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Research Article

Analysis of the Effectiveness of an Antimicrobial Edible Coating Prepared from Sweet Whey Base to Improve the Physicochemical, Microbiological, and Sensory Attributes of Swiss Cheese

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In this research, an edible coating was developed to improve the physicochemical, microbiological, and sensory attributes of Swiss cheese using sweet whey as the main ingredient (84.1%wt/wt). Glycerol (5%wt/wt), sunflower oil (10%wt/wt), guar gum (0.7%wt/wt), and Tween 20 (0.2%wt/wt) were used as other ingredients. Use of sweet whey provided an antibacterial function due to the presence of lactic acid. Delvocid was used as the antifungal agent as it contains 50% of natamycin. In this research, antimicrobial efficiency of three Delvocid concentrations—0.250 g/L (solution 1), 0.275 g/L (solution 2), and 0.300 g/L (solution 3)—was determined. Subsequently, microbial, sensory, and physicochemical properties (hardness, moisture, weight loss, color, pH, fat, and salinity) of the antimicrobial edible solution-coated Swiss cheese obtained at 0, 10, 20, 40, and 60 days of storage at 10°C and 85% relative humidity (RH) were compared with those of commercial paraffin-coated and uncoated Swiss cheeses. Antimicrobial edible solution-coated cheeses exhibited decreased moisture loss, pH change, hardness, color change, salinity change, and fat change. Sensory evaluation tests were carried out by 10 trained panelists using seven-point hedonic scales. Solution 3-coated cheeses obtained the highest acceptability score on 20, 40, and 60 days of storage and exhibited an acceptable and relatively low level of *Coliform*, yeast, and mold counts throughout the storage. As such, solution 3 was selected as the best Delvocid concentration for coating preparation. Shelf life analysis of antimicrobial edible coating solutions revealed that the shelf life of solutions 2 and 3 extended up to 60 days, while that of solution 1 extended up to 40 days at 8°C and 85% RH. Proximate analysis according to the standard Association of Official Analytical Collaboration (AOAC) procedures revealed that total solid, moisture, protein, fat, total ash, lactose, titratable acidity, and antioxidant activity of the antimicrobial edible coating solution were 25.34% (wt/wt), 74.66% (wt/wt), 8.63% (wt/wt), 11.87% (wt/wt), 0.81% (wt/wt), 3.80% (wt/wt), 0.09% (v/v), and 37.13% (Au/Au), respectively.

1. Introduction

Swiss cheese was used in this research. Swiss cheese represents a variety of cheeses of great culinary and economic importance. Swiss cheese is a medium, hard, yellow-color cheese that originated in Emmental, Switzerland [1]. One of the main problems in storage of Swiss cheese is high moisture loss. Loss of moisture from Swiss cheese increases its hardness, thus causing undesirable organoleptic properties [2]. In addition, Swiss cheese is prone to contamination by bacteria, molds, and yeasts, particularly when stored without packaging [3]. Different packaging methods such as modified atmosphere packaging and vacuum packaging are used to mitigate microbial contamination. Generally, polyamide, polyethylene, and polypropylene are used as packaging materials. Coatings provide additional protection when combined with vacuum packaging or modified atmospheric packaging, and thus, coatings act as an individual packing material [4]. Cheese coating helps increase the shelf life and reduce the moisture loss [5].

Commercial coatings made from food-grade substances like paraffin and microcrystalline wax have been in use for a long time. Although these coatings preserve the freshness of cheese and prevent the growth of yeasts and molds [6], they do not contain antibacterial properties. In addition, paraffin and microcrystalline coatings are nonedible because of their nondigestible nature. As such, these coatings should be removed from the cheeses before they are consumed.

In recent years, antimicrobial edible coatings have been increasingly used to preserve cheeses. These coatings have attracted a lot of consumers and food and packaging industries because of low wastage and their ability to increase the shelf life of food products without the aid of chemical preservatives [7–10].

As the name suggests, edible coatings are fabricated using biocompatible polymers such as chitosan, alginate, whey protein isolate, and lipids [4] with the addition of antimicrobial agents such as lactic acid, natamycin, nisin, and potassium sorbate to inhibit the growth of bacteria, yeasts, and molds [11, 12]. According to literature, whey protein isolates along with glycerin, guar gum, sunflower oil, and Tween 20 have efficiently been used to fabricate edible and biodegradable coatings [13]. In the present research, sweet whey was used as the key component of edible coating solution preparation. Sweet whey contains proteins, vitamins, and minerals. It also contains lactic acid produced by lactic acid bacteria. Lactic acid functions as a natural antibacterial agent and inhibits the growth of other bacterial species by lowering the pH [13]. Delvocid was added as the antifungal agent. Delvocid contains 50% natamycin, a good antimicrobial agent to preserve cheese from yeasts and molds [13–15]. Three types of antimicrobial edible coating solutions with different Delvocid concentrations were used in this study to identify the optimum Delvocid concentration for the antimicrobial edible coating. As such, this study reveals the effectiveness of an antimicrobial edible coating prepared from sweet whey base to improve the physicochemical, microbiological, and sensory attributes of Swiss cheese throughout 60 days of storage, as a substitute for commercial nonedible paraffin coatings.

