**An Acad Bras Cienc (2020) 92(2): e20181387 DOI 10.1590/0001-3765202020181387**
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

ENGINEERING SCIENCES

# Kinetics of colour and texture changes of button mushrooms (*Agaricus bisporus*) coated with chitosan during storage at low temperature

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**Abstract:** Kinetics of color and texture changes in coated button mushrooms were investigated as a function of coating agent's rate (1%, 2% and 3% w/v chitosan). The inner and outer surface colours of mushrooms in terms of CIELAB parameters L*, a*, b*, C*, ° h, ΔE, and Browning Index (BI), and their textural properties in terms of firmness were evaluated. The color values on both sides of the mushrooms except for L* values increased and their firmness decreased with the coating treatment. The color changes of the inner and outer surface of mushrooms and their texture changes followed zero-order reaction models with higher R2 (0.9987-0.9999) and lower RMSE (4.8448 x $10^{-5}$-1.6690) and χ2 values (3.9120 x $10^{-9}$-4.6425). The 2% chitosan solution was determined to be the most effective coating agent among the coating agents used to extend the post-harvest shelf life by optimally preserving the color parameters of the mushrooms together with their texture properties.

**Key words:** chitosan coating, kinetics, mushroom, colour, texture.

## INTRODUCTION

Mushrooms have been consumed for centuries in terms of their nutritional and medical properties, which are good sources of polysaccharides (β-glucans, chitin, hemicelluloses), dietary fibers, proteins containing essential amino acids, many biologically active and health-promoting compounds such as polyphenols and carotenoids, and polyunsaturated fatty acids (PUFAs) despite their low fat content (Pardeshi & Pardeshi 2009, Dembitsky et al. 2010, Muszyńska et al. 2018, Rathore et al. 2017). They have nutritionally significant vitamin content (C, E, D, $B_1$, $B_2$, and $B_{12}$) (Heleno et al. 2010, Reis et al. 2012). They are also rich in calcium, potassium, magnesium and phosphorus (Rajarathnam & Shashirekha 1998, Rathore et al. 2017). Button mushroom (*Agaricus bisporus*) which is the most popular mushroom variety grown and consumed is an easily perishable food with shelf life of about 24 h at ambient temperature and between 5 and 7 days under refrigerated conditions (Motevali et al. 2011, Das & Arora 2018). The short shelf life of mushrooms is a major disadvantage limiting its economic value. During harvest and postharvest storage, mushrooms are subjected to a series of quality degradation such as moisture loss, discolouration, off flavour, softening, and nutrition loss (Ding et al. 2016, Zhang et al. 2018). Among the different techniques employed to extend the shelf life and retain the nutritional value of products, the use of edible films or coatings represents one of the best alternative ways of preservation due to their ability to reduce moisture loss, solute migration and respiration and transpiration

rate. They generally increase the shelf life of product (Tezotto-Uliana et al. 2014, Mannozzi et al. 2017). The colour and texture of the product are the most important parameters affecting consumer preference at first glance. Products undergo significant textural and color transformations during storage. The shelf life of products is closely associated with this fact. Edible coatings/films can be used to provide physical protection, such as protection of food products from mechanical damage and from physical, chemical and microbiological activities (Min et al. 2005, Dehghani et al. 2018). The use of edible coatings/films means that the shelf life of products can be extended by minimizing the change in their color and textural properties. Polysaccharide-based coatings such as chitosan have been frequently used for this purpose (Jiang et al. 2013). Chitosan is considered as an ideal protective coating agent for fresh fruits and vegetables due to its excellent film-forming and biochemical properties (El-Ghaouth et al. 2000, Ali et al. 2011). For extending shelf life of fresh or semi-processed foods, chitosan has been attempted in plum (Kumar et al. 2017), Cavendish banana (Suseno et al. 2014), table grape (Gao et al. 2013), strawberry (Wang & Gao 2013), shiitake mushroom (Jiang et al. 2013), guava (Hong et al. 2012), Eksotika II papaya (Ali et al. 2011), litchi (Dong et al. 2004), mango (Kittur et al. 2001) with successful results. The products are expected to maintain their quality properties throughout their shelf life. As the shelf life of products is extended, it is desirable that the quality characteristics do not decrease and they maintain. Both the shelf life of products and their sustainability of the quality characteristics during shelf life are affected by the rate of chitosan used in the edible coating. No published work has been found yet in the literature, which describes by kinetic modelling the effect of the ratio of edible coating agent used on the colour and textural properties of the product during storage. But, there are a limited number of studies describing the changes in both color and textural properties of products as a result of various processes with kinetic modeling (Lau et al. 2000, Chen & Ramaswamy 2002, Kahyaoglu & Kaya 2006, Kumar et al. 2006, Gonçalves et al. 2007, Jaiswal et al. 2012, Jaiswal & Abu-Ghannam 2013).

The use and determination of suitable formulations of edible coatings, which are the most important competitors of conventional packages, provides that the desired quality criteria of products are kept at the maximum level during storage. The objectives of this study are to investigate the effect of chitosan's ratio used in edible coatings on the colour and textural characteristics of button mushrooms using kinetic modelling during storage and to determine the formulation of the edible coating that best preserves both the colour and texture of button mushrooms.

## MATERIALS AND METHODS

### Sample preparation

Button mushrooms were purchased from the commercial market (Migros Trade Inc., Izmir, Turkey) and selected for uniform size, shape, and color prior to coating. Firstly, the selected mushrooms were immersed in a 0.1 % NaClO solution during 1 min for surface-sterilization and air-dried at room temperature for 30 min. Hydrosoluble chitosan powder was purchased from Qingdao Reach International Inc., Qingdao, China (hydrosoluble chitosan from Alaska snow crab shells, 91.6% deacetylated). Chitosan (1.0, 2.0, 3.0 % w/v) powder was dissolved in aqueous solution of malic acid (2% w/v) at room temperature and stirred vigorously using magnetic stirrer for 8 h (Stuart Scientific, UK). The pH in all solutions was adjusted to 6.0 with 0.1 M

sodium hydroxide. The adjusted solutions were also stirred for 2 h at room temperature. Then, the mushrooms dipped for 1 min into chitosan solutions at the following concentrations: 1.0, 2.0, 3.0% (w/v). The mushrooms treated with only 2% malic acid solution were used as control (Eissa 2007). After coating, the mushrooms were left to dry at ambient temperature. All coated samples were placed into macroperforated polypropylene film bag was used (40 µm thickness, $1.3x10^4$ perforations/$m^2$, $0.2mm^2$ surface). This film preserves the atmosphere within the package at normal air composition. Then they are stored during 0, 5, 10, 15 and 20 days at 4°C for evaluation of their colour characteristics. All sample preparation was done in duplicates.

