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ORIGINAL ARTICLE

Effect of Aloe Vera Gel-Carboxymethyl Cellulose Composite Coating on the Degradation Kinetics of Cucumber

Ayesha Sarker[1,2] · **Angelos Deltsidis**[3] · **Tony E. Grift**[1]

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Abstract

Purpose This study aimed to investigate the effect of Aloe vera (AV) gel and carboxymethyl cellulose (CMC) composite edible coating on the postharvest quality and degradation kinetics of stored cucumbers.

Methods Control, 20%, 30%, and 50% (V/V) AV + 1% (W/V) CMC coating formulations were prepared and tested as postharvest treatments on cucumbers stored at 15 °C and 23 °C. Quality parameters such as weight, firmness, color, pH, TSS, TA, and mold count were monitored at regular intervals until day 20. The degradation kinetics of stored cucumbers, namely weight loss, firmness, and color changes, and the effect of coating treatment on the degradation kinetics were studied by fitting kinetic models to the specified experimental data. Pearson's correlation was applied to verify the correlation among the color parameters L*, a*, and b*.

Results Based on the interactive effects of coating treatment, temperature, and storage time, 30% AV + 1% CMC-coated cucumbers retained the most postharvest quality parameters. Overall, the first-order kinetic model fitted well with the weight loss, firmness, and color change data with a reasonably high coefficient of determination (R^2) values (0.66–0.99). Both weight and firmness loss were described well by the first-order kinetic model through linear regression; however, color changes were best explained through the non-linear regression method. Moreover, the color parameters L*, a*, and b* had significant correlations that were revealed through Pearson's correlation. The Arrhenius equation was used to study the effect of temperature on the kinetic parameters, k and E_a. Temperature increment resulted in the acceleration of the degradation process which was reflected by the higher rate constants (k) at 23 °C. From the kinetic study, 30% AV + 1% CMC coating had the most reduced degradation rate among the treatments studied.

Conclusions Cucumbers coated with 30% AV + 1% CMC could be stored at 15 °C for 20 days while overall postharvest quality being maintained.

Keywords AV gel · Cucumber · Kinetics · Model · Quality · Texture

Nomenclature

ANOVA	Analysis of variance
AV	Aloe vera
CFU	Colony-forming unit
CMC	Carboxymethyl cellulose
OVQ	Overall visual quality
PCA	Plate count agar
PDA	Potato dextrose agar
RH	Relative humidity
TA	Titratable acidity
TPA	Texture profile analysis
TSS	Total soluble solids
WL	Weight loss

✉ Ayesha Sarker
ayeshas2@illinois.edu

Angelos Deltsidis
adeltsidis@uga.edu

Tony E. Grift
grift@illinois.edu

[1] Department of Agricultural and Biological Engineering, University of Illinois at Urbana-Champaign, 1304 West Pennsylvania Avenue, Urbana, IL 61801, USA

[2] Department of Food Engineering & Tea Technology, Shahjalal University of Science & Technology (SUST), Sylhet 3114, Bangladesh

[3] Department of Horticulture, University of Georgia, 2360 Rainwater Road, Tifton, GA 31793, USA

Introduction

Cucumber (*Cucumis sativus* L.) is a very popular and available vegetable crop worldwide, but the postharvest water loss, shriveling, yellowing, and fungal decay in cucumbers lead to the shorter shelf life of fewer than 14 days (Bahnasawy & Khater, 2014; Maleki et al., 2018). Edible coating application has been considered an innovative technique that acts as a moisture barrier, resists the exchange of gas and volatile compounds, gives protection from physical damage, and serves as a functional ingredient when applied on the fresh produce (Lin & Zhao, 2007). A variety of edible coatings have been exploited for the extension of the shelf life of fresh cucumber (Adetunji et al., 2014; Maleki et al., 2018; Moalemiyan & Ramaswamy, 2012; Mohammadi et al., 2016; Olufunmilayo & Uzoma, 2017).

Aloe vera (AV) gel was reported to be a promising edible coating material which provides modified atmosphere, reduced moisture loss, respiration rates, and microorganism growth, and delayed oxidative browning in fruits and vegetables (Ahmed et al., 2009; Brishti et al., 2013; Ergun & Satici, 2012; Hassanpour, 2015; Hazrati et al., 2017; Martínez-Romero et al., 2006; Sarker & Grift, 2021; Sarker et al., 2021; Sogvar et al., 2016). However, AV gel could provide insufficient barrier properties leading to water permeability to some extent; therefore, to get the desirable film characteristics, different compounds such as starch, cellulose, gelatin, and gellan gum have been added to the AV solution (Alvarado-González et al., 2012; Ortega-Toro et al., 2017; Sarker & Grift, 2021).

Blending two or three biopolymers has been found to be a promising way to improve the film-forming properties and overall performance of composite coatings (Ghanbarzadeh et al., 2010; Jalali et al., 2016). Carboxymethyl cellulose (CMC) is a cellulose-derived polysaccharide that exhibits thermal gelation and possesses excellent film-forming properties owing to its polymeric structure with a high molecular weight chain (Ghanbarzadeh et al., 2010). Besides, carboxymethyl cellulose has some other desirable properties such as being water-soluble, clear, odorless, tasteless, highly viscous, non-toxic, and flexible, with relatively moderate strength, and relatively moderate resistance to moisture and gas transfer (Krochta & Mulder, 1997; Tongdeesoontorn et al., 2011). As a result, CMC-based coating was reported beneficial for shelf life extension of fresh fruits (Gol et al., 2013; Kumar et al., 2018; Saba & Sogvar, 2016).

Edible coatings are applied to reduce the decay incidence and to maintain the postharvest quality of fresh produce during storage. Coating treatments maintain the quality by reducing the degradation rate of chemical, physical, and microbiological changes during storage. For further understanding of the performance of a coating treatment, it is useful to study the underlying degradation reactions in a quantitative way. Thus, the knowledge of kinetic parameters that describe such reactions is important (Pinheiro et al., 2013). Different kinetic models such as zero-order, first-order, and fractional conversion (FC) first-order have been reported to successfully describe physicochemical changes in foods (Gonçalves et al., 2007; Jaiswal & Abu-Ghannam, 2013; Pinheiro et al., 2013). The kinetic modeling on the effect of coating treatments on the quality of fruits and vegetables is scarce or modeled only one quality parameter (Mohebbi et al., 2014).

Therefore, the main objectives of this research are (1) to evaluate the effects of AV gel + CMC composite coating on the physicochemical parameters, overall visual quality, and fungal decay of cucumbers stored at 15 °C and 23 °C; and (2) to investigate the degradation kinetics of the quality parameters, namely weight loss, color, and texture, of stored cucumbers as influenced by the coating treatment. The optimum temperature and relative humidity for cucumber storage are 10–12.5 °C and 95%, respectively (Suslow & Cantwell, 1997). The idea of the research was to compensate for the low-temperature storage with the application of coatings, i.e., to see if the coated cucumbers could be stored at a higher temperature than the optimum while maintaining the overall postharvest quality. This work provides useful information about the effects of AV gel + CMC edible coating on the quality parameters of cucumbers. To the best of our knowledge, there is no published data on AV gel + CMC coating treatments on cucumbers. Moreover, the main novelty of this work is to quantify the degradation reactions involved and to predict the influence of coating treatments and storage temperature on critical quality parameters. Thus, the kinetic parameters, i.e., reaction order, the rate constant, and activation energy obtained from the modeling, were useful tools to identify an optimal coating concentration and storage temperature for maximum cucumber quality.

Materials and Methods

The materials used in this experiment were comprised of freshly harvested cucumbers (*Cucumis sativus*), pure AV gel (Stockton Aloe 1, Inc., FL, USA), carboxymethyl cellulose (TCI Ltd., Tokyo, Japan), and glycerol (Thermo Fisher Scientific Inc., Fair Lawn, NJ, USA). The methods involve various techniques for measuring the postharvest quality parameters of fruits and vegetables.

