unique aroma and sweet taste also increase market appeal and consumer acceptance. However, limited studies have been conducted on drying melon [16-18].

Recent research on melon has focused mainly on texture characteristics (physical, chemical, and sensory assessments). Studying drying time and rate is valuable for optimizing process parameters, improving product quality, and understanding heat and mass transfer during drying [19]. Taguchi analysis is a global tool for optimizing process parameters and can be used to evaluate the effects of experimental variables and model the process [20, 21]. This study aims to investigate drying time and physical properties of dried melon slices influenced by temperature, coating concentration, and slice thickness, and determine optimal drying parameters.

2. Materials and Methods

2.1. Raw Materials

Melons were purchased from the local market in Jiroft. All chemicals were sourced from Merck and Sigma companies.

2.2. Chitosan Solution

To prepare chitosan solutions of different concentrations (0.5%, 1%, 1.5%, and 2%), chitosan powder was dissolved in 1% (v/v) acetic acid using a magnetic stirrer at 600 rpm for 24 hours. The resulting solutions were then filtered through a 0.45 µm syringe filter to remove impurities.

2.3. Coating and Drying

Melons were sliced using a fruit slicer into various thicknesses and immersed in chitosan solutions for 1 minute. After coating, slices were placed on a mesh in a hot air dryer at different temperatures (as shown in Table 1). Sample weights were recorded every 5 minutes using a digital scale with 0.01 g accuracy. Weight loss was calculated using the following equation [22]:

$$WR = \frac{M_O - M_t}{M_O} \times 100$$

Where M_O = initial weight, M_t = weight at time t

Table 1. Experimental design performed by Taguchi.

Variable / Treatment	Concentration of coating (%)	Temperature (°C)	Slice thickness (cm)
1	0.5	65	0.5
2	0.5	70	0.75
3	0.5	75	1
4	0.5	80	1.25
5	1	65	0.75
6	1	70	0.5
7	1	75	1.25
8	1	80	1
9	1.5	65	1
10	1.5	70	1.25
11	1.5	75	0.5
12	1.5	80	0.75
13	2	65	1.25
14	2	70	1
15	2	75	0.75
16	2	80	0.5

2.4. Rehydration Ratio

Rehydration was measured based on Doymaz et al. (2017) with slight modifications [23]. 2 g of dried samples were immersed in 200 mL of distilled water at 25°C for 300 minutes. After soaking, excess surface moisture was removed and the weight of the rehydrated samples was recorded. The rehydration ratio was calculated as [24]:

$$RR = \frac{W_2 - W_1}{W_1}$$

Where W_1 = dry weight, W_2 = weight after rehydration

2.5. Shrinkage Measurement

Shrinkage was determined by measuring apparent volume before and after drying using liquid displacement (toluene) method [25]:

$$V = \frac{M_1 + M_2 - M_3}{\rho}$$

Where V = sample volume (m^3), M_1= sample weight (kg), M_2 = weight of empty pycnometer with solvent (kg), M_3 = weight of pycnometer with sample and solvent (kg), ρ = density of solvent (kg/m^3)

Shrinkage (%) was calculated by:

$$S = \frac{V_0 + V_1}{V_0} \times 100$$

Where V_0 = initial volume, V_1 = final volume

2.6. Texture Analysis

Texture firmness was measured using a texture analyzer (Stable Micro Systems, UK). A cylindrical probe (20 mm diameter) was used to penetrate samples at a speed of 1 mm/s to a depth of 50%.

2.7. Statistical Analysis

In this study, the effect of independent variables of different coating concentrations, melon slice thickness and dryer temperature on drying time and some physical properties of dried melon slices was investigated. The experiments were designed using Taguchi method with Minitab16 software and data analysis and graphing were performed using Qualitek 4 and Origin 2016 software, respectively.