### Colour and texture determination

A Minolta Colourimeter (CR-400 Model Colourimeter, Konica Minolta Sensing, Inc., Osaka, Japan) was used to measure the L*, a* and b* values of mushrooms during storage. It has two standard illuminant (C and $D_{65}$) and standard colorimetric observer (2°) inside. The instrument was calibrated before taking measurement with a standard white plate (Y = 85.7, x = 0.3179, y = 0.3254). Ten random readings were taken from the inner and outer surfaces of each sample. The L* value shows lightness. The a* value defines greenness when negative and, redness when positive. The b* value measures blueness when negative, and yellowness when positive (Ali et al. 2014). The values of chroma (C*) (Eq. (1)) and hue (°h) (Eq. (2)) were calculated from a* and b* values. Furthermore, the total colour change (ΔE) (Eq. (3)) and browning index (BI) (Eq. (4)) were estimated using L*, a*, b* values.

$$C^* = \sqrt{\left((a^*)^2 + (b^*)^2\right)} \quad \text{Eq. 1}$$

$$^{o}\ h = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad \text{Eq. 2}$$

$$\Delta E = \sqrt{\left(L_0^* - L^*\right)^2 + \left(a_0^* - a^*\right)^2 + \left(b_0^* - b^*\right)^2} \quad \text{Eq. 3}$$

$$BI = \frac{\left[100(x - 0.31)\right]}{0.17} x = \frac{\left(a^* + 1.75L^*\right)}{\left(5.645L^* + a^* - 3.012b^*\right)} \quad \text{Eq. 4}$$

where $L_0^*$, $a_0^*$, $b_0^*$ were the colour values of samples at the initial time, L*, a*, b* were colour values of samples at the pre-specified time.

A penetration test was performed to evaluate the textural properties of the samples using a TA.XT Plus Texture Analyzer (Stable Micro Systems, Godalming, UK) and a 5 mm diameter cylindrical probe on the mushroom caps. Samples were penetrated to 5 mm in depth and the speed of the probe was 2.0 $mm.s^{-1}$ throught the pre-test and penetration. Using the force vs. time curves obtained, firmness was defined as the maximum force (N) (Jiang et al. 2013). All experiments were carried out in five replicates.

### Data analysis

In general, it is seen in the literature that changes in color and texture of foodstuff can be explained by zero- (Eq. (5)) or first-order (Eq. (6)) kinetic models (Lau et al. 2000, Chen & Ramaswamy 2002, Kumar et al. 2006, Kahyaoglu & Kaya 2006, Gonçalves et al. 2007, Jaiswal et al. 2012, Jaiswal & Abu-Ghannam 2013). To describe the changes in colour and texture of mushrooms during storage, zero-order (Eq. (5)) and first order kinetic models (Eq. (6)) were used in this study.

$$C_t = C_0 \pm k_0 \quad \text{Eq.5}$$

$$C_t = C_0 \exp(\pm k_1 \cdot t) \quad \text{Eq.6}$$

where $k_0$ and $k_1$ are the kinetic rate constants ($day^{-1}$), $C_0$ is the rate of change in the quality factor (L*, a*, b*, C*, °h, ΔE, BI and Firmness) at initial time, $C_t$ is the rate of change in the quality factor at time t and $t$ is the reaction time (day).

The values of kinetic parameters ($C_0$, $k_0$, $k_1$) were estimated by fitting the model to the experimental data using the nonlinear least squares procedure (Microsoft Excel 2010 and Solver Add-In package of Excel) which minimizes the sum of squares of errors between the experimental and modelled data (Brown 2001, Lambert et al. 2012). The terms used to evaluate goodness of fit were the correlation coefficient ($R^2$), chi-square ($\chi 2$) (Eq. (7)), the residual sum of squares (RSS) (Eq. (8)) and root mean square error (RSME) (Eq. (9)). The highest $R^2$ and the lowest $\chi 2$ and RMSE values indicate the best model (Kaleta & Górnicki 2010, Horuz et al. 2017). One-way analysis of variance (ANOVA) was performed on the kinetic parameters using SPSS software v 20.0 and significant effects ($p$<0.05) were determined. Significant difference amongst the values was evaluated by Duncan multiple range test.

$$\chi^2 = \frac{\sum_{i=1}^{N}(C_{\exp,i} - C_{pre,i})^2}{N - P} \quad \text{Eq. 7}$$

$$\text{RSS} = \sum_{i=1}^{N}(C_{\exp,i} - C_{pre,i})^2 \quad \text{Eq. 8}$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{N}(C_{\exp,i} - C_{pre,i})^2}{N}} \quad \text{Eq. 9}$$

where $C_{exp,i}$ is the experimental value of the $i$th analysis, $C_{pre,i}$ represents the predicted value of $i$th analysis, $N$ is the total number of experimental data and $P$ is the constants' number in a particular kinetic model.

## RESULTS AND DISCUSSION

### Colour and texture changes in coated samples

Changes in color and browning are the main post-harvest issues that need to be considered for commercialization of mushrooms (Liu & Wang 2012, Khan et al. 2014, Gholami et al. 2017). The change in colour from white to brown occurs over the storage period. This is an expected situation. During storage, mushroom browning occurs as a result of spontaneous oxidation, and/or activation of tyrosinase that is an enzyme belonging to the polyphenoloxidase family. In Figure 1 the changes in the colour parameters of mushroom samples coated with coating agent (chitosan solution) at different ratios during 20 days of storage at 4ºC are illustrated. L* values on both outer and inner surfaces of the mushrooms decreased as the ratio of the coating agent used and storage time increased. However, b* and a* values on both surfaces increased with the increase of storage time and the ratio of coating agent. Coating caused a lower lightness and denser red and yellow colour in the mushroom samples than the control one, probably due to the colour attributes of coating agent. Furthermore, the high water binding capacity of chitosan may supress the dripping loss of mushrooms and this is positively affected by the increase chitosan concentration used in the coating solution. As a result of that transparency may increase and L* value may decrease (Eissa 2007, Nasiri et al. 2018). During storage, a decrease in the L* value is related with mushroom browning. The reduction in L* values on both outer and inner surfaces of the control sample is higher than the others. This reduction is related with the increase in metabolism involving various enzymatic and non-enzymatic reactions and leads to browning (Adiletta et al. 2016, Castelo Branco Melo et al. 2018). The a* and b* values on both outer and inner surfaces of the control sample tended to increase more since the first days of storage compared to the coated samples. The formation of more intense yellow and red colour during storage is the result of over-ripening and is expected. These show