Experimental Design and the Statistical Model

The experiment was laid out in a three factorial completely randomized design (CRD) with three replications. There were four levels of treatment (T1—distilled water as control, T2—20% AV + 1% CMC, T3—30% AV + 1% CMC, and T4—50% AV + 1% CMC), two levels of temperature (15° C and 23 °C) and five storage (sampling) days (d) (d 0, d 5, d 10, d

15, and d 20). Treatment levels were randomly assigned to the cucumber fruits. The statistical model applied was:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\beta\gamma)_{jk} + (\alpha\gamma)_{ik} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijk} \quad (1)$$

where Y_{ijk} = the observed value of Y at ith level of treatment factor at jth level of storage day factor at kth level of temperature factor; μ = the grand mean; α_i = the main effect of ith level of treatment factor; β_j = the main effect of jth level of storage day factor; γ_k = the main effect of kth level of temperature factor; $(\alpha\beta)_{ij}$ = two-way interaction effect of the ith level of treatment factor and the jth level of factor storage day factor; $(\beta\gamma)_{jk}$ = two-way interaction effect of the jth level of storage day factor and the kth level of temperature factor; $(\alpha\gamma)_{ik}$ = two-way interaction effect of the ith level of treatment factor and the kth level of temperature factor; $(\alpha\beta\gamma)_{ijk}$ = three-way interaction effect of the ith level of treatment factor, jth level of storage day factor, and the kth level of temperature factor; and ε_{ijk} = the error term of the ith level of treatment factor at jth level of storage day factor at kth level of temperature factor, which is assumed NID ~$(0, \sigma^2)$.

Material Preparation and Coating Application

Freshly harvested cucumbers were obtained from the Student Sustainability Farm, Crop Sciences, University of Illinois at Urbana- Champaign, USA. Commercially mature cucumber of uniform size and free from damage or decay were selected and brought to the laboratory for the experiments. To conduct the experiments, a total of 720 cucumbers were collected. After washing with tap water, cucumbers were sanitized with an antimicrobial wash additive (Ecolab-Fruit & Vegetable wash, Saint Paul, MN, USA) and again rinsed with tap water, then placed on the metal wire mesh and dried with the help of a fan.

Carboxymethyl cellulose (CMC) powder was added to the distilled water and heated at 85 °C while stirring with a magnetic stirrer (Isotemp, Thermo Fisher Scientific Inc., Fair Lawn, NJ, USA) to completely dissolve the powder and obtain a clear solution. After the solution was cooled down, glycerol was added to the solution to serve as a plasticizer and stirred for another few minutes. Twenty percent, 30%, and 50% (V/V) coating solutions were prepared using pure AV gel solution mixed with CMC (1% W/V of AV gel) and glycerol (0.5% V/V of AV gel). The control coating consisted of 100% distilled water. To determine the optimum concentrations of AV and CMC for the composite coating, trial experiments were conducted with 10, 20, 30, 50, 70, and 100% AV and 0.25, 0.5, and 1.0% CMC. Final coating concentrations were selected based on their ability to reduce weight loss and the overall visual quality of cucumbers. Therefore, the tested coating concentrations were T1—distilled water as control, T2—20% AV + 1% CMC, T3—30% AV + 1% CMC, and T4—50% AV + 1% CMC.

The cucumbers were divided into two batches of 360 fruits, each to be stored at two different temperatures. Then, the fruits were randomly selected from the batches and immersed into the treatment solutions for 5 min. After the coating application, coated cucumbers were placed on a metal wire mesh and allowed to be completely dried. The coated and surface-dried cucumbers were placed into mesh bags, weighed, and kept in two separate growth chambers (Conviron CMP4030, Winnipeg, Canada) operated at 15 °C (86% relative humidity, RH) and 23 °C (75% RH). To maintain the AV-CMC composite coating on the surface, cucumbers were handled carefully and only taken out from the storage at the sampling days just before the quality measurements. Due to the water-soluble properties of both coating materials, water condensation resulted from the fluctuations of storage temperature could wash away the coating. Therefore, temperatures of the growth chambers were strictly maintained throughout the storage period. Quality parameters and kinetics of weight loss, firmness loss, and color changes were studied every fifth day until day 20. At d 0, the fruits were analyzed before any coating application.

Weight Loss

The weight of the cucumbers with different treatments was recorded (SK-2000, A & D Co., Ltd., Korea) at the beginning of storage (d 0). At each sampling day, the weight loss (WL) was calculated as a percentage of the initial weight at d 0:

$$WL(\%) = \frac{(W_a - W_b)}{W_a} \times 100 \quad (2)$$

where WL is the weight loss expressed as a percentage rate, W_a is the initial weight in grams, and W_b is the weight in grams at the sampling day. Each treatment consisted of three replicate batches of cucumbers per sampling day.

Firmness

A Texture Analyzer (TA-XT2, Stable Microsystem Ltd., Godalming, UK) with a 30-kg load cell was used for the firmness test of the cucumbers. Compression tests were carried out with a 5-mm-diameter round probe. The test conditions were pre-test speed 5 mm/s; test speed 5 mm/s; post-test speed 10 mm/s; and trigger force of 5 g. A single puncture measurement to 5 mm depth of penetration at the geometric center of each sample was made (Gonçalves et al., 2007; Mohammadi et al., 2016). Force–distance curves from the puncture tests were obtained, and the maximum force (N) was recorded. In this experiment, cucumbers from three replicate batches per treatment were used. The average of the recorded data was expressed in Newton per millimeter.

Color

A Hunter Lab Mini scan XE Plus colorimeter (Hunter Associates Laboratory Inc., Reston, VA, USA) was used to monitor the color changes of cucumber during storage. Prior to the experiment, the instrument was calibrated using a standard white and black tile. The color values of the skin were expressed as L*, which represents the luminosity of samples (black [0] to white [100]), a* (greenness [−] to redness [+]), and b* (blueness [−] to yellowness [+]). To determine the color changes, reflectance spectra of the cucumbers from three replicate batches at each sampling day were evaluated to record the L*, a*, and b* components, and the results were expressed as the mean ± standard deviation for each of the color components.

pH, TSS, and TA

Cucumbers were homogenized with a blender, filtered with cheesecloths, and the filtrate was used for the chemical tests. A digital pH meter (Mettler Toledo, Columbus, OH, USA) was used to record the pH of the cucumber juice. Total soluble solids (TSS) were measured using a digital pocket refractometer (PAL-1, ATAGO, Japan) and were expressed as percentage. Manual titration with 0.1 N NaOH up to pH endpoint of 8.1 was carried out to determine the TA (titratable acidity) of the samples. All measurements were performed in triplicate, and the results were expressed as the mean ± standard deviation. All pH, TSS, and TA tests were performed in triplicate. Then, the results were averaged and expressed as the mean ± standard deviation.

Overall Visual Quality

The overall visual quality (OVQ) of the cucumbers was evaluated at each sampling day during storage. The test panel consisted of 8 (eight) graduate students with an age range of 25–35 years. Two randomly selected cucumbers from each treatment were used for the OVQ testing. Slices from one cucumber were served to test the interior, and the other one was served as a whole fruit to check the external appearance (Maleki et al., 2018). The OVQ was scored on a 5-point hedonic scale: 1, dislike extremely; 2, dislike moderately; 3, neither like nor dislike; 4, like moderately and 5, like extremely. A limit of acceptance was set at or above point 3.5 (Maleki et al., 2018). The scores received from all members were averaged, and the results were presented as the mean ± standard deviation.

Fungal Analysis

Ten grams of cucumber samples was used for the microbiological analysis of the treatments. The samples were homogenized in 90 mL 0.1% (% V/V) peptone water. The 10^{-1} dilution thus obtained was used to prepare other decimal dilutions. Then, the spread-plating (0.1 mL) was carried out with potato dextrose agar (PDA) for yeasts and molds and incubated at room temperature for 3–5 days. The whole fungal analysis experiment was carried out in duplicate for each dilution. After the incubation period, total fungal colonies were counted, which were expressed as log colony-forming units per gram.

Calculation of Kinetic Parameters

In a food system, the rate of change of a quality parameter can be represented by the following equation:

$$-\frac{dC}{dt} = kC^n \quad (3)$$

where k is the rate constant, C is the concentration of a quality parameter at time t, and n is the order of the reaction. One of the frequently used reactions in foods is the first-order reaction. A degradation equation for $n = 1$ is:

$$-\frac{dC}{dt} = kC \quad (4)$$

Integrating Eq. 4 leads to the following equation:

$$\frac{C_t}{C_0} = e^{-kt} \quad (5)$$

Often, the following logarithmic form of Eq. 5 is used:

$$\ln\frac{C_t}{C_0} = -kt \quad (6)$$

where C_0 is the value of a quality parameter at time (day) zero; C_t is the value of a quality parameter at any time (day) t; k is the temperature-dependent rate constant (day^{-1}) and t is the storage time (day). Also, from Eq. 6, $-k$ is equal to the slope of the plot made between $\ln\frac{C_t}{C_0}$ and time t for a reaction at a constant temperature (Niamnuy et al., 2008). In this experiment, the degradation kinetics of cucumber weight, firmness, and color were modeled as first-order reaction kinetics (Eq. 6).

