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Research article

Effect of sodium alginate edible coating on drying behavior and quality characteristics of ripe pineapple slices

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ABSTRACT

The increasing global demand for tropical fresh cut products is driven by their convenience, quality, and health benefits, highlighting the need for effective preservation methods. Pineapple slices were treated with antioxidant solution, osmodehydrated (OD) and edible sodium alginate coating was applied in different methods to investigate the effect of edible coating on osmotic dehydration, convection drying phenomena, and quality parameters of dried pineapple slices. The findings showed that edible coatings influenced drying kinetics and physicochemical properties of pineapple slices. The optimal drying temperature was identified as 60 °C, while color degradation occurred at 65 °C. Pineapple slices treated with sodium alginate after OD required the highest activation energy (65.93 kJ/mol) for moisture diffusion. Coatings enhanced ash content and moisture retention while reducing shrinkage and improving the rehydration ratio, vitamin C, and total phenolic content (TPC). Sensory assessment indicated improvements in color, flavor, texture, and overall acceptability for all coated samples. Notably, samples coated with sodium alginate after OD exhibited the most favorable physicochemical properties at 60 °C and the highest overall acceptability up to the 15th day of post-processing storage. These results underscore the potential of edible coatings to enhance the preservation and quality of pineapple slices, suggesting scopes for future research in pre-treatment technologies for drying.

1. Introduction

Fresh-cut tropical food consumption is shifting globally as consumers place a higher value on quality, freshness, low calorie content, convenience, and health advantages. Minimal processing technology has significant advantages however, chopping, slicing, and peeling can cause tissue damage that accelerates spoiling [1,2]. This damage accelerates the aging process, alters fruit quality metrics, and shortens the shelf life of the product by raising metabolic activity, respiration rate, and ethylene production [3].

Pineapple is a widely consumed fruit that is valued for its vivid color, sweet taste, and distinct flavor as well as nutritious vitamin, minerals and digestive enzymes [4]. However, drying is the most effective approach to increase its shelf life because of its high perishability. Drying decreases the moisture content and water activity of the product, which inhibits enzyme activity, minimizes microbial spoilage and prevents water-related deterioration processes during storage [5,6]. But in dehydrated products, this process

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can lead to vitamin loss, browning [7,8], and undesirable texture changes [9–11]. An alternative is to apply pretreatments to minimize oxidation during drying in order to reduce nutritional loss and enhance the quality of dried products. To lessen the detrimental effects of drying on the product's physical, sensory, and nutritional qualities, osmotic dehydration (OD) can be used before drying [12]. When OD is applied, a product's texture, color stability, and sugar/acid ratio are all improved, leading to a higher quality and longer shelf life than when this treatment is not used [13].On the other hand, excessive solute uptake during osmotic dehydration is an unwanted side effect since it interferes with the elimination of water and negatively affects the nutritional and sensory qualities, changing the natural, fresh product profile.

Edible coatings are one type of food packaging that can be used which can improve drying performance and product quality [14]. Applying edible coatings to food before air drying can be a useful pretreatment for drying because they create a selective barrier to gas migration [15]. Edible coatings made from proteins, carbohydrates, lipids, and natural polymers [16] have been extensively studied to limit solid uptake during osmotic dehydration and increase the shelf life of minimally processed goods [17–19]. However, there hasn't been much focus on applying edible coatings as a pretreatment for convective drying [20,21]. Edible coatings made of proteins and polysaccharides may be applied to reduce oxidative reactions in food during hot-air drying since these materials have low water vapor barrier capabilities but good gas barrier qualities, especially for oxygen [22,23]. These findings imply that edible coatings could be applied before convective drying to minimize unwanted alterations caused by the food's prolonged exposure to oxygen.

Alginate is an edible and biodegradable polysaccharide preservative that can be placed on fruits and vegetables due to its indigestibility [24]. Fresh fruits and vegetables are better preserved when alginate regulates gas exchange and minimizes moisture loss [25–27]. The purpose of this study is to examine how different application methods of sodium alginate edible coating when combined with traditional preservation methods affect the pineapple slices drying behavior and quality characteristics.

2. Materials and methods

Ripe pineapples, ascorbic acid and citric acid were purchased from the local market of Rajshahi, Bangladesh. Sugar was used to prepare osmotic solution. The coating agent was 99 % sodium alginate (S.D. Fine Chemicals Limited in Mumbai, India) and 97 % calcium chloride (Merck Life Science Private Limited, Mumbai, India).

2.1. Sample preparation

After being thoroughly cleaned with water, the pineapples were manually peeled and then cut into pieces of 7 mm thickness with an electric food slicer (Model: SL524B). Pineapple slices were submerged in a solution containing 1 % citric acid and 0.2 % ascorbic acid for nearly half an hour as part of acid pretreatment procedure keeping fruit to solution ratio 1:6 (w/v) [28]. Pineapple slices treated with antioxidant solution followed by OD considered as control sample (sample 1). Pineapple slices were subjected to antioxidant treatment and sodium alginate edible coating before OD (sample 2), before and after OD (sample 3) and after OD (sample 4).

2.2. Coating application

Distilled water was used to make a 2 % (w/v) sodium alginate coating solution. The mixture was stirred at 70 °C until it turned clear, and then it was cooled to 40 °C. After weighing, pineapple samples were submerged for 60 s in the coating agent solution. Then it was taken out and drained for 30 s to remove any leftover coating solution. Next, these were dipped for 30 s into a 1 % calcium chloride solution (w/v) to start the cross-linking process [29]. To secure the coating layer, the samples were dried for 10 min at 50 °C in a convective air drier.

2.3. Osmotic dehydration (OD)

Sugar solutions with a 60° Brix were prepared with distilled water. Osmotic dehydration was performed at sugar solution:pineapple slice ratio 10:1. Using a different perforated basket submerged in an osmotic solution for coated and uncoated pineapple slices, OD was carried out for 2 h at room temperature followed by cooling and rinsed with distilled water. Finally, the samples were weighed and blotted using absorbent paper for further use [29].

2.4. Convective drying

All samples were placed in specified trays and dried at a distinct air temperature (55 °C, 60 °C, and 65 °C) in a Cabinet dryer (Model DHG-9075A) up to constant weight [29]. For the observation of the effect of sodium alginate edible coating on drying behavior, pineapple slice was dried at different temperature at constant air velocity.