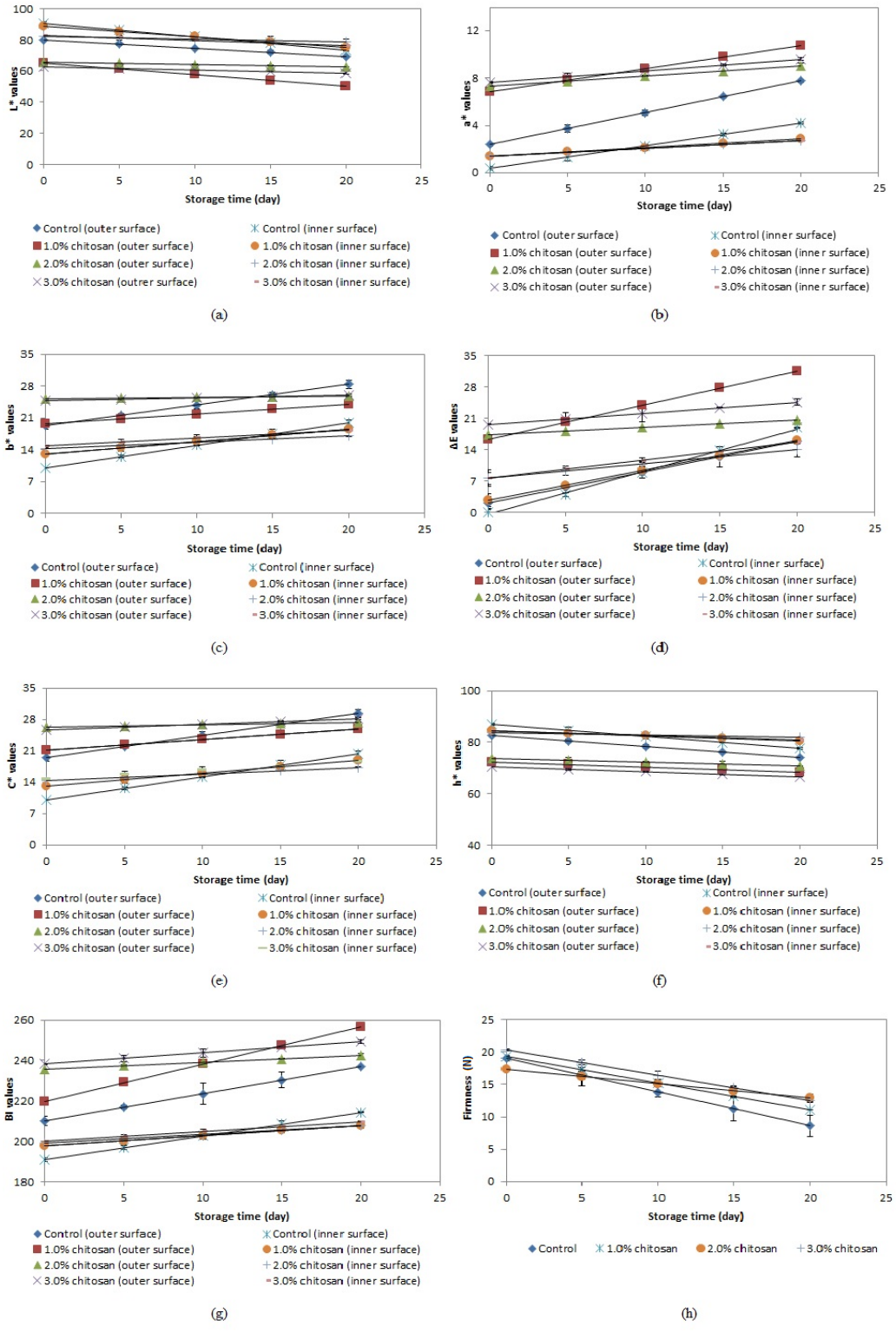


**Figure 1.** Effects of both storage time and the ratio of the coating agent used on the L* (a), a* (b), b* (c), C* (d), °h (e), ΔE (f), and BI (g) and firmness (h) properties of button mushrooms. * Some of the standart deviation bars are smaller than some symbols.

that the use of chitosan coating in mushrooms slows down their senescence process.

Depending on the ratio of the coating agent used, the C* values on both the inner and outer surfaces of the mushrooms increased while the ° h values on both the inner and outer surfaces of the mushrooms decreased during storage. This decrease in ° h values means that the yellowness in the colour of mushrooms reduced and the redness increased. During storage, it was observed that the C* values in the inner surface of mushrooms were slightly decreased and closely followed the b* values. This indicates that the yellow color in the inner surface of the mushrooms is more stable than the outer surface since the C* value expresses the degree of saturation of the color. Also, the C* value of the control sample was lower and the ° h value was higher than that of the coated mushrooms. It was determined that the color of the control sample was more yellowish and dull than the other samples.

Chitosan coating inhibites the increase of oxidative enzyme activity (polyphenoloxidase, peroxidase, phenylalanine ammonia lyase, catalase, laccase) of mushroom which is associated with discoloration (Eissa 2007). Therefore, the changes in color parameters of the control samples in this study were sharper than the coated samples. In the study of Jiang & Li (2001), it was determined that chitosan coating inhibited the growth of some fungi and delayed the increase in decay of stored longan fruit. Similarly, the chitosan coating appeared to reduce the pH of the mushrooms during storage in Eissa (2007)'s study. This is an indication that chitosan coating reduces pathogen development. Pathogen development is one of the main factors causing decay of the mushroom (Eissa 2007). In this study, coating of mushrooms with chitosan could be partially useful in delaying discoloration and browning during storage, as a result of inhibating microbial growth.