To describe the temperature dependency of a chemical reaction, the Arrhenius equation has been used as the empirical equation. Through the Arrhenius equation, the relationship between the rate constant of a reaction and absolute temperature is described:

$$k = k_0 \exp\left[-\frac{E_a}{RT}\right] \quad (7)$$

where k is the rate constant at temperature T (K); k_0 is frequency factor (day^{-1}); E_a is the activation energy (kJ/mol); and R is the universal gas constant (8.314 J/mol/K). A plot of ln$k$versus $\frac{1}{T}$ producing a straight line indicates that the data fitted well to Eq. 7; the slope of the line gives the activation energy E_a whereas the intercept is equal to lnk_0 (Mohebbi et al., 2014).

Statistical Analysis

According to the statistical model, as shown in Eq. 1, a three-way analysis of variance (ANOVA) was performed using R statistical software (R Core Team, 2019) version 3.5.2. ANOVA assumptions, i.e., normal distribution and homogeneity of variances were checked by the Shapiro-Wilk test and Brown-Forsythe test (Levene test), respectively. A Tukey HSD test with a 95% confidence interval was applied to evaluate the differences among mean values. The correlations among the L*, a*, and b* color values of cucumbers during storage were evaluated by Pearson's correlation coefficient (r). The coefficient r indicates the strength and direction of a linear relationship; the value of the Pearson's coefficient lies between 0.00 (no linear correlation) and ±1.00 (perfect linear correlation), and the sign (+/−) represents the direction (positive—if the values increase together and negative—if one value decreases as the other increases) of the relationship (Niamnuy et al., 2008).

The goodness of the model fitting to the experimental data was evaluated by the coefficient of determination (R^2) and mean square error (MSE) (Jaiswal & Abu-Ghannam, 2013; Pinheiro et al., 2013). The higher the R^2 and the lower the MSE, the better the fitting of the model to the experimental data.

Results and Discussion

The effect of the coating treatments and the results of the kinetic study are discussed. In the following figures and tables, T1, T2, T3, and T4 stand for control, 20% AV + 1% CMC, 30% AV + 1% CMC, and 50% AV + 1% CMC, respectively. On d 0, treatments have equal means since data were recorded from the untreated fresh cucumbers.

Weight Loss

All the independent variables, i.e., treatments, storage days, and the temperature, had significant ($P < 0.05$) effects on cucumber weight loss (Table 1). At both temperatures, the weight loss of the cucumber increased with increasing time of storage (Fig. 1); the effect of coating treatment at 15 °C started to become significant after day 15, whereas at 23 °C, it exhibited a significant effect from day 5. T3-coated cucumbers had the least weight loss throughout the storage period at both temperatures studied. At the end of the storage day, T3 cucumbers had 36% and 37% less weight loss compared to the

Table 1 Mean squares from the analysis of variance of the percentage water loss, firmness loss, color changes (L*, a*, b*), mold growth, pH, TSS, TA changes, and OVQ score

Source[a]	Df	MS									
		Weight loss[b]	Firmness	L*	a*	b*	Mold growth	pH	TSS	TA	OVQ
Treat.	3	0.015828**	43.355**	0.0006658**	1.2727**	0.54376**	0.7890**	0.012308**	0.02064NS	0.00071023**	4.9517**
Temp.	1	0.004483**	144.579**	0.0006864**	4.3000**	0.26232**	0.0936NS	0.312120**	0.25854**	0.00011556NS	3.6450**
Day	3# or 4	0.163033**	140.780**	0.0047871**	2.7258**	2.68232**	3.5543**	0.275826**	1.95359**	0.00061462**	16.0075**
Treat × temp.	3	0.000591NS	2.977 NS	0.0000459 NS	0.0675 NS	0.13856 NS	0.0686 NS	0.040602**	0.08160**	0.00008662NS	0.1250NS
Treat. × Day	9# or12	0.000305NS	3.371**	0.0018438**	0.2633**	0.23308**	0.2137NS	0.038861**	0.28432**	0.00010511NS	0.3975NS
Temp.× day	3# or 4	0.000917**	11.378**	0.0001109NS	0.0656NS	0.14541NS	0.0441NS	0.247947**	0.15307**	0.00026998**	0.6825NS
Treat. × temp.× day	9# or12	0.000263NS	0.567 NS	0.0000472NS	0.0788NS	0.04617NS	0.0769NS	0.022338**	0.04830NS	0.00004097NS	0.0458NS
Residuals		0.000299	1.682	0.0001015	0.0586	0.07328	0.2991	0.000831	0.02701	0.00008288	0.4875

NS, not significant

**Significant at $P < 0.05$

[a] Treat.—treatment, Temp.—temperature, Df—degrees of freedom, and MS—mean square

[b] Percentage weight loss sampling was started from d 5

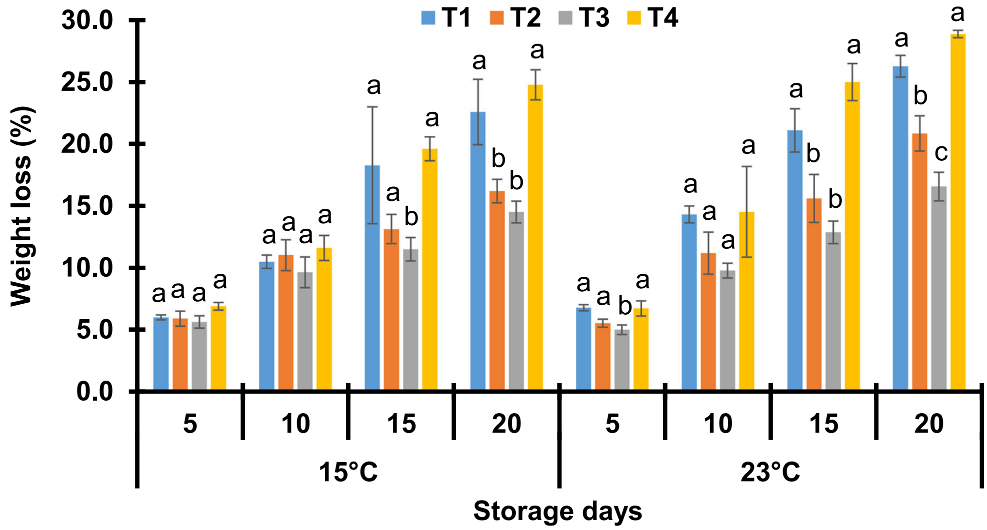

Fig. 1 Weight loss in control and AV + CMC-coated cucumbers during storage at 15 °C and 23 °C. In each point, vertical bars represent the standard deviation of the replications. Different letters at the same storage day are significantly different at $P < 0.05$. Note: T1—distilled water as control, T2—20% AV + 1% CMC, T3—30% AV + 1% CMC, and T4—50% AV + 1% CMC

control cucumbers at 15 °C and 23 °C temperatures, respectively. On the other hand, T4 cucumbers showed the highest weight loss regardless of the storage temperature. Postharvest reduction of fruit weight loss is one of the main objectives of coating treatment, and generally, the moisture loss during storage leads to the weight loss of the produce (Mohebbi et al., 2014). Moisture loss occurs as a result of the moisture migration from the fruit surface to the environment, and the rate of the migration depends on the water pressure gradient between the fruit tissue and the storage atmosphere (Mohammadi et al., 2015; Sogvar et al., 2016). In this study, T3, i.e., 30% AV + CMC,-coated cucumbers' superior performance among all the treatments in reducing the water loss could be attributed to the desirable water barrier properties of the coating formulation (Kahramanoğlu et al., 2019; Kumar et al., 2018). In contrast, T4-coated cucumbers had the highest water loss, even higher than the control, despite being coated. This phenomenon can be explained by the term osmotic dehydration; it takes place when a fresh food with high moisture content encounters a solution of high solute concentration. In this case, the existing concentration gradient between the solution and the intracellular fluid draws the water out of the fresh produce (Camirand et al., 1992; Dermesonlouoglou et al., 2008; Phisut, 2012).