The effective moisture diffusivity was calculated using the Fick's second law of diffusion as expressed in eq. (1) that describes the movement of moisture inside the solid in falling rate period where D_{eff} represents the effective moisture diffusivity (m^2/s), M represents moisture content (kg/kg dry solid), and t represents drying time (s).

$$\frac{\partial M}{\partial t} = D_{\mathrm{eff}} \nabla^2 \mathrm{M} \tag{1}$$

According to Kumar et al. the solution when the sample is dried from one major face for an infinite slab with thickness, it can be expressed as [30],

$$MR = \frac{M_t - M_e}{M_0 - M_e} = \frac{8}{\pi^2} \sum_{n=0}^{n=\infty} \frac{1}{(2n+1)^2} exp \frac{-(2n+1)^2 \pi^2 D_e t}{l^2} \tag{2}$$

Equation (2) can be simplified with an acceptable error for long drying times to drying kinetics prediction for the first stage of falling rate period of drying as in the following [31].

$$\text{MR} = \frac{M_t}{M_0} = \frac{8}{\pi^2} e^{-\frac{\pi^2 D_e t}{l^2}} = \frac{8}{\pi^2} e^{-kt} \tag{3}$$

Where, k = $\frac{\pi^2 D_e}{l^2}$ = Drying rate constant (sec^{-1}),

t = time.

MR = moisture ratio.

Again, by rearranging eq. (3)

$$ln\left(MR \times \frac{\pi^2}{8}\right) = -kt \tag{4}$$

Upon plotting $ln\left(MR \times \frac{\pi^2}{8}\right)$ vs, time (t), a straight line will be obtained from eq. (4). The regression line's slope is the drying rate constant.

$$D_{eff} = k\left(\frac{l^2}{\pi^2}\right) \tag{5}$$

An Arrhenius type relation relates the effective coefficient moisture diffusivity with the dry air bulb temperature expressed in eq. (5) [30].

$$lnD_e = ln\, D_0 - \frac{E_a}{RT_{abs}} \tag{6}$$

Here, D_0 is the integration constant and usually represent the frequency factor in the Arrhenius equation (Eq. (6)), E_a is the activation energy of diffusion of water (kj/g-mole), R is the gas constant (kj/g-mole.K), T_{abs} is the absolute temperature (K).

2.5. Quality characteristics analysis of pineapple slice

2.5.1. Moisture and ash content

Moisture and ash content were determined according to Standard method (AOAC, 2000) [32].

2.5.2. Rehydration ratio

Rehydration ratio (RR) of the dried samples was measured by submerging them in 100 °C hot water for 10 min. Following the sample's draining, an electronic balance (accurate to 0.001 g) was used to quantify its mass both before and after immersion. The following Equation (Eq. (7)) was utilized to compute the sample's rehydration ratio [33].

$$\text{RR} = \frac{\text{M}}{\text{Mo}} \times 100 \tag{7}$$

where M_0 and M are the weights of the sample before and after immersion in hot water, respectively.

2.5.3. Shrinkage

Typically, the apparent volume (Eq. (9)) was used to express it. This volume can be measured using a number of displacement techniques or the Archimedes principle.

$$\text{Shrinkage, S} = \frac{V_d}{\text{V}_o} \times 100 \tag{8}$$

where V_o denotes the sample's apparent volume in its raw state and V_d its apparent volume after drying (Eq. (8)).

In this instance, the volume was determined gravimetrically by always distancing the sample with an organic solvent. Water was used as a solvent, however in order to avoid water uptake, the immersion time was limited to less than 30 s [34].

The following equation was used to calculate the apparent volume [35].

$$\text{Apparent volume}, v = v_f - \frac{M_{sf}}{\rho_s} \tag{9}$$

Where, M_{sf} is the weight of solvent added to fill the flask, ρ_s is the solvent's density, v is the sample's volume, and v_f is the volumetric flask's volume.

2.5.4. Vitamin C

Here, 1 mL aliquot of the extract was combined with 15 mL of distilled water and 1.6 mL of Folin-Ciocalteu Reagent (FCR). The mixture was then refrigerated for 5 min followed by centrifugation at 5000 rpm for 5 min. Next, 0.4 mL of 10 % FCR and 3 mL of distilled water were added to correct its volume. After cooling at room temperature, absorbance was taken at 760 nm utilizing ascorbic acid (AA) as standard [36,37].

By entering the absorbance values into the following formula (Eq. (10)), the vitamin C concentration was determined:

$$\text{Vitamin} - \text{C}(\text{mg}\,/\,100\text{g}) = \frac{\text{Conc.(ppm)} \times \text{Working volume} \times \text{Extract volume}}{1000 \times \text{Amount of extract} \times \text{Sample weight}} \times 100 \tag{10}$$

2.5.5. Total phenolic compound (TPC)

The Folin-Ciocalteu method was used to calculate the TPC spectrophotometrically [38] using gallic acid (500 mg/mL) as the standard. A predetermined volume of the 10-fold diluted Folin-Ciocalteu reagent and 7.5%sodium carbonate was combined with each sample/standard solution. After 30 min of incubation, the absorbance was measured spectrophotometrically at 760 nm (Shimadzu UV-3600i plus, Japan). The following formula (Eq. (11)), which is expressed in mg GAE (gallic acid equivalent)/g dry powder, was used to determine the TPC values [39]:

$$\text{TPC} = \frac{\text{Conc.(ppm)} \times \text{Working volume} \times \text{Extract volume}}{1000 \times \text{Amount of extract} \times \text{Sample weight}} \times 100 \tag{11}$$

2.5.6. Organoleptic evaluation of dried pineapple cubes

An organoleptic evaluation of dehydrated pineapple cubes was carried out. To compare the organoleptic taste of the formulated ones with the control samples, a 9-point hedonic rating scale was used [40] where; 9 = Like extremely, 8 = Like very much, 7 = like moderately, 6 = like slightly, 5 = neither like or dislike, 4 = dislike slightly, 3 = dislike moderately, 4 = dislike very much, 3 = dislike extremely. On each occasion, coded samples were given to the panelists for evaluation. Samples were tested for color, taste, texture, flavor, and stickiness.

2.5.7. Statistical analysis

The data was analyzed using Microsoft Excel 2021. All the experiments were done in triplicate, and the data was calculated as an average value with standard deviations. The analysis of variance (ANOVA) for the sensory qualities study was performed to estimate the significant difference ($p \leq 0.05$) between the pairs of means [41].