2. Materials and Methods

Sweet whey was obtained from Richlife Dairies Ltd, Wadduwa, Sri Lanka, as a byproduct of the cheese production process. The composition of sweet whey was as follows: total solid 6.29% (wt/wt), protein 0.55% (wt/wt), fat 0.10 (wt/wt), ash 0.53% (wt/wt), and moisture 93.71% (wt/wt) (according to the wet basis). Also, the titratable acidity (analyzed by following the method of AOAC 1990), pH, and Brix value were 0.10% (v/v), 6.48 (at 20°C), and 7°, respectively.

Glycerin (99.7% purity) was obtained from Evyap Sabun Malaysia Sdn Bhd. Guar gum was obtained from Shree Ram Gum Chemicals Pvt Ltd. Sunflower oil consisting of 12% saturated fat, 21% monounsaturated fat, and 67% polyunsaturated fat was obtained from Pyramid Wilmar Pvt Ltd. Tween 20 (T-20) was obtained from Taiwan Surfactant. Vitamin *E* tablets as D-alpha Tocopheryl Acetate ph. Eur (400 IU) were obtained from Mega Lifesciences Public Company Ltd. Delvocid, which contains 50% natamycin, was obtained from JK Tradelink PVT Limited.

Swiss cheese was kindly supplied by Richlife Dairies Ltd, without any previous coating, after 30 days of manufacture. Approximately 200 g of cheese samples were used for the research. Before applying coatings, the Swiss cheese samples were washed well and allowed to drain off the residual water. Then, the cheese samples were kept at 10°C and 85% relative humidity for 12 hours until completely dried. The composition of Swiss cheese was recognized previously according to the dry weight basis: total solid 54.33% (wt/wt), moisture 45.47% (wt/wt), protein 25.70% (wt/wt), fat 29.60% (wt/wt), ash 3.76% (wt/wt), and lactose 0.10% (wt/wt). Titratable acidity (analyzed using the method of AOAC 1990) and pH were identified as 0.52% (v/v) and 5.8, respectively.

2.1. Production of Antimicrobial Edible Coatings

2.1.1. Edible Coating Solution Preparation. The solution was prepared following the procedure described by Ramos et al. [13] with some modifications. Briefly, 84.1% (wt/wt) of sweet whey was added into a beaker containing glycerol (5% wt/wt). The resulting solution was stirred using a magnetic stirrer for approximately 2 hours. The stirred solution was heated in a water bath at 80 ± 2°C for 20 minutes. Then, 0.7% (wt/wt) of guar gum was added in small quantities while continuously stirring and maintaining the temperature at 80 ± 2°C for 20 minutes. The solution was stirred well to avoid lump formation by guar gum. The mixture was removed from the water bath and kept in an ice bath to cool. Following cooling in the ice bath, the solution was kept at room temperature. 10% (wt/wt) sunflower oil was incorporated into the mixture and stirred well for 20 minutes, after the mixture reached room temperature. Two Vitamin *E* capsules were added to the same mixture by piercing the tablets. Subsequently, 0.2% of Tween 20 was added and stirred well. Then, the solution was homogenized by beating at 1100 rpm for 5 minutes.

2.1.2. Antimicrobial Edible Coating Solution Preparation. The lactic acid content of sweet whey was identified previously as 0.10% (v/v) according to the volume. Delvocid, which has 50% of natamycin, was added to inhibit the growth of yeasts and molds. 0.250 g/L, 0.275 g/L, and 0.300 g/L of antimicrobial edible coating solutions were prepared by adding subsequently 0.250 g, 0.275 g, and 0.300 g of Delvocid for each 1 L of previously prepared edible coating solutions.

Solution 1: 0.250 g/L Delvocid-added antimicrobial edible coating solution. Solution 2: 0.275 g/L Delvocid-added antimicrobial edible coating solution. Solution 3: 0.300 g/L Delvocid-added antimicrobial edible coating solution.