The first-order reaction model (Eq. 6) best described the weight loss characteristics of cucumbers during the kinetic study. Regression equations for weight loss (y) as affected by storage time (t) were obtained (Table 2), and the reaction rate constants (k) were observed (Table 4) from the slope of the graph.

In agreement with the percentage weight loss (Fig. 1) data, weight loss rate constants of cucumbers increased with increasing storage temperature (Table 4). However, at both temperatures, there were smaller rate constants in T3 cucumbers than the control, T2, and T4 cucumbers. The Arrhenius equation (Eq. 7) was used to calculate the activation energies as influenced by the temperature dependency of the rate constants. From the plot of natural logarithms of rate constants (ln$k$) against reciprocal absolute temperature ($\frac{1}{T}$), activation energies of control, T1-, T2-, and T3-coated cucumbers were calculated as 13.39, 39.87, 26.56, and 23.22 kJ/mol, respectively (Table 4). Like the present observation, a linear model was found appropriate to explain the moisture loss kinetics of wax-coated cucumbers (Li et al., 2018). The increment in weight loss with the temperature indicates a higher energy transfer to the cucumbers as temperature increases (Mohebbi et al., 2014). The lower activation energy for weight loss in control samples indicates that control cucumbers are more prone to faster weight loss than the coated counterparts (Koca et al., 2005). Moreover, the higher activation energies of the coated cucumbers also suggest the higher temperature dependence of the coated samples (Gonçalves et al., 2007; Koca et al., 2005; Mohebbi et al., 2014). From the regression results summarized in Table 4, it can be found that the correlation coefficients R^2 of all regression models were sufficiently larger (0.82–0.98), meaning that there were good agreements between the predicted data and experimental data. Thus, the kinetic models

Table 2 Regression equations for a first-order weight loss from cucumbers stored at different temperatures

Treatment[a]	15 °C	23 °C
T1	$y = -0.0135x + 0.0108$	$y = -0.0157x + 0.0052$
T2	$y = -0.0074x - 0.0311$	$y = -0.0116x + 0.0004$
T3	$y = -0.0063x - 0.0304$	$y = -0.0085x - 0.0123$
T4	$y = -0.0147x + 0.009$	$y = -0.0191x + 0.024$

[a] T1—distilled water as control, T2—20% AV + 1% CMC, T3—30% AV + 1% CMC, and T4—50% AV + 1% CMC

were expected to adequately describe the associated weight loss.

Firmness

Firmness is one of the critical factors which determines the consumer acceptability of fresh produce. Fig. 2 shows the changes in firmness in cucumbers as affected by different coatings and storage at 15 °C and 23 °C.

In general, at both temperatures, there was a steady loss of firmness in both control and coated cucumbers with the passage of time. All the factors, i.e., treatments, storage days, and temperature, had significant (P < 0.05) effects on firmness loss (Table 1). Control and T4 cucumbers suffered from the highest firmness loss at the temperatures studied. By contrast, T2- and T3-coated cucumbers were firmer during the entire storage period, where T3 cucumbers significantly retained their firmness (P < 0.05). Freshly harvested cucumbers had a firmness of 12.37 N/mm. After the 20 days of storage, the loss of firmness in control fruit was around 32% and 51% at 15 °C and 23 °C, respectively, while the T3 cucumbers only lost 14% and 29% firmness at 15 °C and 23 °C, respectively. Pectin depolymerization and cellulase activity are some of the leading causes of firmness loss and softening in fruits and vegetables (Gol et al., 2013; Mohammadi et al., 2016). The modified atmosphere and reduced cellulase activity provided by the combination of AV (Benítez et al., 2013) and CMC (Gol et al., 2013; Saba & Sogvar, 2016) coating might delay the respiration rate, which ultimately slowed down the degradation process and maintained the firmness during storage (Sarker et al., 2021). Nonetheless, the poor retention of firmness by the T4 cucumbers could be attributed to the loss of cell turgor pressure resulted from the excessive water loss (Hertog et al., 2004).

The first-order linear regression model was fitted well to the firmness experimental data with coefficients of determination lie within the range of 0.83–0.99 (Table 4). The degradation rate constant k for firmness increased with the temperature increment. However, at both temperatures, the rate constants were the lowest for T3 cucumbers, which validates better firmness retention by these cucumbers (Table 4). The relationship between the reaction rate constant and storage temperature was evaluated by applying the Arrhenius model (Eq. 7) and the activation energies obtained were 28.22, 46.31, 59.61, and 50.38 kJ/mol for control, T2, T3, and T4 cucumbers, respectively. Similar to the present observation, the first-order kinetic model was found suitable in describing the firmness change of coated and uncoated limes during storage (Maftoonazad & Ramaswamy, 2019). Like the weight loss observation, the lower activation energy of the control fruits implies the lower sensitivity to the changes of storage temperature, whereas the higher activation energy of the coated fruits indicates that a smaller temperature change would affect the firmness degradation of the coated fruits (Mohebbi et al., 2014; Remini et al., 2015). T3-coated cucumbers presented not only the lowest degradation rate constant k compared to the other but also exhibited a higher temperature dependence for firmness loss.

Color

Like firmness, color also determines consumer acceptability (Cubero et al., 2011; Maleki et al., 2018). The effect of coating treatment, temperature, and storage time was found to be significant (P < 0.05) for the color changes of cucumbers through the ANOVA (Table 1). The observed L*, a*, and b* values in cucumbers either coated or uncoated and stored at temperatures 15 °C and 23 °C are shown in Table 3. At all studied treatments and temperatures, lightness (L*) and yellowness

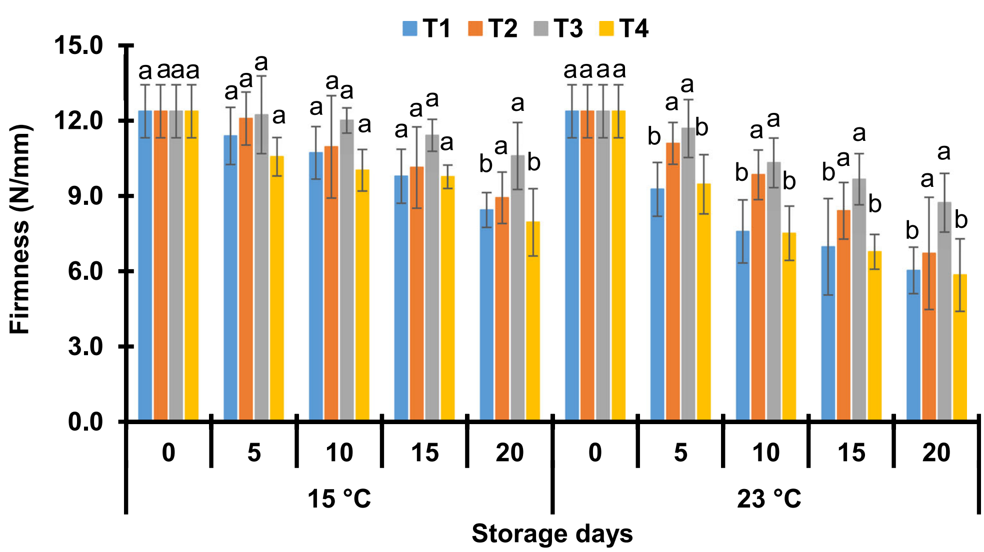

Fig. 2 Firmness (N/mm) changes in control and AV + CMC-coated cucumber slices during storage at 15 °C and 23 °C. In each point, vertical bars represent the standard deviation of the replications. Different letters at the same storage day are significantly different at P < 0.05. Note: T1—distilled water as control, T2—20% AV + 1% CMC, T3—30% AV + 1% CMC, and T4—50% AV + 1% CMC

Table 3 L*, a*, and b* changes in control and AV + CMC-coated cucumber slices during storage at 15 °C and 23 °C