3. Results and Discussion

3.1. Drying Time

The effect of temperature, different coating concentrations and slice thickness on the drying time of melon slices was investigated. The drying time of the slices was measured in the range of 114 to 230 minutes (Figure 1). Treatment number 13 with a temperature of 65 °C, a coating concentration of 2% and a thickness of 1.25 cm had the longest drying time, and treatment number 12 with a temperature of 80 °C, a coating concentration of 1.5% and a thickness of 0.75 cm had the shortest drying time. Figure 2 shows the effect of different levels of independent variables on melon slices. As can be seen, with increasing temperature, the drying time decreased. The decrease in drying time was more significant from 65 °C to 70 °C. With increasing drying air temperature, the enthalpy of the drying air increased, increasing mass and heat transfer and consequently reducing drying time [26 and 27]. While the drying time increased with increasing the concentration of edible coating. This increase was greater with changing the concentration from 1.5 to 2%. With increasing the concentration of coating, mass transfer from the interior of the slice to the surface of the slice occurred slower. Also, increasing the thickness of the melon slices increased the drying time. This finding can be attributed to the increase in resistance to moisture transfer in higher slice thicknesses [28]. According to Figure 2, it is clear that temperature and coating concentration have the greatest and least effect on the drying time, respectively.

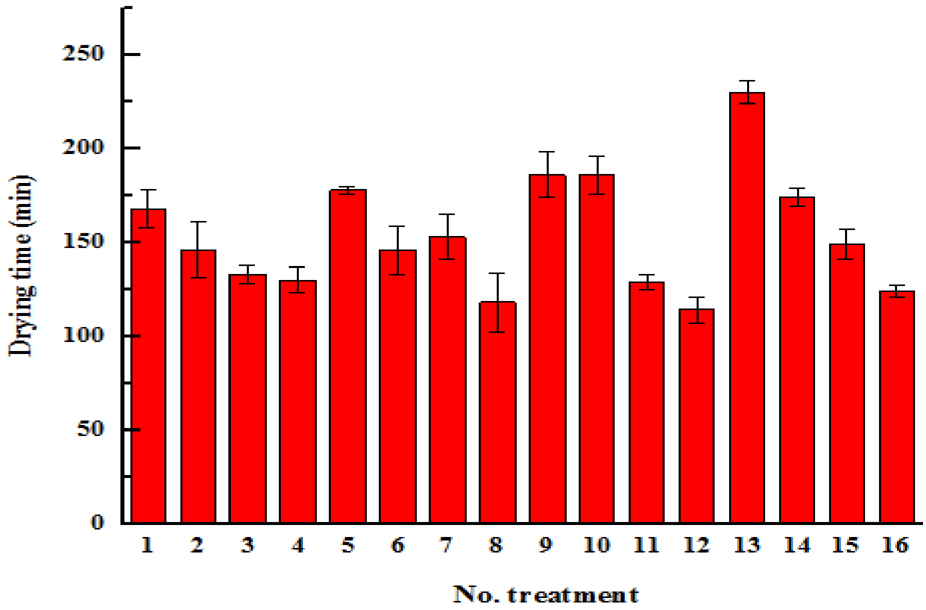
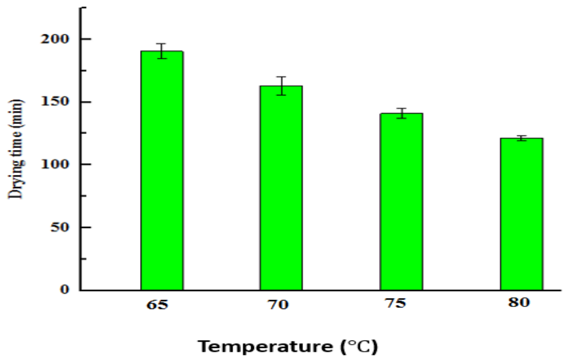
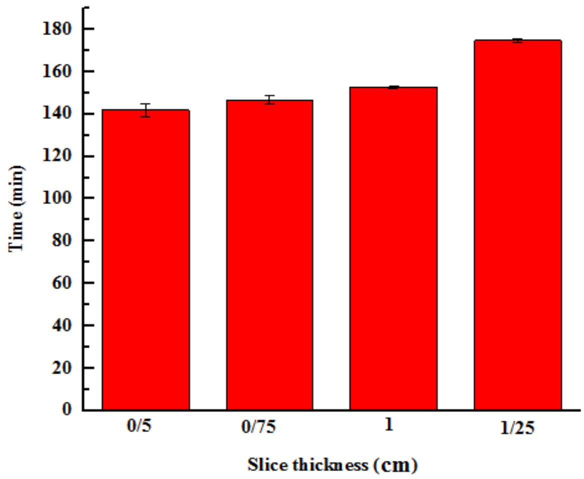


Fig 1. Drying time for different treatments.