3. Results and discussion

3.1. Sodium alginate coating on drying behavior of pineapple slice

To analyze the effect of temperature on the drying rate constant, effective coefficient moisture diffusivity, and activation energy, pineapple samples of 7 mm thickness were dried at 55 °C,60 °C, and 65 °C in a convective dryer. Drying rate constant was obtained from the regression line of the ln ($MR.\pi^2/8$) vs. t curve as per equation (4) at different temperatures.

Table 1 displays the effective coefficient moisture diffusivity determined by Equation (5) along with the drying rate constant at various temperatures. Effective moisture diffusivity values ranged from 2.37×10^{-10} to 5.89×10^{-10} m^2/s and the diffusivity values mostly lie within the general range of 10^{-9} to 10^{-10} m^2/s for drying of food materials [42]. However, no significant differences ($p < 0.05$) were found among the samples in drying rate constant and effective moisture diffusivity. The drying rate consistently raised with

Table 1
Drying rate constant and effective coefficient moisture diffusivity at different temperature.

Sample No.	Temperature, T (°C)	Drying rate constant, k (hr^{-1})	Diffusivity coefficient, D_e (m^2/sec)
Sample 1	55	0.2727	3.76×10^{-10}
	60	0.3826	5.28×10^{-10}
	65	0.427	5.89×10^{-10}
Sample 2	55	0.179	2.47×10^{-10}
	60	0.247	3.41×10^{-10}
	65	0.355	4.90×10^{-10}
Sample 3	55	0.2258	3.11×10^{-10}
	60	0.2689	3.71×10^{-10}
	65	0.3886	5.36×10^{-10}
Sample 4	55	0.172	2.37×10^{-10}
	60	0.2261	3.12×10^{-10}
	65	0.352	4.85×10^{-10}

temperature for all samples. It is evident that the lowest temperature (55 °C) yielded the lowest effective coefficient moisture diffusivity. Whereas, the maximum effective coefficient moisture diffusivity occurred at the highest temperature of 65 °C for all samples. The results of the calculations demonstrate a direct correlation between temperature and effective spread, with an increase in temperature corresponding to an increase in the effective distribution coefficient. It could be due to increased vapor pressure within the samples. Moreover, among the samples, Sample 1 had the highest effective coefficient moisture diffusivity and sample 4 had the lowest effective coefficient moisture diffusivity at 55 °C, 60 °C, and 65 °C. The figures in 1(a), 1(b), 1(c) and 1(d) demonstrate how temperature significantly affects drying time. To reach ln (ln $\left(MR.\pi^2/8\right) =$ -1, all the samples required the least amount of time at 65 °C, followed by 60 °C, and 55 °C, respectively. Sample 1 was quickest across all temperatures in terms of correct moisture ratio, followed by samples 3, 2, and 4, in order. Furthermore, at 60 °C, all samples required 11 h to reach a stable moisture ratio and to complete the drying process. It was apparent that the drying process for the four samples necessitated around 8 h at 65 °C, whereas, it exceeded 11 h at 55 °C (see Fig. 1).

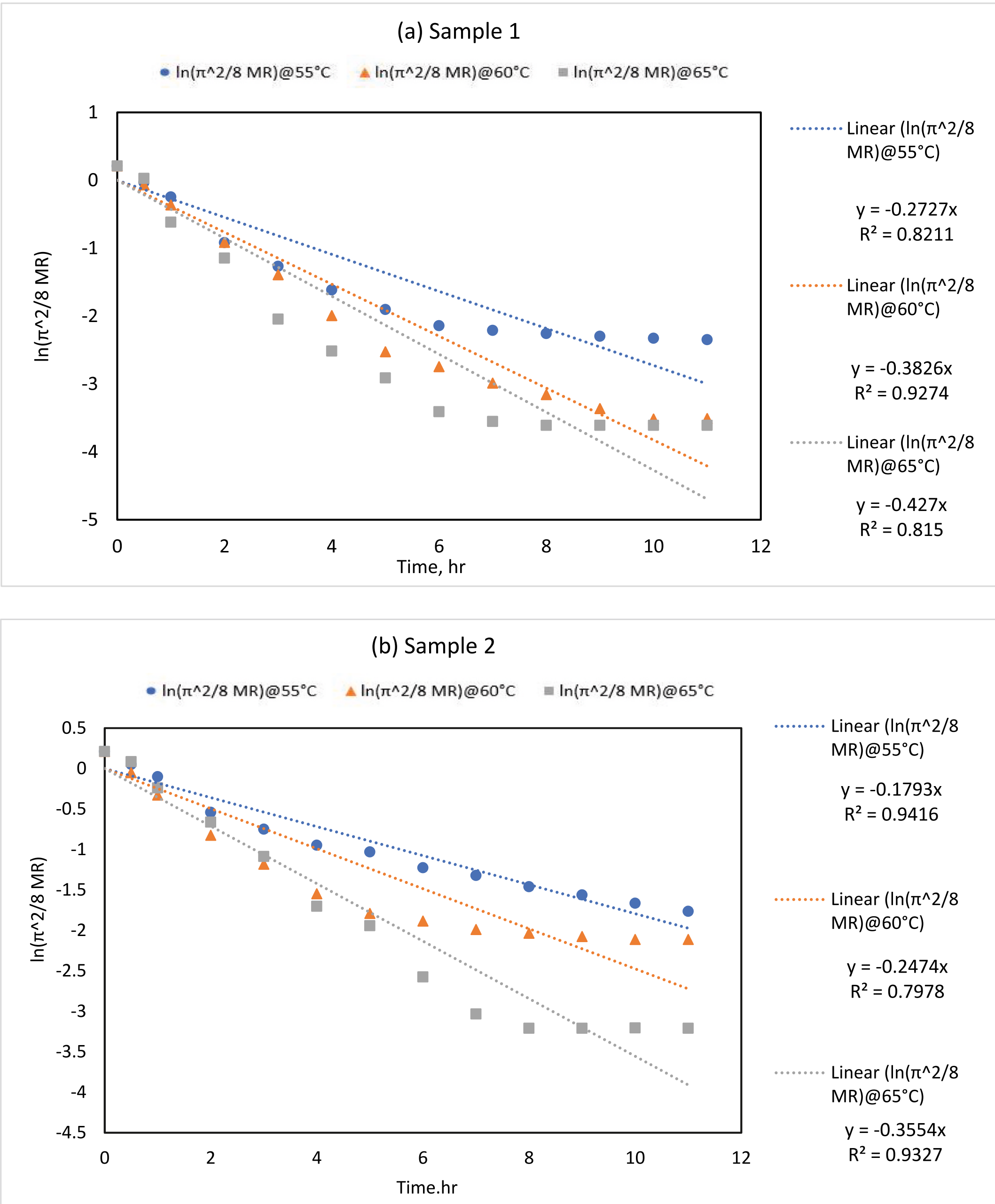
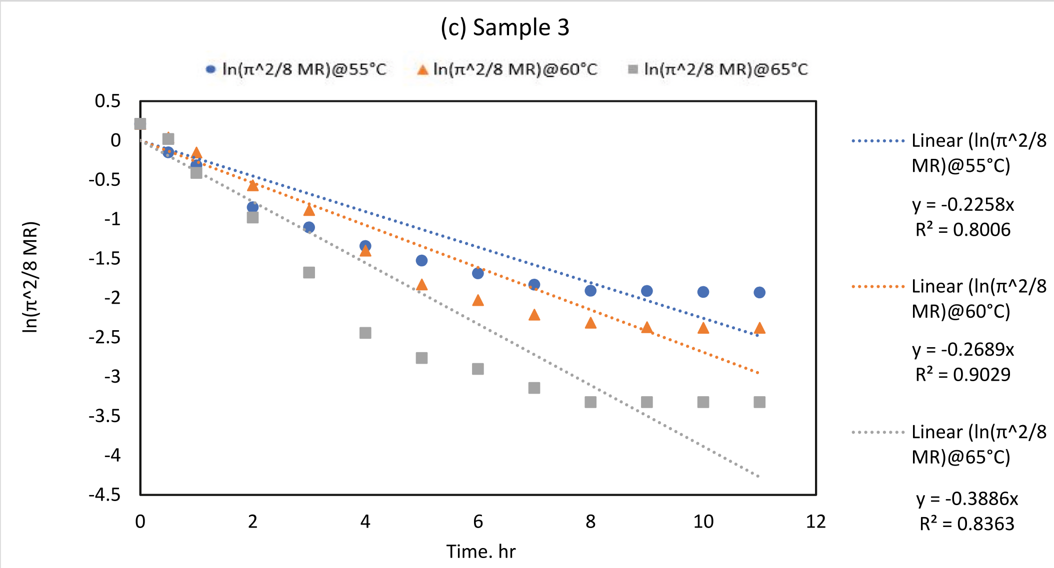