Treatments[a]	Days of storage at 15 °C					Days of storage at 23 °C			
	0	5	10	15	20	5	10	15	20
L*									
T1	26.11 ± 4.28^{a}	27.58 ± 1.68^{a}	33.23 ± 5.71^{a}	37.46 ± 5.17^{a}	40.25 ± 3.15^{a}	28.77 ± 3.68^{a}	34.92 ± 3.77^{a}	39.96 ± 2.01^{a}	42.18 ± 2.90^{a}
T2	26.11 ± 4.28^{a}	26.75 ± 2.53^{a}	30.98 ± 3.00^{ab}	32.69 ± 2.45^{ab}	35.15 ± 3.21^{ab}	28.06 ± 2.80^{a}	31.84 ± 5.19^{a}	32.44 ±2 .23^{ab}	35.46 ± 3.19^{ab}
T3	26.11 ± 4.28^{a}	26.46 ± 3.62^{a}	26.79 ± 1.66^{b}	29.04 ± 1.32^{b}	28.63 ± 1.18^{c}	27.59 ± 3.03^{a}	28.87 ± 2.76^{a}	28.90 ± 1.25^{b}	33.57 ± 2.38^{b}
T4	26.11 ± 4.28^{a}	28.62 ± 1.93^{a}	29.87 ± 1.76^{b}	31.51 ± 1.83^{b}	34.31 ± 4.58^{bc}	27.57 ± 2.05^{a}	31.60 ± 4.37^{a}	33.61 ± 4.23^{ab}	40.67 ± 1.12^{ab}
a*									
T1	− 13.50 ± 0.08^{a}	− 11.12 ± 2.22^{a}	− 8.47 ± 1.59^{b}	− 7.05 ± 1.33^{b}	− 6.47 ± 1.67^{b}	− 8.34 ± 1.08^{b}	− 7.00 ± 0.99^{b}	− 5.96 ± 1.07^{b}	− 5.32 ± 0.85^{b}
T2	− 13.50 ± 0.08^{a}	− 10.95 ± 0.91^{a}	− 8.68 ± 1.21^{b}	− 8.62 ± 0.81^{ab}	− 7.98 ± 1.06^{ab}	− 9.51 ± 0.90^{ab}	− 7.60 ± 1.03^{ab}	− 7.35 ± 1.06^{ab}	− 6.65 ± 1.35^{ab}
T3	− 13.50 ± 0.08^{a}	− 12.98 ± 1.53^{a}	− 12.21 ± 1.27^{a}	− 10.28 ± 1.99^{a}	− 9.15 ± 1.22^{a}	− 10.53 ± 1.17^{a}	− 8.95 ± 1.19^{a}	− 8.17 ± 0.93^{a}	− 8.07 ± 0.65^{a}
T4	− 13.50 ± 0.08^{a}	− 10.78 ± 0.95^{a}	− 8.12 ± 0.94^{b}	− 8.20 ± 0.80^{ab}	− 7.37 ± 0.83^{ab}	− 8.57 ± 1.25^{b}	− 6.76 ± 1.10^{b}	− 6.43 ± 1.24^{ab}	− 5.50 ± 2.05^{b}
b*									
T1	10.27 ± 2.03^{a}	10.22 ± 3.53^{a}	17.97 ± 7.53^{a}	17.46 ± 3.96^{a}	18.17 ± 1.44^{a}	10.10 ± 4.36^{a}	20.79 ± 4.99^{a}	19.71 ± 1.38^{a}	20.29 ± 1.36^{ab}
T2	10.27 ± 2.03^{a}	9.80 ± 2.15^{a}	16.90 ± 5.29^{a}	15.54 ± 2.76^{ab}	15.75 ± 2.98^{ab}	9.40 ± 3.29^{a}	13.03 ± 4.18^{b}	16.15 ± 1.71^{a}	17.31 ± 2.35^{ab}
T3	10.27 ± 2.03^{a}	9.93 ± 1.59^{a}	10.84 ± 2.18^{a}	11.59 ± 1.25^{b}	12.13 ± 1.53^{b}	10.91 ± 2.37^{a}	12.68 ± 2.70^{b}	13.74 ± 3.53^{a}	15.79 ± 3.45^{b}
T4	10.27 ± 2.03^{a}	11.53 ± 2.08^{a}	14.78 ± 2.77^{a}	14.58 ± 2.56^{ab}	17.18 ± 3.99^{a}	9.42 ± 1.98^{a}	14.47 ± 4.28^{ab}	15.92 ± 2.83^{a}	25.32 ± 2.10^{a}

Data (mean ± SD) in the same column followed by different letters (a–b) are significantly different for the treatment factor. On d 0, treatments have equal means since data were recorded from the untreated fresh cucumbers before storage

[a] T1—distilled water as control, T2—20% AV + 1% CMC, T3—30% AV + 1% CMC, and T4—50% AV + 1% CMC

(b*) in cucumber skin increased while greenness (a*) decreased. Therefore, to assess the relationship between the variables, Pearson's correlation tests were conducted.

From Fig. 3, it can be observed that there was a positive and highly significant ($P < 0.05$) correlation between L* and b* whereas L* and a* were significantly ($P < 0.05$) correlated but there exists a negative correlation. Similarly, between a* and b*, there was a negative and highly significant ($P < 0.05$) correlation. These correlations accurately describe the experimental data; the increase in yellowness leads to a lighter green surface of cucumbers during storage. Furthermore, an increased storage temperature of 23 °C triggered the yellowing process, especially in T4 cucumbers (Table 3). Excessive water loss from T4-coated cucumbers might lead to water stress that accelerated ethylene production and yellowing (Burdon et al., 2005). On the other hand, T3 cucumbers significantly ($P < 0.05$) reduced the changes in color parameters compared to control at both temperatures. The modified atmosphere within the cucumbers created by the coatings might delay the factors triggering the chlorophyll degradation (Maleki et al., 2018; Mohammadi et al., 2016). Similarly, reduced changes in L*, a*, and b* values in the coated fruits may be attributed to the reduced oxidative and enzymatic browning of the skin (Park, 1999; Rocha & De Morais, 2000). The performance of edible films largely depends on the water vapor permeability (WVP) and mechanical strength of the film. An optimum dose/concentration is one of the vital factors (Kahramanoğlu et al., 2019) ensuring those qualities in coating materials. Thirty percent AV + 1% CMC presumably provided an optimum permeability property and film thickness necessary for the reduction of respiration rate and other associated changes.

The first-order model (Eq. 6) with non-linear regression was best fitted (R^2, 0.75–0.99) to the L*, a*, and b* experimental data (Table 4). Following the Arrhenius equation (Eq. 7), activation energies were calculated and ranging from 2.55 to 65.38 kJ/mol, 11.07 to 19.79 kJ/mol, and 17.54 to 80.40 kJ/