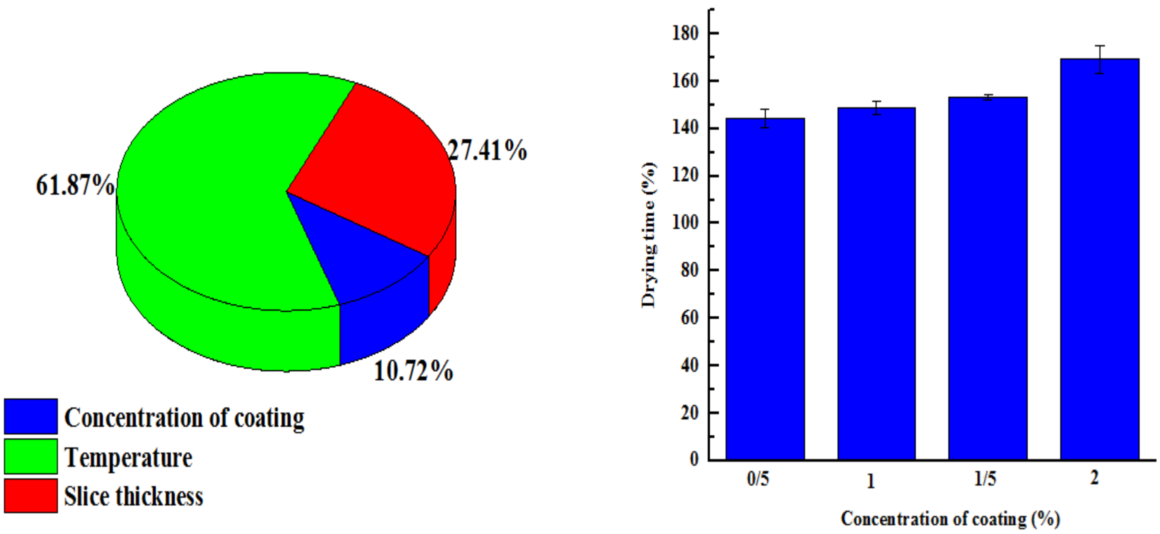


Fig 2. Effects of different variables and their levels on drying time and Severity index of independent factors on drying time

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٣.2. Rehydration Ratio

The water reabsorption ratio is a qualitative characteristic that indicates physical and chemical changes during drying. It is considered as a measure of the physical damage to the cell wall and tissue during drying. This factor depends primarily on the internal structure of the product and then on the amount of damage to the water-retaining compounds during drying [19]. The water reabsorption of dried melon slices was obtained in the range of 1.609 to 6.419 g/g (Figure 3). Treatment 13 with a temperature of 65 °C, a coating concentration of 2% and a thickness of 1.25 cm had the lowest water reabsorption and treatment 1 with a temperature of 65 °C, a coating concentration of 0.5% and a thickness of 0.5 cm had the highest water reabsorption. The results show that all variables are effective on water reabsorption (Table 2). The coating concentration had a greater effect (58.682%) on water reabsorption than other variables. As shown in Table 2, the water reabsorption rate decreased steadily with increasing coating concentration. Higher water reabsorption indicates a faster reabsorption ability of the dried product. With increasing coating concentration, a larger proportion of the outer surface of the slices was coated, which resulted in less cell damage during the drying process and consequently lower water reabsorption [24]. Water reabsorption increased with increasing process temperature, which can be attributed to tissue breakdown and the formation of damaged cells, which in turn tend to absorb moisture at higher temperatures [29]. Water reabsorption rate increased with decreasing slice thickness. With decreasing thickness, the surface area to volume ratio increased; thus, the water reabsorption ability increased [5]. Similar results have been reported in research works conducted on carrot slices and [30, 33].