The presence of the coating caused an increase in BI values as well as in ΔE values on both the inner and outer surfaces of the mushrooms at the beginning of storage. These can be ascribed to the inherent yellowish color of chitosan (Gholami et al. 2017). In addition, BI and ΔE values on both the inner and outer surfaces of the mushrooms increased with increasing storage time. The shelf life of the mushroom is closely related to the rate of respiration in the postharvest period. Nutrients such as carbohydrates, proteins and fats in its tissue are metabolized by $O_2$ to simple end products such as $CO_2$ or organic acid. This results in both the ripening and senescence of mushroom (Cliffe-Byrnes & O'Beirne 2007, Li et al. 2017). The increase in BI and ΔE values of the product during storage is also inevitable. Since the $O_2$ permeability of chitosan is higher than its $CO_2$ permeability, chitosan coating modifies the internal atmosphere of the product. In the coated mushrooms, the $CO_2$ concentration is higher compared with the control sample. The high $CO_2$ concentrations can cause damage to the mushroom cap surface tissue, resulting in high BI and ΔE values. However, another phenomenon that causes colour change and browning is the occurrence of enzymatic browning in the presence of oxygen. Gholami et al. (2017) stated that enzymatic browning played an important role in the color changes of the control samples, but was less effective on the color change of the coated mushrooms. Findings about changes in their color parameters as a result of the mushrooms coated with chitosan and their storage are in agreement with the results of studies conducted by Eissa (2007), Ali et al. (2011), Mannozzi et al. (2017), Gholami et al. (2017), Castelo Branco Melo et al. (2018), Sneha Nair et al. (2018) and Nasiri et al. (2018).

Loss of firmness is a very important parameter that gives an idea about the quality of mushroom during marketing. The chitosan coating significantly improved firmness of the mushrooms. The firmness of all samples decreased with storage, but chitosan-coated mushrooms exhibited higher firmness compared to the control sample during storage. At the end of the storage period, the control samples had the fastest firmness loss with approximately 54.59%. This was followed by 1.0% chitosan, 3.0% chitosan and 2.0% chitosan coated mushrooms with softening rates of approximately 42.53, 38.41 and 25.61%, respectively. The reason for the higher firmness values of the coated mushrooms is probably the presence of the coating agent which provides a structural rigidity at the surface of the product (Duan et al. 2011, Mannozzi et al. 2017). During storage, the mushrooms tend to soften. Softening depends on cell structure deterioration, cell wall composition and intracellular materials (Seymour et al. 1993, Hong et al. 2012). Preservation of the firmness of chitosan-treated mushrooms may be due to the reduction of respiration and other maturation processes during storage as a result of covering the cuticle and lentils of the mushrooms with the chitosan coating (Ali et al. 2005, Martínez-Romero et al. 2006, Hong et al. 2012). The observed firmness loss is similar to that reported by Ali et al. (2011), Hong et al. (2012) and Jiang et al. (2012), in studies on the effect of chitosan coating on papaya, guava, shiitake mushroom and button mushroom, respectively.

## Kinetics consideration of colour and texture parameters

Experimental data for colour and texture parameters were fitted to different kinetic models. A regression analysis was performed for the kinetic equations of zero- and first-order. The estimated kinetic parameters and statistical values are presented in Tables I-IV.

Zero-order kinetic model Eq. (5) was determined to be appropriate for modelling the changes in color and textural properties of the chitosan-coated mushrooms during storage with higher $R^2$ and lower RMSE and $\chi 2$ values. Similar findings indicating that the changes in color and textural properties of foods during various treatments were compatible with the zero-order kinetic model, were observed by Kumar et al. (2006) and Jaiswal & Abu-Ghannam (2013). The kinetic reaction rates determined on both the outer and inner surface of mushrooms for all colour and texture parameters changed by varying of the ratio of chitosan used in edible coatings (Tables I-IV).

It could be said that when the ratio of chitosan coating was increased from 1% to 2%, the luminosity of the mushrooms' colour increased, the intensity of the reddish color decreased, and thus the rate of browning and total colour change decreased ($p<0.05$). Similar trends were observed in the study of Eissa (2007). When the chitosan coating ratio was increased from 2% to 3%, no significant change was observed in the lightness of the mushrooms' colour, the intensity of the reddish color, and the rate of browning and total colour ($p>0.05$). It was determined that the change of firmness showed the same tendency as the color change. The highest firmness was observed in 2% chitosan coated mushrooms ($p<0.05$) followed by both 3% and 1% chitosan coated mushrooms ($p>0.05$). The very high viscosity of the 3% chitosan solution causes the prolongation of its drying time on the mushrooms' surface after the coating of the solution and that make also coating more difficult. This reduces the efficiency of the coating and makes it difficult to maintain a desired property such as texture. During storage, it was determined that both the colour and texture

of the mushrooms were best preserved in 2% chitosan coated samples. In previous studies, neither the effect of 3% chitosan coating on the color and texture changes nor the effect of coating on the inner color change of the product have been determined. In this study, it was seen that the coating treatment significantly preserved the inner color of the product. The rate of chitosan coating that best preserved the inner color of the mushrooms was both 2% and 3%. It was observed that most of the kinetic reaction rates for colour parameters (except a*, ° h and BI for 3% chitosan coated mushrooms) on the inner surface of the samples coated with 2% and 3% chitosan were higher than those of the outer surface (Tables I-IV).

These mean that the yellowness on the colour of inner surface is more dominant than the redness. In addition, the browning of the inner surface in the 3% chitosan coated samples is faster than the outer surface. Results showed that the kinetic reaction rates on the inner surface of 2% chitosan coated mushrooms were 1.22 times (-0.1484 to -0.1810 $day^{-1}$) for L*, 4.01 times (0.0333 to 0.1335 $day^{-1}$) for b*, 2.51 times (0.0564 to 0.1416 $day^{-1}$) for C*, 1.90 times (0.1646 to 0.3128 $day^{-1}$) for ΔE and 1.21 times higher (0.3468 to 0.4183 $day^{-1}$) for BI compared to those on the outer surface. The kinetic reaction rates on the inner surface of 3% chitosan coated mushrooms were also 1.67 times (-0.1986 to -0.3319 $day^{-1}$) for L*, 2.90 times (0.0617 to 0.1790 $day^{-1}$) for b*, 1.54 times (0.1232 to 0.1903 $day^{-1}$) for C* and 1.64 times (0.2450 to 0.4023 $day^{-1}$) for ΔE compared to those on the outer surface. Also, the kinetic reaction rate for firmness of 2% chitosan mushrooms was determined as -0.2214 $day^{-1}$ (Table III).