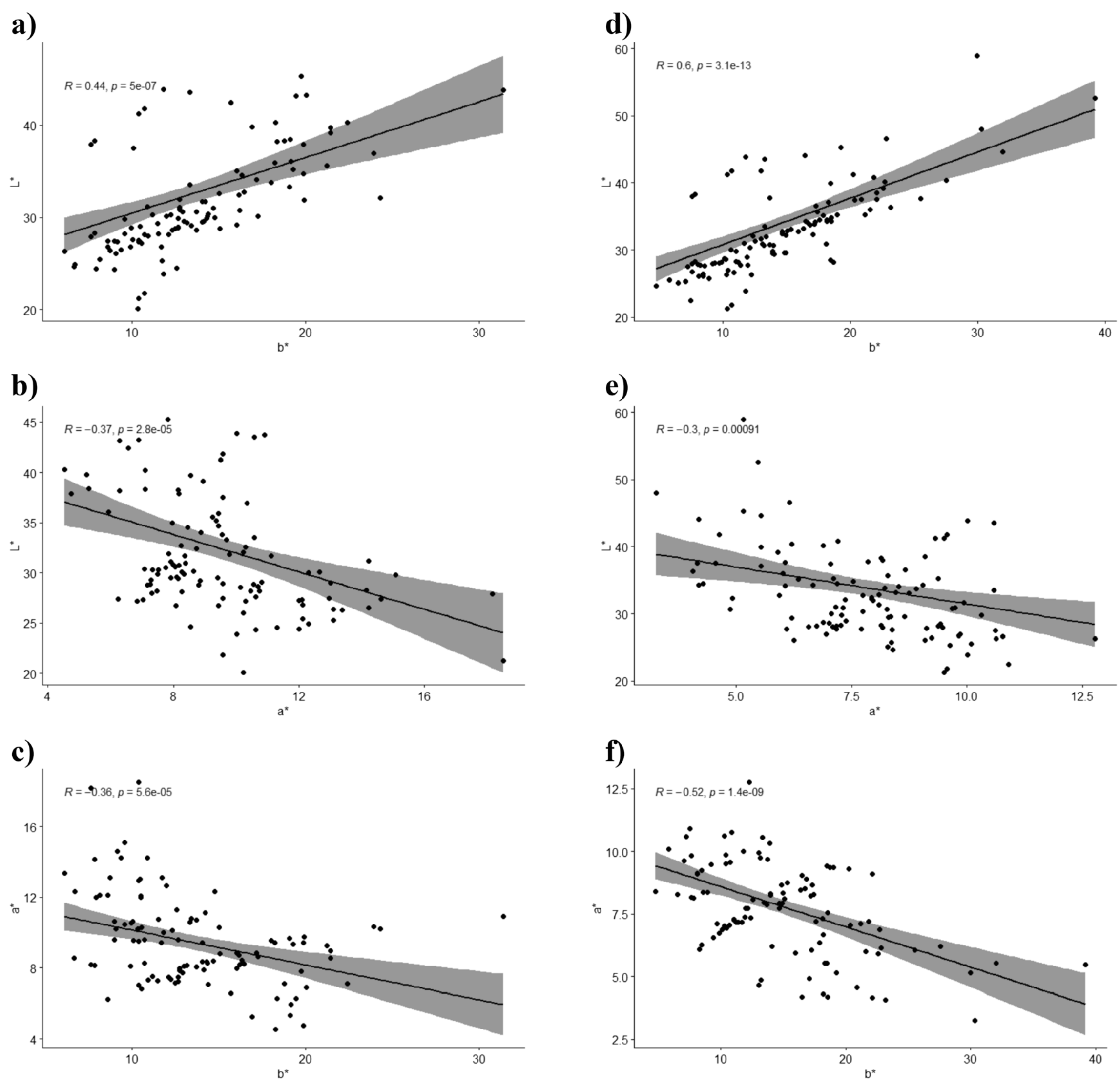

Fig. 3 Pearson correlation *r* (R) of measured L*, a*, and b*. **a**–**c** Representing correlation at 15 °C and **d**–**f** representing correlation at 23 °C

mol for L*, a*, and b*, respectively (Table 4). Similar to the present study, the rates of color deterioration of conventionally frozen and osmo-dehydrofrozen cucumbers were adequately modeled by a first-order reaction (Dermesonlouoglou et al., 2008). Overall, the lower activation energies of the color parameters for control cucumbers (Table 4) represent lower sensitivity to the changes in storage temperature. On the other hand, high activation energies which are indicative of higher temperature dependency (Gonçalves et al., 2007) were observed in coated cucumbers. However, this observation was contradictory to what was reported for coated bell peppers; the lowest activation energies were observed for coated fruits using a first-order linear approach (Mohebbi et al., 2014), and no literature was found focusing on the kinetic study of fresh or coated whole cucumber color parameters. A different modeling approach applied to different horticultural produce stored at a different range of temperatures might lead to this discrimination (Pinheiro et al., 2013). Moreover, looking into the rate constants *k* (Table 4), it is observed that the color degradation rates for control cucumbers were always higher

Table 4 Kinetic parameter estimates (k and Ea) and corresponding coefficient of determination (R^2) of cucumber weight loss, firmness loss, and color changes during storage at 15 °C and 23 °C

Quality parameters	Treatment[a]	Temperature (°C)	*k* (day 1)	R^2	E_a (kJ/mol)
Weight loss	T1	15	0.0135	0.82	13.39
		23	0.0157	0.98	
	T2	15	0.0074	0.90	39.87
		23	0.0116	0.93	
	T3	15	0.0063	0.90	26.56
		23	0.0085	0.96	
	T4	15	0.0147	0.97	23.22
		23	0.0191	0.93	
Firmness	T1	15	0.0198	0.96	28.22
		23	0.0274	0.98	
	T2	15	0.0197	0.99	46.31
		23	0.0332	0.98	
	T3	15	0.0096	0.94	59.61
		23	0.0188	0.99	
	T4	15	0.0175	0.83	50.38
		23	0.0309	0.97	
L*	T1	15	0.2740	0.99	2.550
		23	0.2820	0.99	
	T2	15	0.1910	0.99	17.38
		23	0.1570	0.95	
	T3	15	0.0680	0.76	47.36
		23	0.1160	0.66	
	T4	15	0.1220	0.88	65.38
		23	0.2550	0.90	
a*	T1	15	0.3980	0.99	18.52
		23	0.3230	0.96	
	T2	15	0.2180	0.92	11.07
		23	0.2470	0.96	
	T3	15	0.2500	0.89	19.79
		23	0.2000	0.97	
	T4	15	0.2600	0.90	12.70
		23	0.3000	0.92	
b*	T1	15	0.4110	0.78	17.54
		23	0.5010	0.75	
	T2	15	0.3380	0.66	26.36
		23	0.4550	0.99	
	T3	15	0.1440	0.99	49.63
		23	0.2520	0.97	
	T4	15	0.2610	0.90	80.40
		23	0.6460	0.92	

[a] T1—distilled water as control, T2—20% AV + 1% CMC, T3—30% AV + 1% CMC, and T4—50% AV + 1% CMC

regardless of the storage temperature, which further indicates less sensitivity to temperature changes. On the other hand, coated cucumbers, for example, T3 cucumbers generally had a color degradation rate almost 2-fold higher at 23 °C than that of 15 °C indicating higher temperature dependence. Color is one of the critical quality indices of cucumbers, and the color changes are noticeable by the human eye (Dermesonlouoglou et al., 2008). The color changes can be considered a sign of cucumber quality deterioration, and the extent of the deterioration and shelf life of the stored cucumbers can be calculated following the kinetic approach with a pre-defined acceptability threshold.

Fungal Analysis

The growth of molds and yeasts is the most significant factor which leads to the spoilage of cucumber (Maleki et al., 2018). Table 5 shows the fungal growth in control and coated cucumbers over the storage period at 15 °C and 23 °C. The factors treatment and day had significant effects ($P < 0.05$) on the fungal growth (Table 1). In both control and coated fruits, mold and yeast counts increased with the storage days. However, irrespective of temperature and days to storage, the mean fungal count in T3-coated cucumbers was significantly ($P < 0.05$) lower throughout the storage period than that of the control cucumbers (Table 5). After the end of the storage period, the reduction of fungal counts by T3 cucumbers was 34.70% and 37.94% at 15 °C and 23 °C, respectively, when compared to control. At any sampling day, treatment had no significant effect on mold growth; however, coated cucumbers, especially T2 and T3 cucumbers, had lower mold and yeast counts than that of control and T4 cucumbers at both temperatures studied. AV gel has been demonstrated to possess antifungal activity against a range of postharvest pathogenic fungi (De Rodrıguez et al., 2005; Saks & Barkai-Golan, 1995). Owing to the antimicrobial and antifungal activity, edible coatings made from AV gel have been reported to suppress overall microbial counts in stored fruits (Martínez-Romero et al., 2006; Valverde et al., 2005). In the present study, the exhibited antifungal activity of AV + CMC composite coatings might be attributed to the presence of AV gel as an antimicrobial agent. Similarly, AV gel contributed to the antifungal activity of starch-based edible films as applied to cherry tomatoes (Ortega-Toro et al., 2017). Moreover, after 20 days of storage, mold and yeast counts in all the cucumbers were higher when stored at 15 °C than that at 23 °C, although the effect of temperature on the fungal growth was not significant (Table 1). A similar lower fungal count was reported in cucumbers stored at room temperature, which was attributed to lower humidity of storage at a higher temperature (Maleki et al., 2018).