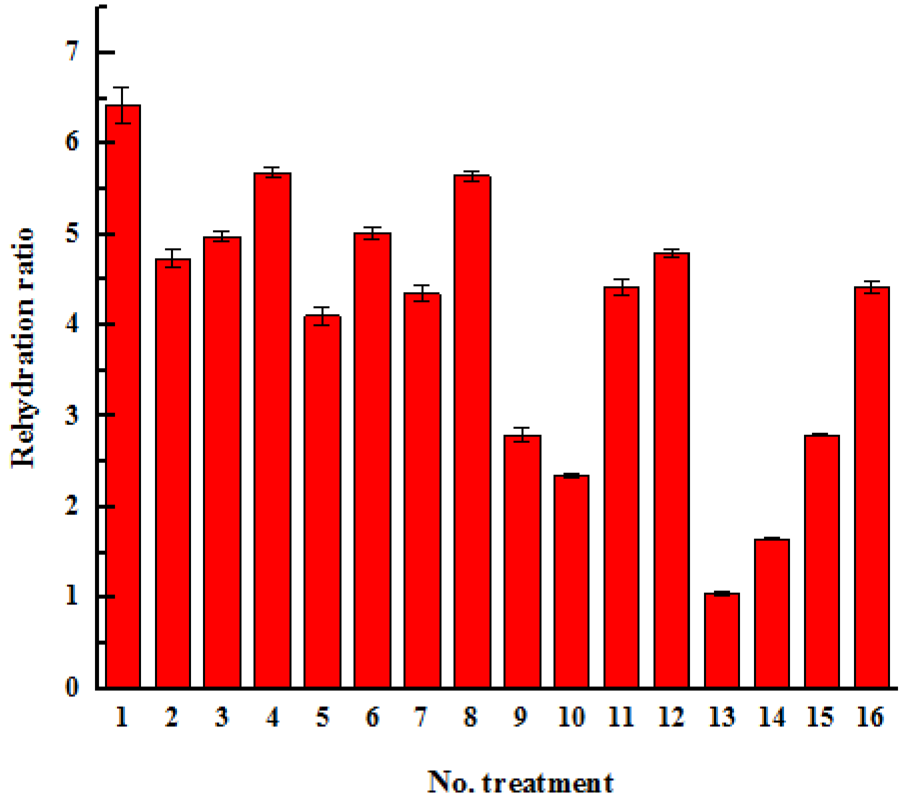

Fig 3. Rehydration ratio for different treatments.

Table2. Effects of different variables and their levels on Rehydration ratio and Severity index of independent factors on Rehydration ratio.

Factors	Level 1	Level 2	Level 3	Level 4	Percent
Concentration of coating (%)	5.451	4.779	3.604	2.479	58.682
Temperature (°C)	3.449	3.591	4.135	5.136	21.666
Slice thickness (mm)	5.069	4.106	3.769	3.368	19.652

3-3. Shrinkage

The percentage of shrinkage can be considered as a measure of physical damage during the drying process. Figure 4 shows the percentage of shrinkage of different treatments. Treatment 4 with a temperature of 80 °C, a coating concentration of 0.5% and a thickness of 1.25 cm had the highest percentage of shrinkage (90%), and treatment 14 with a temperature of 70 °C, a coating concentration of 2% and a thickness of 1 cm showed the lowest percentage of shrinkage (7%). As shown in Table 3, the coating concentration has the greatest effect on the percentage of shrinkage. Studies show that with increasing coating concentration, the percentage of shrinkage decreases; in other words, it can be concluded that chitosan coating effectively protects melon slices from physical damage during the drying process. The percentage of shrinkage depends on the drying speed and the moisture content of the slices in the early stages of the process. Higher drying speed and lower moisture content increase the shrinkage percentage. Increasing the process temperature by increasing the drying speed and decreasing the product moisture content increases the shrinkage percentage [24]. The results also indicate a slight effect of slice thickness on the shrinkage percentage. The shrinkage percentage increased with increasing thickness. The results obtained in the present study are consistent with the results of investigating the effects of processing conditions and edible coating of papaya [32 and 33].