## CONCLUSIONS

As the food industry tends to innovative packaging practices such as edible coatings instead of traditional food packaging, chitosan coating could be considered as a potential source for senescence inhibition of cold-stored mushrooms. Chitosan coating treatment provided the maintenance of tissue firmness and colour quality of mushrooms. Colour change kinetics on the inner and outer surfaces of mushrooms and texture change kinetics were explained by zero-order kinetic models. Using 2% chitosan as the coating material, it was found that the color parameters of the mushrooms together with their texture properties were better preserved during storage compared to other coating applications. However, microbiological evaluations are required in future studies to express that this coating extends the shelf life of the mushrooms. The results revealed that the chitosan coating, especially the use of high ratio chitosan solution as the coating agent, has the potential to retard color changes and improve texture quality of the button mushrooms. This study presents valuable data to producers that can help meet the demand and expectations of consumers regarding extending shelf life by preserving the color and texture properties of mushrooms. This study can be a reference for future studies about edible coating of different foods.

**Table I.** The values estimated from the fittings (k, $C_0$) and statistical parameters ($R^2$, RSS, RMSE, $\chi^2$) of zero-order and first-order models for the values of L*, a*, b* and ΔE on the outer surface of chitosan-coated mushrooms.

| Kinetic Model Types | Quality Parameters | Chitosan Concentration | Kinetic Parameters | | Statistical Parameters | | | |
|---|---|---|---|---|---|---|---|---|
| | | | k ($day^{-1}$) | $C_0$ | $R^2$ | RSS | RMSE | $\chi^2$ |
| Zero Order | L* | Control | -0.5213(0.0737)b | 79.8096(5.6434)a | 0.9999 | 2.3446E-07 | 2.1655E-04 | 7.8153E-08 |
| | | 1% | -0.7359(0.1145)a | 65.0279(6.4374)b | 0.9999 | 3.7221E-07 | 2.7284E-04 | 1.2407E-07 |
| | | 2% | -0.1484(0.0315)c | 65.5118(2.7794)b | 0.9999 | 8.9173E-08 | 1.3355E-04 | 2.9724E-08 |
| | | 3% | -0.1986(0.0169)c | 62.6643(2.6586)b | 0.9999 | 2.1520E-06 | 6.5606E-04 | 7.1735E-07 |
| | a* | Control | 0.2694(0.0419)a | 2.3955(0.0678)b | 0.9990 | 9.4377E-07 | 4.3446E-04 | 3.1459E-07 |
| | | 1% | 0.1933(0.0273)a | 6.9017(0.5856)a | 0.9999 | 1.1736E-08 | 4.8448E-05 | 3.9120E-09 |
| | | 2% | 0.0876(0.0186)b | 7.3036(0.5164)a | 0.9996 | 9.6523E-07 | 4.3937E-04 | 3.2174E-07 |
| | | 3% | 0.0998(0.0212)b | 7.6301(0.6474)a | 0.9989 | 3.8343E-08 | 8.7570E-05 | 1.2781E-08 |
| | b* | Control | 0.4468(0.0632)a | 19.3906(2.7422)a | 0.9988 | 1.6170E-06 | 5.6869E-04 | 5.3901E-07 |
| | | 1% | 0.2206(0.0406)b | 19.6381(2.7772)a | 0.9997 | 4.2760E-07 | 2.9244E-04 | 1.4253E-07 |
| | | 2% | 0.0333(0.0061)c | 25.1598(3.2023)a | 0.9999 | 5.0925E-07 | 3.1914E-04 | 1.6975E-07 |
| | | 3% | 0.0617(0.0026)c | 24.6809(1.7452)a | 0.9999 | 1.7994E-07 | 1.8971E-04 | 5.9981E-08 |
| | ΔE | Control | 0.6863(0.0971)a | 2.0616(0.1749)b | 0.9995 | 8.4120E-08 | 1.2971E-04 | 2.8040E-08 |
| | | 1% | 0.7605(0.0538)a | 16.2681(0.4601)a | 0.9998 | 9.8862E-07 | 4.4466E-04 | 3.2954E-07 |
| | | 2% | 0.1646(0.0349)b | 17.2429(2.4385)a | 0.9991 | 1.2540E-07 | 1.5837E-04 | 4.1801E-08 |
| | | 3% | 0.2450(0.0346)b | 19.6490(1.3894)a | 0.9998 | 7.8097E-08 | 1.2498E-04 | 2.6032E-08 |
| First Order | L* | Control | -0.0070(0.0010)b | 79.8873(5.6489)a | 0.9996 | 2.9295E-02 | 7.6544E-02 | 9.7651E-03 |
| | | 1% | -0.0129(0.0020)a | 65.4063(6.4749)b | 0.9986 | 2.8422E-01 | 2.3842E-01 | 9.4739E-02 |
| | | 2% | -0.0023(0.0005)c | 65.5268(2.7801)b | 0.9999 | 3.0385E-01 | 2.4651E-01 | 1.0128E-01 |
| | | 3% | -0.0033(0.0003)c | 62.7008(2.6602)b | 0.9999 | 1.9889E-01 | 1.9945E-01 | 6.6297E-02 |
| | a* | Control | 0.0524(0.0082)a | 2.8247(0.0799)b | 0.9770 | 6.5402E-01 | 3.6167E-01 | 2.1801E-01 |
| | | 1% | 0.0203(0.0029)b | 7.1840(0.6096)a | 0.9964 | 4.1766E-02 | 9.1396E-02 | 1.3922E-02 |
| | | 2% | 0.0102(0.0022)b | 7.3851(0.5222)a | 0.9991 | 1.9784E-03 | 1.9891E-02 | 6.5945E-04 |
| | | 3% | 0.011(0.0023)b | 7.7250(0.6555)a | 0.9989 | 2.9455E-03 | 2.4271E-02 | 9.8184E-04 |
| | b* | Control | 0.0180(0.0025)a | 19.7781(2.7970)a | 0.9972 | 1.5865E-01 | 1.7813E-01 | 5.2884E-02 |
| | | 1% | 0.0097(0.0018)b | 19.7998(2.8001)a | 0.9992 | 1.0998E-02 | 4.6900E-02 | 3.6661E-03 |
| | | 2% | 0.0013(0.0002)c | 25.1631(3.2027)a | 0.9999 | 1.9559E-05 | 1.9778E-03 | 6.5196E-06 |
| | | 3% | 0.0024(0.0001)c | 24.6889(1.7458)a | 0.9999 | 1.2945E-03 | 1.6090E-02 | 4.3149E-04 |
| | ΔE | Control | 0.0747(0.0106)a | 3.7657(0.3195)b | 0.9551 | 1.6242E+01 | 1.8023E+00 | 5.4140E+00 |
| | | 1% | 0.0308(0.0022)b | 17.2838(0.4889)a | 0.9918 | 1.4450E+00 | 5.3759E-01 | 4.8166E-01 |
| | | 2% | 0.0086(0.0012)c | 17.3149(2.4487)a | 0.9994 | 4.7436E-03 | 3.0801E-02 | 1.5812E-03 |
| | | 3% | 0.0108(0.0023)c | 19.8028(1.4003)a | 0.9990 | 1.6347E-02 | 5.7179E-02 | 5.4491E-03 |