Table 5 Fungal growth (log CFU/g) in cucumbers during storage at 15 °C and 23 °C

Treatments[a]	Days of storage at 15 °C					Days of storage at 23 °C				Mean
	0	5	10	15	20	5	10	15	20	
T1	1.33 ± 0.36a	1.52 ± 1.00a	1.75 ± 0.08a	2.77 ± 0.23a	3.17 ± 0.29a	1.75 ± 0.04a	1.79 ± 0.41a	1.84 ± 0.11a	2.82 ± 0.14a	1.94 ± 0.72a
T2	1.33 ± 0.36a	1.36 ± 0.50a	1.56 ± 0.04a	1.58 ± 0.02a	2.29 ± 0.37a	1.42 ± 0.50a	1.68 ± 0.15a	1.74 ± 0.10a	2.28 ± 0.36a	1.63 ± 0.50ab
T3	1.33 ± 0.36a	1.39 ± 0.45a	1.44 ± 1.01a	1.50 ± 0.41a	2.07 ± 0.46a	1.38 ± 0.01a	1.53 ± 0.01a	1.69 ± 0.13a	1.75 ± 0.11a	1.52 ± 0.47b
T4	1.33 ± 0.36a	1.42 ± 0.76a	1.99 ± 0.43a	2.33 ± 0.50a	2.63 ± 0.04a	1.17 ± 0.35a	1.71 ± 0.41a	2.32 ± 0.45a	2.45 ± 0.19a	1.82 ± 0.61ab

Data (Mean ± SD) in the same column followed by different letters (a-b) are significantly different for the treatment factor. On d 0, treatments have equal means since data were recorded from the untreated fresh cucumbers before storage

[a] T1—distilled water as control, T2—20% AV + 1% CMC, T3—30% AV + 1% CMC, and T4—50% AV + 1% CMC

pH, TSS, and TA

From Table 1, coating treatment, storage temperature, and days, and their interactions were found to have a significant effect on pH change ($P < 0.05$). At both temperatures, initially, there was an increment which was then followed by a reduction in pH later in the storage period (Table 6). However, this trend was more apparent at higher storage temperature and with T1 and T4 cucumbers. The change in pH depends on the respiration rate and metabolic activity determined by any postharvest treatment or enzymatic activity affecting the biochemical composition of the fruits and vegetables (Jitareerat et al., 2007; Maleki et al., 2018). With the progression of storage days, pH generally increases because of the organic acids being used up as substrates in the respiration metabolism. However, later in the storage days, T1 and T4 cucumbers returned to more acidic pH, which might be due to the fact that the sugar converted to acids (Maleki et al., 2018). The pH in T3 cucumbers, at both temperatures, were significantly ($P <$ 0.05) stable throughout the storage period, which was followed by the T2 cucumbers. Lower internal oxygen levels resulting in a reduced respiration rate in the AV + CMC-coated cucumbers might be responsible for the stability of pH. On the other hand, the acid buildup in T4-coated cucumbers might be attributed to fruit fermentation caused by the low oxygen levels along with high coating concentration (Jitareerat et al., 2007).

Overall, as shown in Table 1, AV + CMC coating treatment had no significant ($P < 0.05$) effect on TSS during storage, but the effect of storage temperature and day was significant. Like the pH trend observed in this study, TSS content was increased at the earlier storage days, which later begun to decrease (Table 6). Overall, the T2- and T3-coated cucumbers were relatively stable as compared to the control and T4 cucumbers at the temperatures studied. Since the ripening process continues after harvest, organic acids are being used up during respiration metabolism, which increases the TSS (Benítez et al., 2013; Wiley, 1994). After the end of the storage period, at both temperatures, control and T4 cucumbers suffered the lowest TSS, which might be due to the senescence and fermentation leading to TSS reduction (Ali, Khan, Anjum, et al., 2019a; Jitareerat et al., 2007). Moreover, due to the accelerated senescence at the higher temperature, the mean TSS content of the cucumbers was significantly ($P < 0.05$) lower at 23 °C than that at 15 °C (data not shown).

As far as the TA is concerned, coating treatment and storage days had a significant effect (Table 1). From Table 6, at both temperatures, TA was gradually reduced as the storage day progressed; however, there was an increment again during the last days of storage which eventually led the TA at the end of storage to be higher than that of the initial TA at d 0, especially at 23 °C. T2 and T3 cucumbers, especially T3 cucumbers, exhibited substantial stability to TA changes compared to the control and T4 cucumbers. TA of fresh produce changes as a result of postharvest ripening and senescence (Ali, Khan, Nawaz, et al., 2019b). Organic acids, which are the substrates for the respiration process, are consumed during the senescence of the produce in the storage. Therefore, with the progression of the storage period, TA of the fresh produce decreases. However, TA could further start to increase due to the sugars converting to acids (Hazrati et al., 2017; Maleki et al., 2018). Nevertheless, the stability of TA can be maintained by the optimal coating application, which reduces senescence and oxidation of organic acids (Song et al., 2013).

Overall Visual Quality

On d 0, treatments have equal means since data were recorded from the untreated fresh cucumbers before storage.

Aloe vera + CMC coating, temperature, and storage days all have a significant effect on the overall visual quality (OVQ) of cucumbers during storage (Table 1). As shown in Fig. 4, the OVQ score of the cucumbers decreased over time regardless of the coating treatment. However, T3-coated cucumbers had the highest ($P < 0.05$) overall OVQ score and were acceptable (OVQ score > 3.5) after 20 days of storage at both temperatures. Unlikely, both control and T4 cucumbers fell short of the acceptance limit (3.5) after 5 days of storage at both temperatures. On the other hand, T2-coated cucumbers were acceptable after 20 days of storage at 15° C; however, they were no longer acceptable after 15 days of storage at 23 °C. Moreover, as expected, the mean OVQ score of the cucumbers was significantly higher at a storage temperature of 15 °C than that of 23 °C (data not shown). The loss of acceptability by the control and T4 cucumbers at earlier storage periods could be ascribed to the incidence of color change (yellowness, surface pitting, and browning) and shrinkage due to excessive water loss. The remarkable OVQ score observed in T3 cucumbers presumably due to limited enzymatic browning and color changes on the surface (Ali, Khan, Nawaz, et al., 2019b; Du et al., 2009; Mohammadi et al., 2016). There was a good agreement between the OVQ score and other quality parameters investigated throughout the study. Therefore, AV + CMC composite coating treatment can be suggested for retaining the visual quality of cucumbers during storage. Similar to the present study, AV coating was found beneficial for maintaining the visual quality of post-cut lotus root slices (Ali, Khan, Anjum, et al., 2019a).

Conclusions

In this study, a range of coating solutions made with AV + CMC was used. Both coating materials, along with the plasticizer, glycerol are water-soluble; they could be removed by

Table 6 pH, TSS, and TA changes in control and AV + CMC-coated cucumbers during storage at 15 °C and 23 °C