Proximate composition of antimicrobial edible coating solutions was identified as follows: total solid 25.34 ± 0.23% (wt/wt), moisture 74.66 ± 0.23% (wt/wt) (according to wet weight basis), total fat 11.87 ± 0.32% (wt/wt), protein 8.63 ± 0.51% (wt/wt), lactose 3.80 ± 0.027% (wt/wt), and total ash 0.81 ± 0.05% (wt/wt). The titratable acidity (analyzed by

following the method of AOAC 1990), Brix value, and antioxidant activity (1,1-diphenyl-2-picrylhydrazyl radical scavenging activity) (analyzed by following the method of Lutfiye Yilmaz–Ersan et al. (2016) [16] with some modifications) were $0.093 \pm 0.006\%$ (v/v), $12^0 \pm 0.00$, and $37.13 \pm 0.51\%$ (Au/Au), respectively.

2.1.3. Commercial Paraffin Coating Solution Preparation. A paraffin block was taken and was put into a metallic vessel, and the paraffin block was melted using a burner at 120°C. pH of the paraffin solution was 7.0.

2.1.4. Cheese Coating. The antimicrobial edible coating solution was adjusted to pH 7.0 by 0.1 mold m^{-3} NaOH solution to confirm that the coatings were devoid of any significant antimicrobial activity related to pH itself; therefore, any antimicrobial activity observed would be caused by the antimicrobial compounds included in the formulation [13]. Coating was applied by dipping the cheese samples for 2 minutes until all surfaces were covered followed by the residual coating being allowed to drip off. Coating application was performed under appropriate aseptic conditions. Then, the samples were left for 8 h at 10°C and 85% relative humidity in a temperature- and humidity-controlled aging room. Samples were turned periodically (every 30 minutes) until the coating was essentially dry (based on visual inspection) [13]. For making commercial paraffin-coated cheese, the cheese samples were dipped in paraffin wax solution at 120°C. Then, both antimicrobial edible solution-coated cheese and commercial paraffin-coated cheeses were stored in the aging room for 60 days at 10°C and 85% relative humidity. The coated cheeses were compared with their uncoated (negative control) counterparts, which were stored under same conditions [13].

2.2. Shelf Life Analysis of Antimicrobial Edible Coating Solutions. Prepared antimicrobial edible solutions (0.250 g/L, 0.275 g/L, and 0.300 g/L Delvocid concentrated) were poured into the well autoclaved glass bottles in the aseptic chamber, and the sample bottles were kept at 8°C for 60 days. pH, total plate count (TPC), *Coliform* count, and yeast and mold counts were taken within 5-day intervals throughout the storage period. Triplicate readings were taken from each solution.

2.3. Cheese Analyses. Cheeses were assayed, in triplicate, on 1, 10, 20, 40, and 60 days after coating application for identification of physicochemical properties including moisture, fat, salinity, weight loss, pH, texture, and color. Microbiological and sensory analyses were also performed.

2.3.1. Moisture Determination of Cheese—AOAC (1990) with Some Modifications. About 5 g of a grated cheese sample was taken from a homogenized highest acceptable product and placed into a cleaned, oven-dried, cooled moisture dish of known weight. Then, the weight of the dish with the sample was recorded. Then, the moisture dish containing the sample was placed in an oven (MEMERT) for 16 hours while maintaining the temperature at 105°C. Then, the moisture dish was removed from the oven and allowed to cool in a desiccator. Again, the weight of the dish was noted. This procedure was repeated until the difference between two consecutive weights did not exceed one milligram. Moisture percentage was calculated as

$$\%\ \text{moisture} = \frac{m1 - m2}{m1 - m0} \times 100\%, \quad (1)$$

where $m0$ = mass of the empty dish (g), $m1$ = mass of the dish + sample before drying (g), $m2$ = mass of the dish- + sample after drying (g), and % of moisture content of the product = 100% − TS%

2.3.2. Weight Loss Determination of Cheese—Ramos et al. (2012). Cheese was individually weighed on an automatic electro-balance (Ohaus PA 313) with a precision of ±0.001 g, at the beginning and during the storage period; the relative weight loss was calculated as

$$\Delta W = \frac{(Wi0 - Wft)}{Wft} \times 100\%, \quad (2)$$

where $Wi0$ = initial weight and Wft = final weight at time t. Three readings of each cheese sample were produced.

2.3.3. Fat Determination of Cheese—AOAC 933.05 with Some Modifications. About 15 g of sulfuric acid was added into the Van Gulik butyrometer, closed at the scale end. Then, 3 g ± 0.2 g of cheese, measured on a weighing boat, was added to the glass rod, and the filler opening was sealed using a stopper. Finally, the sealed butyrometer was placed in a 70°C–80°C water bath with scale pointing upward and shaken repeatedly until the cheese was dissolved.

Then, 1 mL of amyl alcohol was added followed by sulfuric acid until it reached approximately 15% mark of the scale. Then, the butyrometer was closed and the content was mixed. Finally, the butyrometer was tempered for 5 minutes in an electronic water bath (RDL-EQP-00204) at 65°C and the fat column was adjusted to zero point. The reading was taken from the lower end of the meniscus.