**Table II.** The values estimated from the fittings (k, $C_0$) and statistical parameters ($R^2$, RSS, RMSE, $\chi^2$) of zero-order and first-order models for the values of L*, a*, b* and ΔE on the inner surface of chitosan-coated mushrooms.

| Kinetic Model Types | Quality Parameters | Chitosan Concentration | Kinetic Parameters | | Statistical Parameters | | | |
|---|---|---|---|---|---|---|---|---|
| | | | k ($day^{-1}$) | $C_0$ | $R^2$ | RSS | RMSE | $\chi^2$ |
| Zero Order | L* | Control | -0.8441(0.1074)a | 90.4206(8.9512)a | 0.9999 | 8.2267E-07 | 4.0563E-04 | 2.7422E-07 |
| | | 1% | -0.6814(0.0193)b | 88.7522(6.2757)a | 0.9999 | 8.5869E-07 | 4.1441E-04 | 2.8623E-07 |
| | | 2% | -0.1810(0.0282)c | 82.0317(3.4803)a | 0.9999 | 2.0389E-07 | 2.0194E-04 | 6.7964E-08 |
| | | 3% | -0.3319(0.0282)c | 82.9425(2.3460)a | 0.9999 | 5.7279E-07 | 3.3846E-04 | 1.9093E-07 |
| | a* | Control | 0.1914(0.0271)a | 0.3743(0.0159)b | 0.9991 | 1.6140E-07 | 1.7967E-04 | 5.3802E-08 |
| | | 1% | 0.0762(0.0162)b | 1.3696(0.1162)a | 0.9999 | 1.8185E-07 | 1.9071E-04 | 6.0618E-08 |
| | | 2% | 0.0643(0.0100)b | 1.4127(0.1199)a | 0.9992 | 3.7582E-08 | 8.6697E-05 | 1.2527E-08 |
| | | 3% | 0.0691(0.0098)b | 1.3792(0.0975)a | 0.9999 | 1.7128E-06 | 5.8528E-04 | 5.7092E-07 |
| | b* | Control | 0.4897(0.0346)a | 10.0785(0.8552)b | 0.9995 | 1.2414E-06 | 4.9828E-04 | 4.1380E-07 |
| | | 1% | 0.2769(0.0235)b | 13.0635(0.7390)a | 0.9999 | 1.7908E-06 | 5.9846E-04 | 5.9692E-07 |
| | | 2% | 0.1335(0.0057)c | 14.3525(1.0149)a | 0.9999 | 1.2416E-06 | 4.9832E-04 | 4.1387E-07 |
| | | 3% | 0.1790(0.0152)c | 14.8141(1.4665)a | 0.9998 | 4.9657E-08 | 9.9656E-05 | 1.6552E-08 |
| | ΔE | Control | 0.9962(0.1127)a | -1.0869(0.0922)c | 0.9995 | 1.0356E-06 | 4.5511E-04 | 3.4520E-07 |
| | | 1% | 0.6675(0.0472)b | 2.6045(0.3683)b | 0.9987 | 1.7105E-06 | 5.8490E-04 | 5.7017E-07 |
| | | 2% | 0.3128(0.0354)c | 7.6778(0.2172)a | 0.9990 | 7.1695E-07 | 3.7867E-04 | 2.3898E-07 |
| | | 3% | 0.4023(0.0284)c | 7.5756(0.5357)a | 0.9999 | 1.6050E-06 | 5.6657E-04 | 5.3500E-07 |
| First Order | L* | Control | -0.0123(0.0017)a | 93.339(6.6001)a | 0.9987 | 6.0201E-01 | 3.4699E-01 | 2.0067E-01 |
| | | 1% | -0.0083(0.0018)b | 88.8988(3.7717)a | 0.9994 | 5.4973E-01 | 3.3158E-01 | 1.8324E-01 |
| | | 2% | -0.0023(0.0004)c | 82.068(8.1243)a | 0.9999 | 3.0876E-01 | 2.4850E-01 | 1.0292E-01 |
| | | 3% | -0.0042(0.0004)c | 83.0353(3.5229)a | 0.9998 | 1.3386E-01 | 1.6362E-01 | 4.4620E-02 |
| | a* | Control | 0.0731(0.0114)a | 1.0098(0.0714)b | 0.9569 | 2.0258E+00 | 6.3652E-01 | 6.7526E-01 |
| | | 1% | 0.0318(0.0067)b | 1.5329(0.1301)a | 0.9913 | 1.9356E-02 | 6.2219E-02 | 6.4520E-03 |
| | | 2% | 0.0269(0.0038)b | 1.5672(0.0443)a | 0.9937 | 1.0012E-02 | 4.4749E-02 | 3.3374E-03 |
| | | 3% | 0.0296(0.0063)b | 1.5269(0.1296)a | 0.9924 | 1.3326E-02 | 5.1625E-02 | 4.4419E-03 |
| | b* | Control | 0.0290(0.0041)a | 11.1375(1.2601)b | 0.9927 | 6.5031E-01 | 3.6064E-01 | 2.1677E-01 |
| | | 1% | 0.0160(0.0007)b | 13.4799(1.3344)a,b | 0.9978 | 5.2498E-02 | 1.0247E-01 | 1.7499E-02 |
| | | 2% | 0.0083(0.0011)c | 14.4341(1.2248)a,b | 0.9994 | 2.9284E-03 | 2.4201E-02 | 9.7612E-04 |
| | | 3% | 0.0102(0.0014)b,c | 14.9831(1.0595)a | 0.9991 | 8.2258E-03 | 4.0561E-02 | 2.7419E-03 |
| | ΔE | Control | 0.0952(0.0040)a | 2.9799(0.1686)b | 0.9306 | 2.3329E+01 | 2.1600E+00 | 7.7763E+00 |
| | | 1% | 0.0712(0.0050)b | 4.1258(0.1167)b | 0.9589 | 1.1457E+01 | 1.5137E+00 | 3.8190E+00 |
| | | 2% | 0.0253(0.0025)c | 8.3633(0.7096)a | 0.9944 | 2.0119E-01 | 2.0060E-01 | 6.7064E-02 |
| | | 3% | 0.0311(0.0026)c | 8.4222(0.5955)a | 0.9917 | 5.0173E-01 | 3.1677E-01 | 1.6724E-01 |