Fig. 1. Drying rate constant determination for (a) sample 1, (b) sample 2, (c) sample 3, and (d) sample 4 at different temperature (55 °C, 60 °C, 65 °C)



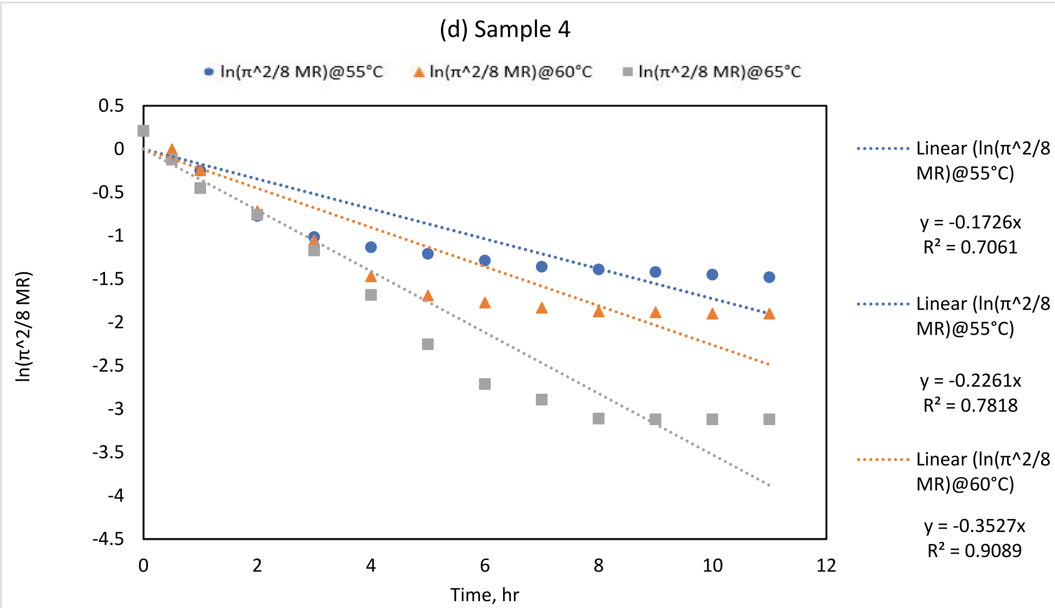


Fig. 1. (*continued*).

Fig. 2 illustrates the relationship between temperature and effective coefficient moisture diffusivity under various situations. The results of linear regression were used to create Fig. 2. When the coefficient of determination (R^2) for the effective coefficient moisture diffusivity of correlation between temperature was examined, the highest value of 0.9999 was found. This indicate that temperature has a significant impact on the effective coefficient moisture diffusivity for Sample 3, since this sample might rupture cells if it is double-coated before and after osmotic dehydration.

Furthermore, by using equation (6), the activation energy for moisture diffusion from sample 1, 2, 3 and 4 had been obtained at 41.43 kJ/mol, 63.09 kJ/mol, 49.95 kJ/mol, and 65.93 kJ/mol respectively. The activation energy refers to how much energy is needed to remove moisture from the surface. This observation also conforms with the diffusivity observation. Due to the higher effective coefficient moisture diffusivity of sample 1, the lowest activation energy had been observed for it, followed by sample 3, sample 2, and sample 4, respectively.