2.3.4. Salt Determination of Cheese (Mohr Method)—Sheen and Kahler (1938) with Some Modifications. 5% K_2CrO_4 solution was prepared by dissolving 1.0 g of K_2CrO_4 in 20 mL of distilled water [17]. Standard $AgNO_3$ solution (approximately 0.1 M) was prepared by dissolving 9.0 g of $AgNO_3$ in 500 mL of distilled water. This solution was standardized against NaCl. Reagent-grade NaCl was dried overnight and cooled to room temperature. 0.250 g portions of NaCl were weighed into Erlenmeyer flasks and dissolved in about 100 mL of distilled water. In order to adjust the pH of the solutions, small quantities of $NaHCO_3$ were added until effervescence ceased. About 2 mL of K_2CrO_4 was added, and the solution was titrated to the first permanent appearance of red Ag_2CrO_4. The grated cheese sample was

dried at 110°C for 1 hour and cooled in a desiccator. About 1 g of individual samples were weighed into 250 mL of Erlenmeyer flasks and dissolved in about 100 mL of distilled water. Small quantities of $NaHCO_3$ were added until effervescence ceased. About 2 mL of K_2CrO_4 was introduced, and the solution was titrated to the first permanent appearance of red Ag_2CrO_4. An indicator blank was determined by suspending a small amount of chloride-free $CaCO_3$ in 100 mL of distilled water containing 2 mL of K_2CrO_4. The following reactions take place:

$$\begin{aligned} Ag + Cl^- &\longleftrightarrow AgCl\,(s), \\ 2Ag + CrO_4^{2-} &\longleftrightarrow Ag_2CrO_4\,(s). \end{aligned} \tag{3}$$

Salt% can be determined using equations (4) and (5).

Calculations for Replicate 1 of Standardization

Molecular mass of NaCl = 58.44 g/mole. Reacted moles of $AgNO_3$ with NaCl = 0.25 g/58.44 $gmol^{-1}$

$$\text{Molarity of AgNO} = \frac{0.25\ \text{g}/58.44\ \text{gmol}^{-1}}{\left(\text{Reacted volume of } AgNO_3 \text{ with NaCl} - \text{Blank volume}\right)} = M. \tag{4}$$

Average molarity of AgNO3 was taken by triplicating the titration of reagent-grade NaCl with AgNO3

$$\begin{aligned} \text{Atomic mass of Cl} &= 35.45\ \frac{\text{g}}{\text{mole}}\ \%\text{Cl}^{-1} \text{ in cheese} \\ &= \frac{M \times \left(\text{Reacted volume of } AgNO_3 \text{ with cheese sample} - \text{Blank volume}\right)35.45 \times 100\%}{\text{weight of the cheese sample}}. \end{aligned} \tag{5}$$

2.3.5. pH Determination of Cheese—Ramos et al. (2012) with Some Modifications. The pH value was measured using a pH meter (HANNA-CHI 99161) equipped with a probe for solids inserted directly into the cheese sample at 20°C. Three readings of each cheese sample were taken from three places of the cheese sample.

2.3.6. Hardness Determination of Cheese—Ramos et al. (2012) with Some Modifications. The textural properties of cheese samples cut into (20 mm × 20 mm × 20 mm) identical cubes were evaluated by a double compression test using a texture analyzer (CT Texture Analyzer; Brookfield) with a 4500 g load cell and a 4-mm cylindrical plunger (TA44) at a constant penetration speed of 2 mm/s, 75% compression, and a contact force of 3.0 g. Three penetrations were performed at the center of three identical cubes per cheese sample. The force deformation readings were converted into hardness values using CT Texture Pro V1.8 Build 31 (Brookfield Engineering Labs Inc.) software.

2.3.7. Color Change Determination of Cheese—Ramos et al. (2012). Cheese color was evaluated using a portable chroma meter CR-400 (Minolta Chroma, Osaka, Japan). Cubic samples of 2 cm edge was used for color analysis. Changes in the color of the cheese surface were measured using a CIELab color scale (where L = lightness, a = red-yellow color, and b = blue-green color) under daylight (D65 illuminant). A standard white plate was used to calibrate the equipment with color coordinates.

$L_{standard} = 97.6$, $a_{standard} = 0.01$, and $b_{standard} = 1.60$. The total color difference (ΔE) was calculated as

$$\Delta E = \left[\left(L - L_0\right)^2 + \left(a - a_0\right)^2 + \left(b - b_0\right)^2\right]^{1/2}, \tag{6}$$

where L_0, a_0, and b_0 are the initial values (1 d after coating application) obtained for cheese under each experimental condition. L, a, and b are the values measured throughout the storage period. For each cheese sample, 5 readings were made on each side.