**Table III.** The values estimated from the fittings (k, $C_0$) and statistical parameters ($R^2$, RSS, RMSE, $\chi^2$) of zero-order and first-order models for the values of C*, ° h, BI and Firmness on the outer surface of chitosan-coated mushrooms.

| Kinetic Model Types | Quality Parameters | Chitosan Concentration | Kinetic Parameters | | Statistical Parameters | | | |
|---|---|---|---|---|---|---|---|---|
| | | | k ($day^{-1}$) | $C_0$ | $R^2$ | RSS | RMSE | $\chi^2$ |
| Zero Order | C* | Control | 0.4938(0.0489)a | 19.5022(0.5516)b | 0.9989 | 4.6667E-07 | 3.0551E-04 | 1.5556E-07 |
| | | 1% | 0.2399(0.0068)b | 21.1080(0.8955)b | 0.9999 | 1.3927E+01 | 1.6690E+00 | 4.6425E+00 |
| | | 2% | 0.0564(0.0080)c | 26.2358(2.2262)a | 0.9999 | 5.2451E-07 | 3.2389E-04 | 1.7484E-07 |
| | | 3% | 0.1232(0.0139)c | 25.6115(1.8110)a | 0.9999 | 5.9252E-07 | 3.4424E-04 | 1.9751E-07 |
| | ° h | Control | -0.4290(0.0182)a | 82.6782(3.5077)a | 0.9999 | 2.1278E-07 | 2.0629E-04 | 7.0925E-08 |
| | | 1% | -0.2048(0.0174)b | 72.3979(6.1432)a | 0.9999 | 4.7313E-07 | 3.0761E-04 | 1.5771E-07 |
| | | 2% | -0.1571(0.0244)b | 73.7961(5.2182)a | 0.9999 | 8.4291E-08 | 1.2984E-04 | 2.8097E-08 |
| | | 3% | -0.1868(0.0264)b | 70.4251(6.9717)a | 0.9999 | 4.6924E-07 | 3.0635E-04 | 1.5641E-07 |
| | BI | Control | 1.3418(0.0569)b | 210.1296(14.8584)a | 0.9999 | 1.7580E-06 | 5.9297E-04 | 5.8601E-07 |
| | | 1% | 1.8335(0.1556)a | 219.8700(21.7660)a | 0.9999 | 1.8892E-07 | 1.9438E-04 | 6.2973E-08 |
| | | 2% | 0.3468(0.0245)c | 235.6385(19.9946)a | 0.9999 | 1.9410E-05 | 1.9703E-03 | 6.4701E-06 |
| | | 3% | 0.5469(0.0464)c | 238.1944(13.4743)a | 0.9999 | 8.7384E-05 | 4.1805E-03 | 2.9128E-05 |
| | Firmness | Control | -0.5190(0.0587)a | 19.0129(0.5378)a | 0.9988 | 5.5021E-07 | 3.3172E-04 | 1.8340E-07 |
| | | 1% | -0.4119(0.0466)a,b | 19.3679(2.7390)a | 0.9997 | 3.8416E-08 | 8.7654E-05 | 1.2805E-08 |
| | | 2% | -0.2214(0.0157)c | 17.2904(1.2226)a | 0.9991 | 6.9652E-07 | 3.7323E-04 | 2.3217E-07 |
| | | 3% | -0.3901(0.0276)b | 20.3109(1.7234)a | 0.9996 | 5.4191E-07 | 3.2922E-04 | 1.8064E-07 |
| First Order | C* | Control | 0.0195(0.0028)a | 19.9376(1.4098)c | 0.9967 | 2.2540E-01 | 2.1232E-01 | 7.5134E-02 |
| | | 1% | 0.0098(0.0003)b | 21.2894(1.5054)b,c | 0.9992 | 1.3471E-02 | 5.1907E-02 | 4.4905E-03 |
| | | 2% | 0.0021(0.0003)c | 26.2456(1.1135)a | 0.9999 | 3.7620E-05 | 2.7430E-03 | 1.2540E-05 |
| | | 3% | 0.0045(0.0004)c | 25.6472(2.1762)a,b | 0.9998 | 7.4756E-04 | 1.2228E-02 | 2.4919E-04 |
| | ° h | Control | -0.0055(0.0002)a | 82.7266(3.5098)a | 0.9997 | 9.8944E-01 | 4.4485E-01 | 3.2981E-01 |
| | | 1% | -0.0048(0.0003)a | 74.1412(2.0970)a | 0.9998 | 2.9031E-02 | 7.6199E-02 | 9.6772E-03 |
| | | 2% | -0.0022(0.0003)b | 73.8300(7.3088)a | 0.9999 | 1.1760E-01 | 1.5336E-01 | 3.9198E-02 |
| | | 3% | -0.0027(0.0002)b | 70.4447(5.9774)a | 0.9999 | 2.5699E-01 | 2.2671E-01 | 8.5665E-02 |
| | BI | Control | 0.0060(0.0008)b | 210.4270(20.8312)a | 0.9997 | 1.4402E-01 | 1.6972E-01 | 4.8006E-02 |
| | | 1% | 0.0076(0.0003)a | 220.6032(24.9584)a | 0.9995 | 4.3923E-01 | 2.9639E-01 | 1.4641E-01 |
| | | 2% | 0.0014(0.0002)d | 235.6689(19.9972)a | 0.9999 | 1.0763E-01 | 1.4672E-01 | 3.5876E-02 |
| | | 3% | 0.0028(0.0002)c | 236.7062(13.3901)a | 0.9999 | 9.9709E-02 | 1.4122E-01 | 3.3236E-02 |
| | Firmness | Control | -0.0350(0.0015)a | 19.0688(1.3484)a,b | 0.9895 | 1.6657E-04 | 5.7718E-03 | 5.5523E-05 |
| | | 1% | -0.0358(0.0025)a | 21.7647(0.6156)a | 0.9890 | 6.4510E-03 | 3.5919E-02 | 2.1503E-03 |
| | | 2% | -0.0149(0.0015)c | 17.4196(1.2318)b | 0.9981 | 2.6909E-03 | 2.3199E-02 | 8.9698E-04 |
| | | 3% | -0.0257(0.0022)b | 21.0615(1.7871)a,b | 0.9943 | 1.3000E-02 | 5.0990E-02 | 4.3334E-03 |