Furthermore, the findings suggested that the temperature 55 °C dried samples with pleasant sensory qualities, although the time requirement is high. On the other hand, despite its less time requirement, sample dried at 65 °C failed to maintain good sensory qualities. But for dried samples, when 60 °C were applied, the overall sensory qualities were pleasant and time requirement was

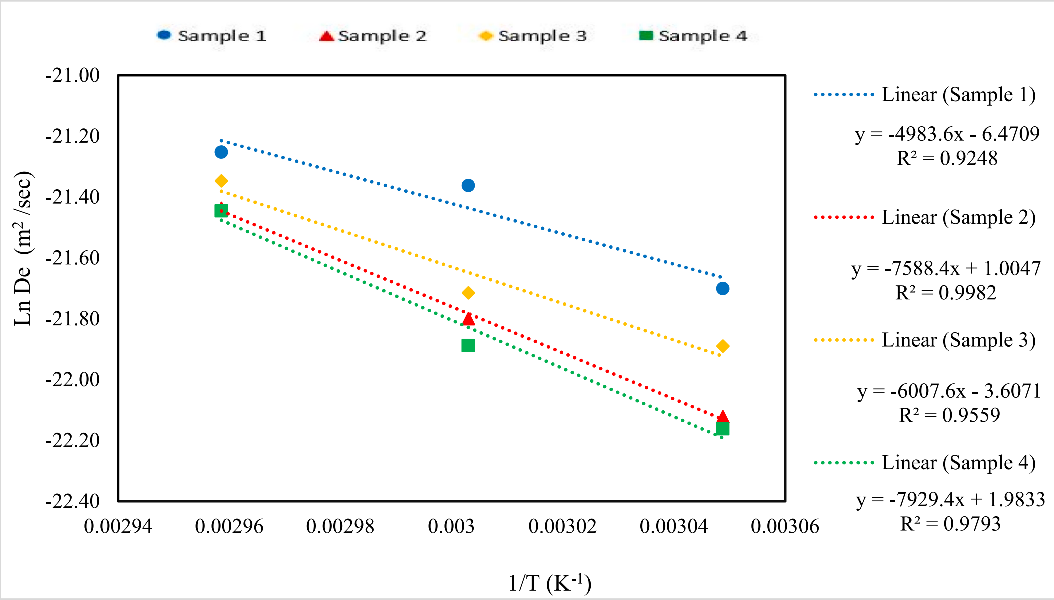


Fig. 2. Relationship between effective coefficient moisture diffusivity and temperature for sample 1, sample 2, sample 3 and sample 4.

optimum that matches the previous studies of pineapple drying [43,44]. So, regarding coating, drying at 60 °C for 11 h can be considered as the optimal condition.

3.2. Effect of edible coating on drying kinetics at 60 °C

Fig. 3 shows the drying curves for pineapple samples, which reflect typical food material behavior. Due to the high moisture content, a fast moisture removal phase occurs first, followed by a longer extraction phase as the samples approach equilibrium. Sample 1 acts as a benchmark, achieving the fastest drying rate because it was not coated. In striking contrast, Sample 4 had the slowest drying rate due to its entire coating, which considerably reduced moisture loss. Notably, despite its slower initial drying rate due to its double coating, Sample 3 eventually exceeded Sample 4 in drying efficiency. These findings underscore how repeated treatments compromise tissue structure, resulting in greater moisture loss during later drying stages. According to previous research, higher concentrations of coating agents may reduce surface adhesion, which in turn decreases protective effects and negatively impacts [45]. The first coating likely serves as a barrier, slowing down initial moisture loss, while osmotic dehydration weakens the fruit's cell structure. The addition

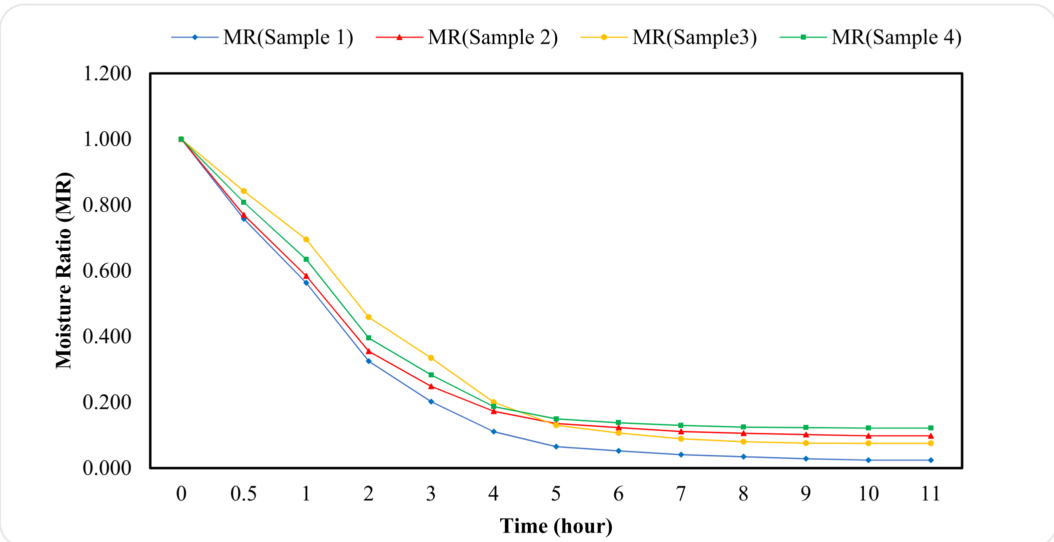


Fig. 3. Moisture ratio of sample 1, sample 2, sample 3, sample 4 during drying at 60 °C.

of a second layer may further degrade the tissue, leading to faster moisture loss and more rapid drying. Sample 2 had a balanced drying rate, falling between Samples 3 and 4. Our results are consistent with other studies, which demonstrate that minimizing moisture loss during drying maintains fruit structure, inhibits shrinking, guarantees uniform drying, and prevents over- or under-drying while maintaining texture and appearance [46].

Fig. 4 shows an experimental evaluation of the drying rate constant (k) for several pineapple samples using equation (5). Every sample exhibited an initial warming up or induction period, followed by a negligible period of constant drying rate, and then all samples entered the falling drying rate period, during which the drying rate started to decrease. During this decreasing period, the value of k first declined quicker, but gradually slowed as the moisture content approaches equilibrium. As seen in earlier research, the drying of pineapple mostly took place during the falling rate period, suggesting that diffusion dominated the process [47,48]. However, it was observed that the value of k was higher for the non-coated sample than the coated ones. The thin layer of the product, which restricts the moisture supply to the surface during the initial drying phase, may be the reason why some products do not exhibit a constant rate period, as observed by other researchers. This observation aligns with our research findings [49].