2.3.8. Microbiological Analyses of Cheese—AOAC (1995) with Some Modifications. Microbiological development on the cheese surface was evaluated via enumeration of *Coliform* count and yeast and mold count by 1, 10, 20, 40, and 60 d after application of coatings. All media used in the industry were available in commercial manner. The required amount for preparing the required volume of a medium was measured and then dissolved in distilled water and heated in a water bath for further dissolving until a semisolid was obtained, prior to autoclaving. For *Coliform* enumeration, VRBA (Violet Red Bile Agar) was used, and for yeast and mold enumeration, PDA (Potato Dextrose Agar) was used. Culture media, Ringer's solution-containing bottles, and sodium citrate solution-containing bottles were sterilized by autoclaving for 20 minutes at 121°C and 15 psi. Glassware including Petri dishes and pipettes was sterilized by placing in an oven for 2 hours at 200°C.

The pour plate method was used in most of the tests to get the count of existing microorganisms. A portion from the surface of the cheese sample was taken on a spoon and

was dipped in 75% alcohol and flamed and transferred immediately into a sterilized sodium citrate-containing bottle. Cheese samples were prepared by dissolving approximately 10 g of the sample in 90 mL of sterile sodium citrate solution (2% solution warmed to 47 ± 2°C). For dilution purposes, sterile Ringer's solution was used. The sample (1.00 mL) was pipetted out and transferred into sterile Ringer's solution-containing bottles (9.00 mL) to prepare 10-fold dilutions.

For *Coliform* enumeration, this direct plating was done using the Violet Red Bile Agar (VRBA) medium. The test sample (1.00 mL) was pipetted out using a sterile pipette and transferred into a sterile Petri dish aseptically. (Test sample were diluted based on the purpose and by using sterile Ringer's solution as mentioned above.) Then, sterile VRBA (15.00 ml) at the temperature of 45 ± 2°C was poured into the Petri dish aseptically, and the contents were mixed clockwise, anticlockwise, up, and down. The plates were allowed to solidify and were inverted and incubated 48 hours at 36 ± 1°C. After the incubation, the amount of well-separated colonies was counted. Presence of fecal coliforms was checked by the presence of *Escherichia coli* colonies, which gives a characteristic greenish metallic sheen. The results were expressed in colony forming units per gram (CFU/g).

For yeast and mold enumeration, Potato Dextrose Agar (PDA) was used and samples were inoculated as described previously, but after solidifying the plates, Parafilm was used to seal them. Then, the plates were inverted and incubated 5 days at room temperature. After the incubation period, the amount of well-separated colonies was counted. The results were expressed in CFU/g.

2.3.9. Sensory Analyses of Cheese—Ramos et al. (2012) with Some Modifications. Sensory analyses were carried out in 0, 10, 20, 40, and 60 days after application of coatings in the Quality Assurance Lab of Richlife Dairies Ltd by a trained panel of 15 members (including both men and women, with ages ranging between 26 and 40 years) familiar with Richlife's Swiss cheeses. The panel had been screened previously and selected among staff of the company.

2.3.10. Testing Criteria. The organoleptic evaluations were carried out by a test panel of 10 trained panelists. A seven-point hedonic scale ranging from dislike very much (1) to like very much (7) was used to evaluate the degree of liking for the quality attributes, namely, odor, color, surface shininess, hardness, taste, and overall acceptability.

2.3.11. Preparation of the Sample. Uncoated, commercial paraffin-coated, and three antimicrobial edible solution-coated cheeses were used for sensory evaluation.

2.3.12. Serving of Samples. Cheese samples were cut into cubes approximately 2 cm × 2 cm × 2 cm including cheese surface and placed in 500 mL individual identical plastic cups. (In paraffin-coated cheese, the paraffin coat was removed before cutting the cheese into cubes.)

The cups were coded using random 3 digit codes and presented in random order to panelists under white fluorescent light. The panelists used water to cleanse their palates between samples. The ballet paper included a "comment" section in which the panelists were asked to indicate any defects noticed or any descriptors considered useful to better define the coating attributes.

2.3.13. Statistical Analyses. Analysis of variance was performed to assess the differences between the physicochemical, microbiological, and sensory properties of the cheeses coated with the antimicrobial edible coating solutions or commercial paraffin coating compared with uncoated cheese on 0, 10, 20, 40, and 60 d of storage.

MINITAB 17 software and IBM SPSS statistics 21 were used for analysis. The post hoc test was performed, and differences were considered significant at $P < 0.05$.