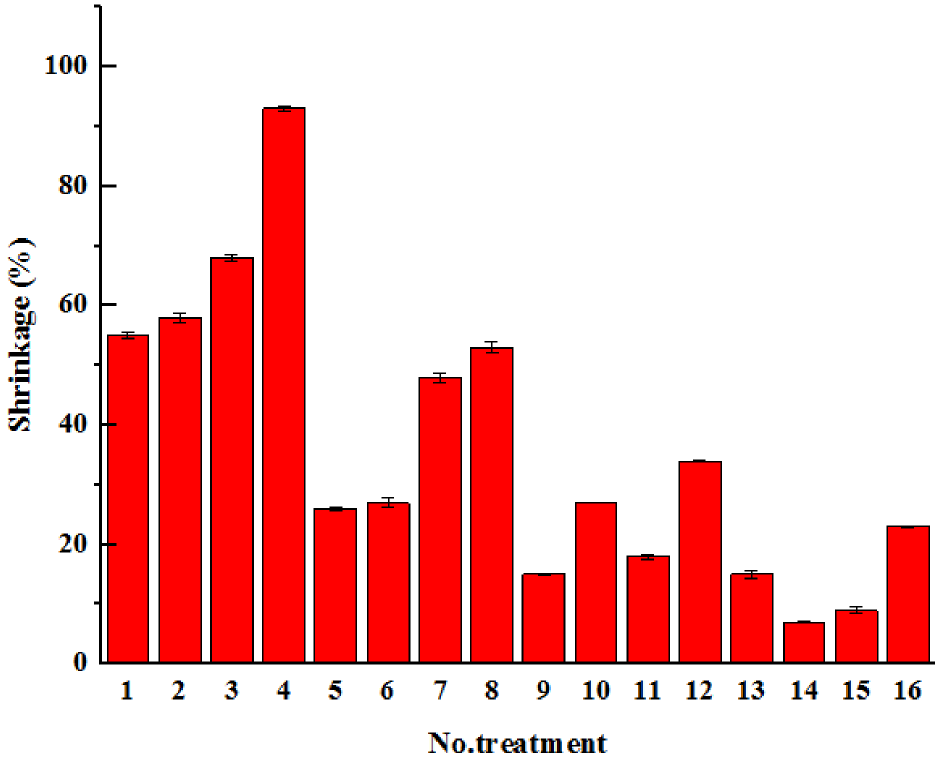

Fig 4. Shrinkage for different treatments.

Table3. Effects of different variables and their levels on shrinkage and Severity index of independent factors on shrinkage.

Factors	Level 1	Level 2	Level 3	Level 4	Percent
Concentration of coating (%)	68.5	38.5	23.5	13.5	78.749
Temperature (°C)	27.75	29.75	35.75	59.75	14.825
Slice thickness (mm)	30.70	31.75	31.75	35.75	6.426

3-4. Texture

The stiffness of the samples was obtained in the range of 3 to 18.2 Newtons (Figure 5). Treatments 16 (temperature 80°C, coating concentration 2% and thickness 0.5 cm) and 1 (temperature 65°C, coating concentration 0.5% and thickness 0.5 cm) had the highest and lowest stiffness of the samples, respectively. The results show that all variables are effective in the stiffness of the sample (Table 4). The effect of coating concentration and process conditions on the texture of dried melon slices is given in Figure 5. Increasing the coating concentration led to an increase in the stiffness of the dried samples. In other words, samples coated with a higher concentration of chitosan require more energy than samples coated with a lower concentration. A significant increase in the stiffness of papaya and carrot samples pretreated with starch and gum arabic coatings, respectively, has also been reported [24 and 34]. Process temperature showed the greatest effect (82.3%) on firmness. As the drying temperature increased, the firmness of the samples increased. This result could be due to structural changes in the fruit tissue that occurred due to the increase in temperature in the melon slices. Increasing temperature, by increasing the rate of water removal from the sample during the drying process, leads to hardening of the internal membranes of the sample and hardening of the skin and ultimately hardening of the tissue [35-36]. As the thickness of the melon slices increased, the firmness of the samples increased, which can be attributed to the increase in the solid matter of the product in higher slice thicknesses [26].