3.3. *Effect of edible coating on physicochemical properties of samples at 60 °C*

3.3.1. *Moisture*

Due to pretreatment, significant differences ($p < 0.05$) in the moisture content of dried pineapple samples were found (Table 2). Nevertheless, after drying, the coated samples had more moisture than the uncoated sample [50]. This is also consistent with another study that found that the moisture content of the uncoated apple samples was lower than that of all the samples coated with semi-permeable edible coatings such as potato starch, maltodextrin, pectin, purity gum, and capsule-E [51]. Hence, Sample 1 had the lowest moisture content whereas Sample 4, which had an effective coating applied just before the drying process, had the highest moisture content. Moreover, sample 2 displayed a lower moisture content than sample 4. Initially, the moisture content of sample 3 seemed to contradict the hypothesis that samples with a coating before OD and drying should have higher moisture retention rates than sample 2 and sample 4. This could happen because the pre-OD coating increased the water loss during OD. However, that amount of water loss was higher than the water retention due to coating applied just before drying. As a result, the net moisture loss of sample 3 was greater than that of sample 2 and sample 4, resulting in lower moisture content after drying.

3.3.2. *Ash content*

The ash contents of the samples were measured and presented in Table 2; statistical analysis indicates that the pretreatments significantly ($p < 0.05$) affected the ash content of the dried pineapples. It was found that sample 4 had the highest ash content of 2.4 ± 0.145 %, while sample 1 had the lowest ash content of 0.787 ± 0.067 %. According to earlier findings for pineapple, at 60°Brix OD and 60 °C temperature dried pineapple ash content was discovered as 2.18 %, which is lower than sample 4 ash content since coating was employed in our study [52].

The sodium alginate coating helped to retain inorganic compounds and minerals in the samples during OD and drying. As sample 2 had a higher water loss during the OD period, which explains the possibility of leaching of inorganic compounds and minerals from the sample 2 and ensures lower ash content than sample 4. Sample 3, which had a double coating, experienced increased leaching of

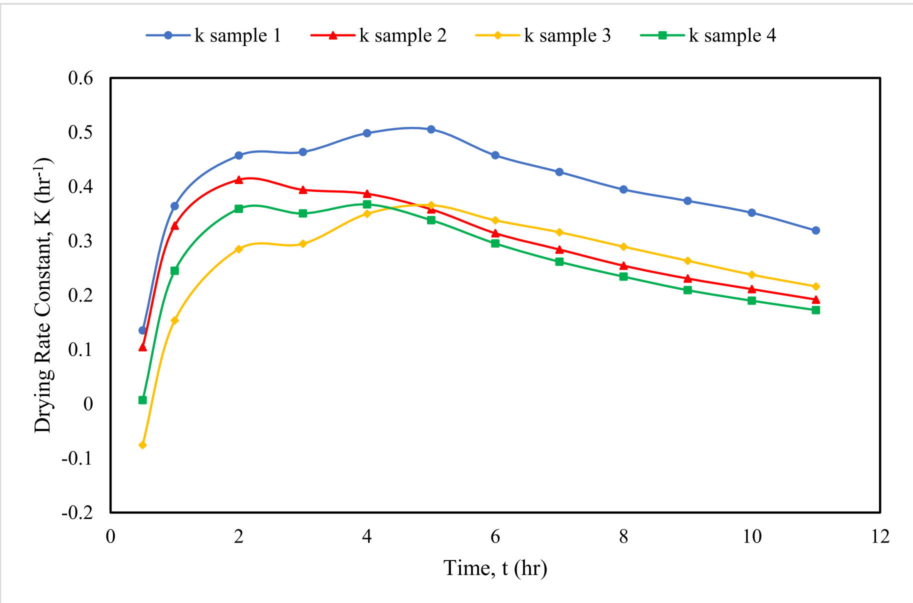


Fig. 4. Drying rate constant of sample 1, sample 2, sample 3, sample 4 during drying at 60 °C.

Table 2
Effect of edible coating on physicochemical properties of samples at 60 °C.

Properties	Sample 1	Sample 2	Sample 3	Sample 4
Moisture (%)	27.84 ± 0.74^{d}	33.25 ± 0.805^{b}	30.67 ± 0.477^{c}	39.002 ± 0.246^{a}
Ash (%)	0.787 ± 0.067^{d}	1.58 ± 0.081^{b}	1.38 ± 0.110^{c}	2.4 ± 0.145^{a}
Rehydration Ratio	2.22 ± 0.264^{c}	2.65 ± 0.0.096^{b}	2.67 ± 0.070^{b}	3.1 ± 0.161^{a}
Shrinkage (%)	71.32 ± 0.431^{a}	67.76 ± 0.271^{c}	69.017 ± 0.578^{b}	65.91 ± 0.688^{d}
Vitamin C (mg/100g)	28.22 ± 0.303^{d}	50.5 ± 1.376^{b}	45.26 ± 1.416^{c}	85.89 ± 0.842^{a}
TPC (mg GAE/g dry powder)	37.56 ± 0.722^{d}	66.42 ± 0.973^{b}	61.32 ± 0.704^{c}	87.11 ± 0.859^{a}

The data is shown as mean ± SD (n = 3). The mean value in each row with the same superscript indicated no significant variance ($p > 0.05$).

minerals and inorganic compounds during osmotic dehydration (OD) and drying due to poor adhesion between the layers. Excess moisture in the first layer created a slick surface, hindering the second layer's adherence. This overhydration weakened the bond and diluted the calcium ions needed for alginate gelation, compromising the coating's integrity and longevity [53]. As a result, sample 3 had a lower ash content than sample 2 and sample 4. These findings will be useful in further research on the effects of sodium alginate coating on the ash content and mineral retention in food samples.

3.3.3. Rehydration ratio (RR)

The Rehydration Ratio describes the method by which a plant's cell wall collects water while submerged and food coating can improve rehydration ratio [54]. Rehydration Ratio differed significantly ($p < 0.05$) in the dried samples, where the RR 2.22 ± 0.264 was lower in the non-coated samples than in the coated samples. As per prior findings for pineapple when osmotic dehydration at 60° brix and drying at 60 °C are applied, observed the rehydration ratio 2.76, which is lower than sample 4 [55].

The disintegration of the non-coated samples' cell structure during the drying process could be the cause of their lower rehydration ratio [56]. As with earlier findings [53], coating the samples as a pre-treatment for OD (Sample 2, Sample 3) lowered the rehydration ratio in comparison to samples that were not coated prior to OD (Sample 4). Another prior study indicates that the rehydration ratio of dried cherries coated with edible coatings like xanthan gum, guar gum and sage seed gum, increased significantly, reaching 167.26 %, 176.21 %, and 156.87 %, respectively. In contrast, the rehydration ratio of uncoated samples was observed to be 141.81 % [54].