3. Results and Discussion

3.1. Shelf Life Analysis of Antimicrobial Edible Coating Solutions. pH variations in the antimicrobial edible coating solution, total plate count, *Coliform* count, and yeast and mold counts were used as the parameters to determine the shelf life of the coating solutions.

Variations in pH, TPC, *Coliform* count, and yeast and mold count throughout the storage are shown in Figures 1–5, respectively.

As shown in Figure 1, there was a statistically significant difference ($p < 0.05$) in pH among the antimicrobial solutions and the pH value of each solution significantly changed ($p < 0.05$) from their initial value throughout the storage at 8°C. All 3 solutions showed similar pH values (~7.00) at the start of the storage period. The pH value of the solutions gradually increased during the first 25–30 days of storage to reach a maximum mean pH before it rapidly declined over the second half of the storage period.

pH of all 3 solutions had reduced to ~6.60 by the end of 60 days. It could be presumed that the rapid formation of lactic acid by increased lactic acid bacteria population may have resulted in the observed decrease of pH. However, all 3 antimicrobial edible solutions were within the low acidic pH range after 60 days of storage period (around 6.6).

Variations in the TPC of the 3 antimicrobial edible solutions are shown in Figure 2. There was a statistically significant difference ($p < 0.05$) in the TPC of all three solutions. TPC of all three solutions increased with the time, but it was within the acceptable level of pasteurized milk products (<30,000 CFU/mL) (SLS 181:1983).

Coliform count of all 3 solutions drastically decreased over time and reached 0 on the 5th day of storage and remained negative during the rest of the storage period (Figure 3). This was in accordance with the SLS 1558-3:2017 quality standards that specifies <1 CFU of coliforms per gram/mL of food substance. *Coliform* inhibition is likely to be caused by the decrease in pH, as a result of lactic acid production by lactic acid bacteria.

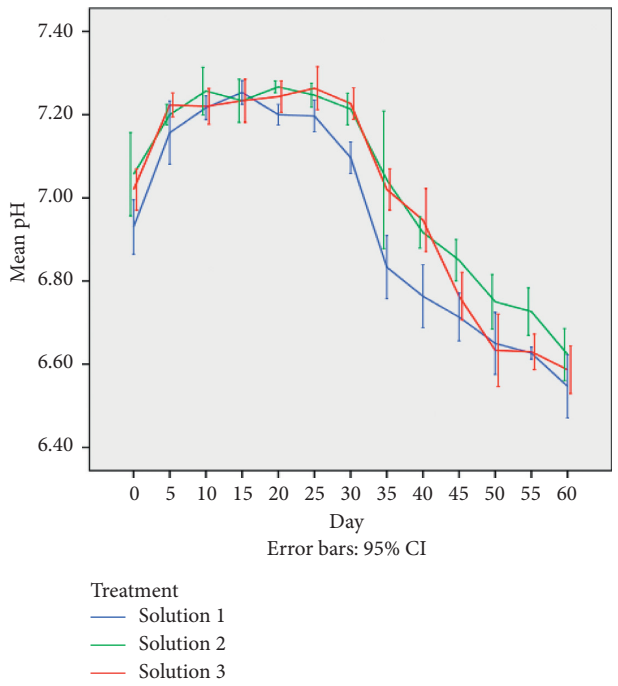

Figure 1: Changes (means ± SD) in the pH of antimicrobial edible coating solutions: solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid) during the storage at 8°C and 85% RH.

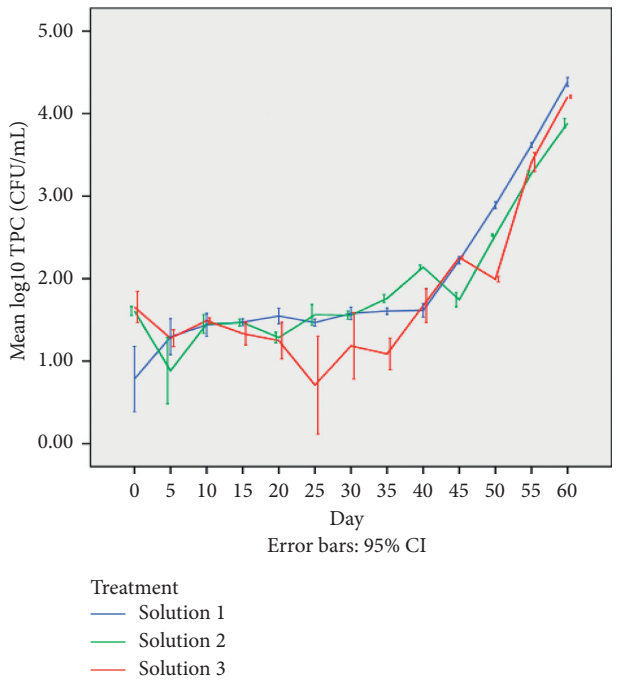

Figure 2: Changes (means ± SD) in the TPC of antimicrobial edible coating solutions: solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid) during the storage at 8°C and 85% RH.