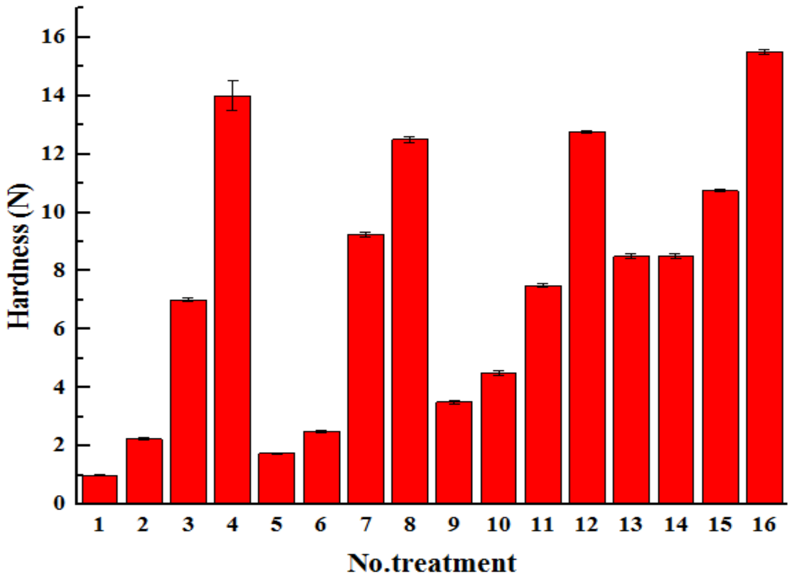

Fig 5. Hardness for different treatments.

Table4. Effects of different variables and their levels on hardness and Severity index of independent factors on hardness

Factors	Level 1	Level 2	Level 3	Level 4	Percent
Concentration of coating (%)	6.062	6.5	7.063	10.812	18.681
Temperature (°C)	3.687	4.437	8.625	13.687	77.148
Slice thickness (cm)	6.625	6.875	7.875	9.062	4.171

4. Conclusion

Edible coating of fruits and vegetables improves their quality at the end of the drying process. In this study, the effects of chitosan pretreatment concentration, drying temperature, and slice thickness on drying time, shrinkage, rehydration ratio, and texture firmness of melon slices dried using hot air oven were evaluated. All three independent variables significantly influenced the dependent variables. Higher drying temperature reduced drying time but increased shrinkage, rehydration ratio, and firmness. Increasing chitosan concentration reduced drying time, shrinkage, and rehydration, but increased firmness. Increasing slice thickness raised all dependent variables. Chitosan concentration had the most influence on shrinkage (78.749%) and rehydration

(58.682%), while drying temperature had the highest effect on firmness (77.148%) and drying time.(۶۱/۸۷۵٪)

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بررسی تاثیر پوشش خوراکی کیتوزان و شرایط فرایند بر زمان خشک شدن و کیفیت برش‌های ملون خشک شده با طرح تاگوچی

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چکیده

پوشش‌های خوراکی لایه‌ای نازک و قابل خوردن از مواد طبیعی هستند که بر روی سطح میوه‌ها و سبزیجات قرار می‌گیرند. هدف از این پوشش‌ها افزایش ماندگاری و جلوگیری از کاهش کیفیت محصولات می‌باشد. در این پژوهش، آزمایش‌های خشک کردن و ارزیابی کیفیت برش‌های ملون تحت تاثیر پیش تیمار کیتوزان و شرایط فرایند، برای بدست آوردن ویژگی‌های خشک کردن برش‌های ملون انجام شد. برش‌های ملون با ضخامت مختلف (۰/۵، ۰/۷۵، ۱ و ۱/۲۵ سانتی‌متر) در محلول‌های کیتوزان (با غلظت ۰/۵، ۱، ۱/۵ و ۲ درصد) غوطه ور و سپس توسط آون با هوای گرم در چهار سطح دما (٦٥ ، ۷۰، ۷٥ و ۸۰ درجه سانتی‌گراد) خشک شدند. تاثیر متغیرهای مستقل غلظت پوشش، دما و ضخامت برش بر متغیرهای پاسخ زمان خشک کردن، چروکیدگی، نسبت جذب مجدد آب و سفتی بافت با کمک روش تاگوچی بررسی گردید. نتایج نشان داد دمای فرایند و ضخامت برش به ترتیب بیشترین (٦۱/۸۷٪) و کمترین (۱۰/۷۲٪) تاثیر را بر زمان خشک کردن داشتند. نسبت جذب مجدد آب و چروکیدگی برش‌های خشک شده با افزایش غلظت پوشش و ضخامت برش‌ها کاهش پیدا کردند؛ در حالی‌که مقدار این متغیرها با افزایش دما افزایش یافتند. غلظت پوشش و ضخامت برش‌ها به ترتیب بیشترین و کمترین تاثیر را بر این دو فاکتور نشان دادند. افزایش غلظت پیش تیمار کیتوزان باعث افزایش سفتی بافت نمونه‌ها شد.