The rehydration ratios of Sample 2 and Sample 3 did not differ significantly.

3.3.4. Shrinkage

In line with earlier research, the study's findings indicate that coated samples shrank less than uncoated samples during convective drying [51]. Among the coated samples, sample 3 showed the greatest shrinkage (69.017 ± 0.578 %). This was still, however, roughly 6.25 % less than the uncoated product's shrinkage of 71.32 ± 0.431 %. The sample coated exclusively prior to OD had the least amount of shrinkage (65.91 ± 0.688 %). Studies shows that coated mango cubes shrank more throughout the OD period than uncoated mango produced similar findings [57]. High shrinkage is a result of extremely distorted and dehydrated cells, which could explain increased water loss and decreased solid gain [58,59]. However, some studies show that shrinkage is proportional to the water loss during the drying process, which is in agreement with the findings of our study [59,60]. Sample 2 (67.76 ± 0.271 %) shrank more than sample 4 even before the drying stage, and sample 2 will continue to shrink more after drying. Likewise, sample 3 shrank more during OD, and among all the coated samples, sample 3 shrank the most as a result of poor coating adhesion during OD.

3.3.5. Vitamin C content

Regarding vitamin C, prior study indicated that it is readily damaged through photo-oxidation, thermal-oxidation, and enzyme-catalyzed reactions; hence, vitamin C is frequently employed as a quality indicator of food processes [61]. As per previous findings, the natural vitamin C content in pineapple is 48 mg/100g [62]. Application of citric acid and ascorbic acid result in an increase of the vitamin C content in samples. After drying, four samples were observed and a significant difference ($p < 0.05$) was found in vitamin C contents. For sample 1, 2, 3, and 4, the values of vitamin C were found 28.22 ± 0.303 mg/100 g, 50.5 ± 1.376 mg/100 g, 45.26 ± 1.416 mg/100 g, and 85.89 ± 0.842mg/100 g, respectively. Moreover, in a previous study, pectin-honey coating was tested on apple, cantaloupe melon, mango and pineapple and evidenced increase in vitamin C content which matches our studies [63].

At low temperatures, loss of vitamin C occurs due to leakage into osmotic solution, and at high temperatures for the inhibition of scavenging activity in addition to leakage [64]. As a result, a large amount of vitamin C was lost during osmotic dehydration, and sample 2 lost more vitamin. Additionally, newly added coating increased the ability to prevent oxidation and vitamin C leakage from sample 4. However, though sample 3 was expected to offer better prevention against vitamin C leakage during the drying period, it didn't happen as the thick coating cannot adhere well to the pineapple slices.

3.3.6. Total phenolic compounds (TPC)

TPCs are used in edible coatings and active packaging films to enhance their antioxidant and antibacterial properties. A prior study revealed that among the coated samples, those treated with high-methoxyl pectin exhibited the highest shrinkage (67.5 %), which was only approximately 1.5 % lower than the shrinkage observed in the uncoated product [65]. Total phenolic content (TPC) of pineapple dried at 60 °C can range from 22.77 mg/g to 46.05 mg/g of dry powder, according to earlier studies [43]. The TPC values of the dried pineapples obtained here are presented in Table 3 and there were significance differences ($p < 0.05$) in the obtained values. The TPC of sample 1 was found 37.56 ± 0.722 mg/g of dry powder. It should be noted that polyphenols' instability in the presence of heat is the cause of the TPC decrease in dried pineapple samples as prolonged exposure to heat might alter polyphenols chemically irreversibly [66]. Therefore, alternative methods should be taken into consideration as the fruit processing in an open dryer can drastically lower the fruit's overall phenolic content.

In this instance, it would make sense to cover the fruit samples as the coated samples had greater TPC mean values (61.32–87.11 mg GAE/g) than uncoated samples (37.56 mg GAE/g) during the course of the storage period, according to prior research [67]. Herein, sample 2 had a lower TPC than sample 4 due to better osmotic dehydration efficiency. Moreover, the lowest TPC content of sample 3 among all the coated samples can possibly be explained by the combination of high dehydration efficiency index (DEI) and more effective coating.

3.4. Effect of coating on sensory parameters at 60 °C

Sensory parameters are important for food quality and consumer acceptance [68]. The scores for sensory acceptance of pineapple samples are displayed in Table 3. At the beginning of the storage period (day 0), there were observable significant variances ($p \leq 0.05$) among the different treatments. Both uncoated and coated fruits were well-received, scoring above the acceptability threshold (4.5) for all the assessed characteristics. Sample 4 received the highest overall acceptability score (Table 3). However, after 9 days of storage, sample 1 showed reduced smell scores, dropping below the acceptability threshold (4.5), and was consequently not approved (Table 3). This drop in sensory acceptability could be attributable to enzymatic and Maillard processes, which produced an unpleasant odor. Additionally, sample 1 fruit received lower appearance evaluations on the ninth day, despite remaining over the acceptability criterion. Furthermore, sodium alginate coatings improved the visual attractiveness of the fruit, which could explain the better appearance scores acquired by the coated samples.

Using osmotic dehydration or sodium alginate edible coatings had no effect on melon scent during shelf-life testing. By day five of storage, sample 4 had achieved the highest sensory acceptability. In contrast, sample 3 persistently scored lower for flavor until the end of storage, implying that the double coating may have impaired the taste and so affected the flavor scores. Furthermore, consumer purchase intention indicated a clear preference for sample 4 due to its higher acceptance.

At the end of 15 days of storage, the overall impression retention for sample 1 was calculated about 46 %, whereas for sample 2, sample 3, and sample 4, values were found 60 %, 57 % and 61 % respectively. According to prior studies, the microbiological shelf-life of 'Gold' fresh-cut pineapple was limited to 14 days by mesophilic bacterial growth [69].

The shelf life of sample 1 (untreated dried pineapple) was shown to be restricted to 9 days based on the results of the sensory analysis. This was attributed to both microbiological growth and sensory rejection. However, Sample 2 and Sample 4 both had a 14-days shelf life. At the end, it can be concluded that osmotic dehydration and edible sodium alginate coatings were successful in preserving the pineapple's sensory qualities over the course of storage.