Variation in yeast count of the 3 different concentrations of Delvocid solutions during the 60-day storage period is demonstrated in Figure 4. In terms of yeast count,

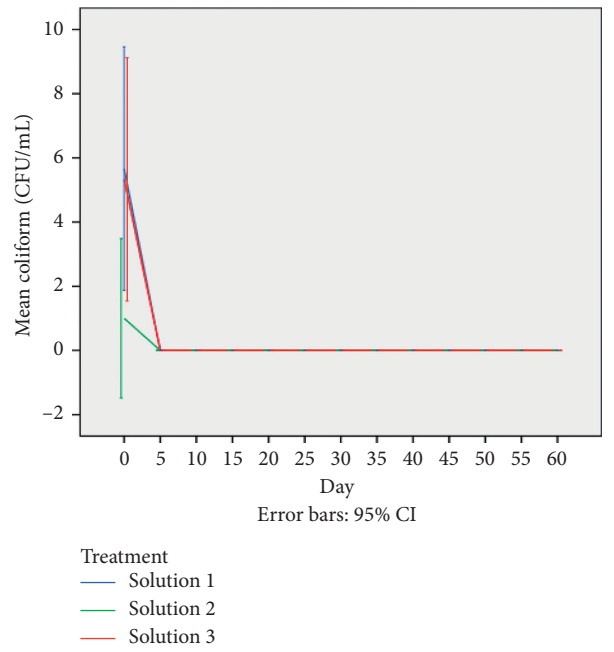

Figure 3: Changes (means ± SD) in *Coliform* count of antimicrobial edible coating solutions: solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid) during the storage at 8°C and 85% RH.

there was a statistically significant difference ($p < 0.05$) among the antimicrobial solutions and the yeast count of each solution significantly changed ($p < 0.05$) from their initial value throughout the storage. Results showed that the yeast count of solution 1 remained within the acceptable range (<100 CFU/mL, SLS 773:1987) during the first half of the storage. However, the yeast population of solution 1 increased after first half of the storage. A large increase in the yeast count was visible during the latter part of the storage. Therefore, the results indicate that although 0.25 g/L Delvocid showed an initial inhibitory effect against yeast, it wore out toward the end of the storage period, resulting in rapid growth of yeast. As the amount of yeast colonies in solution 1 exceeded the acceptable level at 45 days of storage, 0.25 g/L Delvocid was deemed unsuitable for antimicrobial coating application. On the contrary, solutions 2 (0.275 g/L) and 3 (0.3 g/L) were more effective in inhibiting yeast growth throughout the storage period. It was evident that the antimicrobial effect of the solutions was directly proportion to the concentration of Delvocid. Yeast counts for both solutions 2 and 3 were within the acceptable range after 60 days (<100 CFU/mL, SLS 773: 1987). However, solution 3 showed a greater inhibitory effect than solution 2.

In terms of mold counts, all three concentrations of Delvocid were shown to be effective against mold growth. Mold counts remained 0 over the entire storage period, as seen in Figure 5. Based on the variations in pH, TPC, and *Coliform*, yeast, and mold counts, solution 3 consisting of 0.300 g/L Delvocid was chosen as the optimal concentration for antimicrobial coating application.

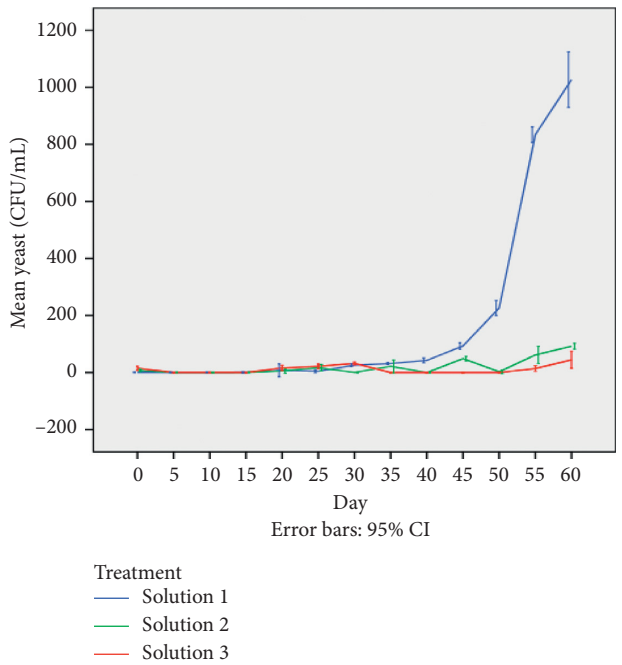

Figure 4: Changes (means ± SD) in yeast count of antimicrobial edible coating solutions: solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid) during the storage at 8°C and 85% RH.