Treats[a]	Days of storage at 15 °C					Days of storage at 23 °C			
	0	5	10	15	20	5	10	15	20
pH									
T1	5.82 ± 0.005^{a}	5.86 ± 0.009^{a}	5.91 ± 0.049^{a}	5.96 ± 0.008^{a}	5.85 ± 0.012^{a}	5.87 ± 0.017^{ab}	5.93 ± 0.033^{a}	5.80 ± 0.017^{b}	5.21 ± 0.005c
T2	5.82 ± 0.005^{a}	5.83 ± 0.012^{a}	5.87 ± 0.031^{a}	5.92 ± 0.034^{ab}	5.87 ± 0.049^{a}	5.85 ± 0.008^{ab}	5.89 ± 0.021^{ab}	5.87 ± 0.012^{a}	5.45 ± 0.022^{b}
T3	5.82 ± 0.005^{a}	5.83 ± 0.012^{a}	5.84 ± 0.025^{a}	5.87 ± 0.024^{b}	5.89 ± 0.009^{a}	5.84 ± 0.008^{b}	5.85 ± 0.021^{b}	5.90 ± 0.022^{a}	5.81 ± 0.074^{a}
T4	5.82 ± 0.005^{a}	5.86 ± 0.017^{a}	5.93 ± 0.026^{a}	5.97 ± 0.034^{a}	5.84 ± 0.024^{a}	5.89 ± 0.012^{a}	5.96 ± 0.008^{a}	5.78 ± 0.021^{b}	5.15 ± 0.022c
TSS									
T1	3.17 ± 0.05^{a}	3.73 ± 0.09^{a}	3.85 ± 0.11^{a}	3.90 ± 0.08^{a}	3.43 ± 0.05^{a}	3.75 ± 0.11^{a}	3.87 ± 0.09^{a}	3.67 ± 0.09^{a}	2.67 ± 0.12^{b}
T2	3.17 ± 0.05^{a}	3.50 ± 0.08^{a}	3.73 ± 0.12^{a}	3.80 ± 0.08^{a}	3.53 ± 0.05^{a}	3.53 ± 0.05^{a}	3.77 ± 0.12^{a}	3.70 ± 0.22^{a}	3.50 ± 0.14^{a}
T3	3.17 ± 0.05^{a}	3.47 ± 0.12^{a}	3.63 ± 0.12^{a}	3.67 ± 0.17^{a}	3.70 ± 0.22^{a}	3.50 ± 0.14^{a}	3.67 ± 0.21^{a}	3.73 ± 0.09^{a}	3.60 ± 0.08^{a}
T4	3.17 ± 0.05^{a}	3.80 ± 0.22^{a}	3.87 ± 0.17^{a}	4.00 ± 0.22^{a}	3.00 ± 0.08^{b}	3.83 ± 0.33^{a}	3.90 ± 0.24^{a}	3.43 ± 0.17^{a}	2.63 ± 0.05^{b}
T[a]									
T1	0.073 ± 0.012^{a}	0.066 ± 0.003^{b}	0.060 ± 0.003^{b}	0.053 ± 0.008^{b}	0.062 ± 0.003^{a}	0.062 ± 0.008^{a}	0.058 ± 0.005^{a}	0.062 ± 0.003^{a}	0.081 ± 0.003^{a}
T2	0.073 ± 0.012^{a}	0.073 ± 0.006^{ab}	0.064 ± 0.005^{ab}	0.062 ± 0.003^{ab}	0.070 ± 0.005^{a}	0.070 ± 0.005^{a}	0.062 ± 0.008^{a}	0.066 ± 0.008^{a}	0.077 ± 0.005^{a}
T3	0.073 ± 0.012^{a}	0.073 ± 0.004^{ab}	0.070 ± 0.009^{a}	0.066 ± 0.003^{a}	0.066 ± 0.003^{a}	0.074 ± 0.004^{a}	0.073 ± 0.008^{a}	0.070 ± 0.005^{a}	0.076 ± 0.004^{a}
T4	0.073 ± 0.012^{a}	0.068 ± 0.003^{b}	0.058 ± 0.005^{b}	0.052 ± 0.008^{b}	0.064 ± 0.005^{a}	0.062 ± 0.012^{a}	0.053 ± 0.008^{a}	0.066 ± 0.003^{a}	0.085 ± 0.003^{a}

Data (mean ± SD) in the same column followed by different letters are significantly different for treatment factor. On d 0, treatments have equal means since data were recorded from the untreated fresh cucumbers before storage

[a] T1—distilled water as control, T2—20% AV + 1% CMC, T3—30% AV + 1% CMC, and T4—50% AV + 1% CMC

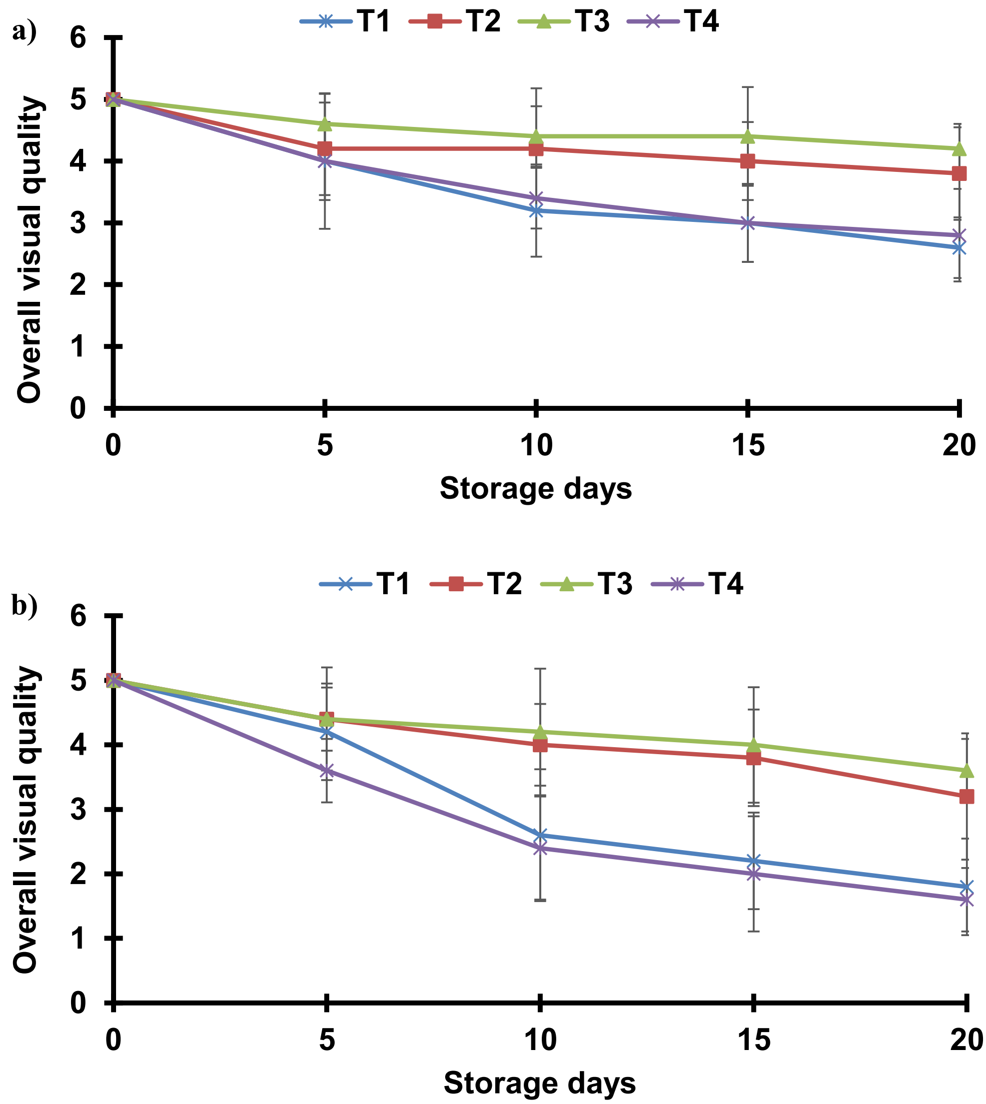

Fig. 4 Overall visual quality (OVQ) score of control and AV + CMC-coated cucumbers during storage at 15 °C (**a**) and 23 °C (**b**). In each point, vertical bars represent the standard deviation of the replications. Note: T1—distilled water as control, T2—20% AV + 1% CMC, T3—30% AV + 1% CMC, and T4—50% AV + 1% CMC

rinsing the cucumbers with water before consumption. The composite coating made with 30% AV + 1% CMC was found to be effective in maintaining postharvest quality parameters. Among the tested coating formulations, 30% AV + 1% CMC better retained the postharvest quality by suppressing physicochemical changes such as weight loss, firmness loss, color changes, pH, TSS, and TA changes, and fungal growth while maintaining the overall visual quality during 20 days of storage at 15 °C and 23 °C. Fifty percent AV + 1% CMC was found not to be a suitable coating concentration since it drew the water out of the coated cucumbers due to the phenomenon of "osmotic dehydration." The suitability of an edible coating as a postharvest treatment depends on its physicochemical properties such as water vapor permeability, thickness, and mechanical strength. From this study, it can be concluded that 30% AV together with 1% CMC provided the optimum coating properties necessary for the reduction of water loss, respiration rate, and other physicochemical changes associated with them. The kinetic study revealed that the degradation kinetics of cucumbers for weight loss, firmness, and color changes followed the first-order reaction model. Moreover, reaction rate constant (k) was found to be temperature-dependent, i.e., degradation rate increased with the increment of storage temperature. Overall, at both temperatures, cucumbers coated with 30% AV + 1% CMC had the lowest degradation rates regarding weight loss, firmness loss, and color changes. Nevertheless, the rates of degradation turned out to be almost 2-fold higher as the storage temperature increased from 15 to 23 °C. Therefore, cucumbers coated with 30% AV + 1% CMC can be recommended to store at 15 °C for 20 days while conserving the postharvest quality.

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Declarations

Conflict of Interest The authors declare no conflict of interest.

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