**Table IV. The values estimated from the fittings (k, $C_0$) and statistical parameters ($R^2$, RSS, RMSE, $\chi^2$) of zero-order and first-order models for the values of C*, ° h and BI on the inner surface of chitosan-coated mushrooms.**

| Kinetic Model Types | Quality Parameters | Chitosan Concentration | Kinetic Parameters | | Statistical Parameters | | | |
|---|---|---|---|---|---|---|---|---|
| | | | k ($day^{-1}$) | $C_0$ | $R^2$ | RSS | RMSE | $\chi^2$ |
| Zero Order | C* | Control | 0.5140(0.0509)a | 10.0480(0.2842)b | 0.9998 | 5.2394E-09 | 3.2371E-05 | 1.7465E-09 |
| | | 1% | 0.2824(0.0240)b | 13.153(0.5580)a | 0.9997 | 2.5691E-08 | 7.1681E-05 | 8.5635E-09 |
| | | 2% | 0.1416(0.0160)c | 14.4137(0.6115)a | 0.9999 | 1.9735E-06 | 6.2825E-04 | 6.5784E-07 |
| | | 3% | 0.1903(0.0108)c | 14.8521(1.0502)a | 0.9996 | 2.3457E-06 | 6.8493E-04 | 7.8189E-07 |
| | ° h | Control | -0.4677(0.0331)a | 86.9153(2.4583)a | 0.9999 | 2.0937E-06 | 6.4709E-04 | 6.9789E-07 |
| | | 1% | -0.1878(0.0159)b | 84.4217(5.9695)a | 0.9999 | 1.5467E-07 | 1.7588E-04 | 5.1557E-08 |
| | | 2% | -0.1031(0.0087)c | 83.8114(7.1116)a | 0.9999 | 3.9577E-07 | 2.8134E-04 | 1.3192E-07 |
| | | 3% | -0.1861(0.0158)b | 84.5941(8.3744)a | 0.9999 | 1.3702E-07 | 1.6554E-04 | 4.5675E-08 |
| | BI | Control | 1.1676(0.1321)a | 191.0624(18.9142)a | 0.9999 | 4.3590E-05 | 2.9526E-03 | 1.4530E-05 |
| | | 1% | 0.5156(0.0438)b | 197.6183(19.5632)a | 0.9999 | 2.1654E-05 | 2.0810E-03 | 7.2179E-06 |
| | | 2% | 0.4183(0.0473)b | 199.3064(14.0931)a | 0.9999 | 7.6273E-05 | 3.9057E-03 | 2.5424E-05 |
| | | 3% | 0.4714(0.0400)b | 200.2262(11.3265)a | 0.9999 | 7.9938E-05 | 3.9984E-03 | 2.6646E-05 |
| First Order | C* | Control | 0.0303(0.0034)a | 11.1287(1.1017)b | 0.9921 | 5.2394E-09 | 3.2371E-05 | 1.7465E-09 |
| | | 1% | 0.0161(0.0005)b | 13.5814(0.9604)a,b | 0.9977 | 1.8511E+01 | 1.9241E+00 | 6.1704E+00 |
| | | 2% | 0.0087(0.0012)c | 14.5042(1.2307)a | 0.9993 | 3.9257E-03 | 2.8020E-02 | 1.3086E-03 |
| | | 3% | 0.0108(0.0009)c | 15.0367(0.6380)a | 0.9990 | 1.0374E-02 | 4.5551E-02 | 3.4581E-03 |
| | ° h | Control | -0.0064(0.0003)a | 87.8475(3.7271)a | 0.9996 | 4.6550E-01 | 3.0512E-01 | 1.5517E-01 |
| | | 1% | -0.0023(0.0002)b | 84.4559(7.1663)a | 0.9999 | 3.7840E-01 | 2.7510E-01 | 1.2613E-01 |
| | | 2% | -0.0012(0.0001)c | 83.8196(8.2977)a | 0.9999 | 3.0697E-01 | 2.4778E-01 | 1.0232E-01 |
| | | 3% | -0.0023(0.0002)b | 84.6166(5.9833)a | 0.9999 | 3.1229E-01 | 2.4992E-01 | 1.0410E-01 |
| | BI | Control | 0.0063(0.0006)a | 189.7318(18.7825)a | 0.9997 | 1.4325E-01 | 1.6927E-01 | 4.7752E-02 |
| | | 1% | 0.0025(0.0002)b | 197.6830(19.5696)a | 0.9999 | 6.2625E-02 | 1.1192E-01 | 2.0875E-02 |
| | | 2% | 0.0020(0.0003)b | 199.4054(16.9201)a | 0.9999 | 6.6830E-02 | 1.1561E-01 | 2.2277E-02 |
| | | 3% | 0.0023(0.0002)b | 200.3130(14.1643)a | 0.9999 | 2.6427E-03 | 2.2990E-02 | 8.8091E-04 |

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**How to cite**
NAKILCIOĞLU-TAŞ E & ÖTLEŞ S. 2020. Kinetics of colour and texture changes of button mushrooms (*Agaricus bisporus*) coated with chitosan during storage at low temperature. An Acad Bras Cienc 92: e20181387. DOI 10.1590/0001-3765202020181387.

*Manuscript received on December 26, 2018;*
*accepted for publication on July 18, 2019*

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## Author contributions

E. Nakilcioğlu-Taş designed the study, performed the experiments and analysed the data. E. Nakilcioğlu-Taş and S. Ötleş discussed the results and commented on the manuscript. E. Nakilcioğlu-Taş wrote the article.