4. Conclusion

Application of sodium alginate edible coating had no significant effect ($p > 0.05$) on drying kinetics of pineapple slices, demonstrating that the coatings can be applied without affecting the effectiveness of the dehydration process. Samples with edible coating had better dehydration efficiency in osmotic dehydration which resulted in better rehydration ratio, moisture content, ash content, vitamin C, and TPC content after the drying period. Among all the coated samples, the highest physicochemical properties were observed in sample 4 due to the coating effectiveness, whereas sample 3 has the lowest attributes because of the poor coating adherence. Furthermore, samples with edible coating retained better sensory attributes after drying as well as throughout the 15 days storage period. Pineapple slices with edible coating application before drying obtained the highest organoleptic acceptability. After 15 days of storage, the overall acceptability for sample 4 and sample 2 was calculated 5 and 4.8 which are still above the threshold (4.5). However, when OD is performed between the two coating applications, it tends to diminish the surface's suitability for adhering to the subsequent coating, potentially compromising the overall coating performance. Though here the double coating method didn't work well, it showed better physicochemical and organoleptic scores than the non-coated samples. To enhance the effectiveness of a double coating, both layers can be applied either before or after the osmotic dehydration (OD) process. However, the viability of edible coating as a drying pretreatment was validated by these analyses, particularly in the case of sample 4 when the coating was applied prior to the drying stage. These findings imply that the coating has potential use as a pretreatment for drying, protection against oxidation during the drying process, and maintaining the product quality characteristics throughout the storage period. However, more comprehensive research is needed, including the stability of different nutrients of the final product during drying and storage periods.

CRediT authorship contribution statement

Shrabony Sarker: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Md Sajjad Hossain:** Writing – review & editing, Visualization, Supervision, Conceptualization. **Md Nurul Huda Bhuiyan:** Writing – review & editing, Supervision. **Pias Sarker:** Writing – review & editing, Formal analysis. **Farhana Boby:** Writing – review & editing, Supervision. **Mohammad Nurur Rahman:** Supervision.

Table 3
Effect of coating on sensory parameters at 60 °C.

Color value (rating score) of different samples during storage				
Samples	DAY 0	Day 5	Day 10	Day 15
Sample 1	$5.9 \pm 0.737^{b,A}$	$5.4 \pm 0.516^{b, AB}$	$4.5 \pm 0.422^{b, AB}$	$4.0 \pm 0.471^{b,B}$
Sample 2	$8.3 \pm 0.675^{a,A}$	$8.0 \pm 0.816^{a, AB}$	$7.0 \pm 0.666^{a, AB}$	$5.8 \pm 0.516^{a,B}$
Sample 3	$7.3 \pm 0.949^{ab,A}$	$7.0 \pm 0.918^{a,A}$	$6.2 \pm 0.632^{a, AB}$	$5.1 \pm 0.737^{ab,B}$
Sample 4	$7.9 \pm 0.966^{a,A}$	$7.4 \pm 0.966^{a,A}$	$6.3 \pm 0.674^{a, AB}$	$5.5 \pm 0.527^{ab,B}$
Flavor value (rating score) of different samples during storage				
Sample 1	$5.6 \pm 0.516^{b,A}$	$4.7 \pm 0.483^{b,A}$	$3.9 \pm 0.567^{b. AB}$	$2.8 \pm 0.632^{b,B}$
Sample 2	$7.8 \pm 0.632^{a,A}$	$6.6 \pm 0.516^{a,A}$	$5.7 \pm 0.674^{ab,B}$	$4.8 \pm 0.632^{a,B}$
Sample 3	$7.5 \pm 1.08^{a,A}$	$6.7 \pm 0.823^{a,A}$	$5.7 \pm 0.823^{ab,B}$	$4.9 \pm 0.737^{a,B}$
Sample 4	$8.1 \pm 0.994^{a,A}$	$7.3 \pm 0.823^{a,A}$	$6.3 \pm 0.823^{a.B}$	$5.4 \pm 0.699^{a,B}$
Texture value (rating score) of different samples during storage				
Sample 1	$6.4 \pm 0.699^{b,A}$	$5.7 \pm 0.483^{a,A}$	$4.5 \pm 0.527^{b,B}$	$3.2 \pm 0.632^{b,B}$
Sample 2	$8.5 \pm 0.527^{a,A}$	$7.6 \pm 0.516^{a,A}$	$6.5 \pm 0.527^{a,B}$	$5.6 \pm 0.516^{a,B}$
Sample 3	$7.7 \pm 1.059^{ab,A}$	$7.0 \pm 0.942^{a,A}$	$6.1 \pm 0.737^{ab,B}$	$5.0 \pm 0.666^{ab,B}$
Sample 4	$8.0 \pm 0.667^{ab,A}$	$7.6 \pm 0.516^{a,A}$	$6.3 \pm 0.483^{ab,B}$	$5.0 \pm 0.471^{ab,B}$
Overall acceptability value (rating score) of different samples during storage				
Sample 1	$5.8 \pm 0.788^{b,A}$	$4.8 \pm 0.788^{b,A}$	$3.9 \pm 0.567^{b,B}$	$2.7 \pm 0.674^{b,B}$
Sample 2	$7.9 \pm 0.875^{a,A}$	$6.9 \pm 0.875^{a,A}$	$6.0 \pm 0.816^{a,B}$	$4.8 \pm 0.632^{a,B}$
Sample 3	$7.2 \pm 1.032^{ab,A}$	$6.4 \pm 0.699^{ab,A}$	$5.5 \pm 0.707^{ab,B}$	$4.1 \pm 0.737^{ab,B}$
Sample 4	$8.2 \pm 0.788^{a,A}$	$7.1 \pm 0.737^{a,A}$	$6.2 \pm 0.788^{a,B}$	$5.0 \pm 0.666^{a,B}$

The data is shown as mean ± SD (n = 10). Mean values followed by different lowercase letters in the same column and by different uppercase letters in the same row are significantly different ($P < 0.05$) by Tukey–Kramer's test. Here lowercase letters compare sensory property changes between treatments (rows), and uppercase letters compare changes between days of analysis for a single sample (columns), simultaneously.

Ethics statement

The study was approved by the institutional review board of Rajshahi University of Engineering & Technology, Bangladesh. The experiments were conducted according to the established ethical guidelines and each panelist was asked to provide informed written consent before progressing the process. It is necessary to mention that, there are no strict requirements for ethical approval for sensory tests in Bangladesh.

Data availability statement

Data included in the article/supplementary material is referenced in the article.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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