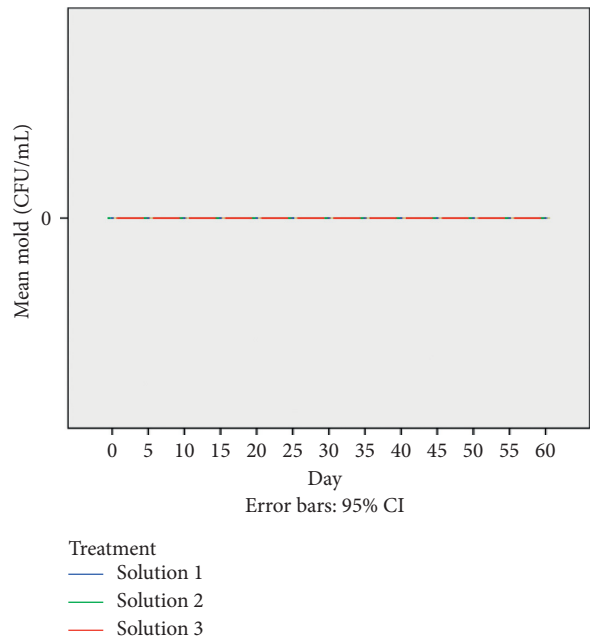

Figure 5: Changes (means ± SD) in mold count of antimicrobial edible coating solutions: solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid) during the storage at 8°C and 85% RH.

3.2. Cheese Analyses. Appearance of antimicrobial edible solution-coated, paraffin-coated, and uncoated cheeses at 0 day of storage is shown in Figure 6.

3.3. Physiochemical Analysis. Antimicrobial edible coated cheeses, paraffin-coated cheeses, and uncoated cheeses were assayed, in triplicate, for their physiochemical properties (moisture content, weight loss, pH, fat content, salt content, hardness, and color) on 1, 10, 20, 40, and 60 days after coating application. Results of the physiochemical analysis of all cheese varieties are shown in Figures 7–13, respectively.

According to the moisture content throughout the storage, there was a statistically significant difference ($p < 0.05$) in the moisture content among the same cheese categories and between the different cheese categories (Figure 7). However, the moisture loss in antimicrobial edible solution-coated cheese was lower than that in both paraffin-coated cheese and uncoated cheese. Our results showed that edible antimicrobial coating presented an effective moisture barrier, preventing the loss of moisture during extended periods of storage. It also showed that the edible antimicrobial coating was less moisture permeable compared with paraffin. Uncoated cheese had the highest moisture decrease, as expected due to the absence of a waxy layer.

In terms of weight loss (Figure 8), there was a significant difference between all coated and uncoated cheese samples from 10 days of storage ($p < 0.05$). The weight loss reflected the loss of moisture content from the cheese samples. As such, uncoated cheese with the highest moisture loss showed the highest loss in weight, whereas antimicrobial edible solution-coated cheese showed the lowest moisture loss.

The pH level of all cheeses decreased during storage (Figure 9). There was a statistically significant difference ($p < 0.05$) in pH variation among the same cheese categories and between different cheese categories. According to the results, uncoated cheese showed the highest drop in pH level during storage, whereas antimicrobial solution 3 exhibited the least variation. pH changes in solution 1 and 2 coated cheeses were similar to those in paraffin-coated cheese. These results indicate that antimicrobial solution 3 was most efficient in maintaining the pH of Swiss cheese during storage. In fact, this novel coating exhibited better pH regulation than the commercially available paraffin coating.

In terms of fat content (Figure 10), there was no significant difference ($p > 0.05$) between antimicrobial edible coated cheeses and paraffin-coated cheese over the first 20 days of storage. However, there was a significant difference in the fat content ($p < 0.05$) of uncoated cheese over the 10 days of storage. The fat increasing rate was very low in both paraffin-coated cheese and antimicrobial edible solution-coated cheese.

An increase in the salt content was visible in all cheeses during the storage period (Figure 11). Antimicrobial solution 3-coated cheese showed the lowest increase in salt content, while the uncoated cheese showed the highest increase. Results showed that antimicrobial solution 1- and solution 2-coated cheeses showed similar salinity variations to that of the paraffin-coated cheeses ($p > 0.05$). According to these observations, it is apparent that the edible antimicrobial coating is as effective as the commercially available paraffin coating in terms on salinity regulation.

(a) (b) (c) (d) (e)

Figure 6: Appearance of cheeses coated with antimicrobial edible coatings incorporated with (a) solution 1(0.250 g/L Delvocid), (b) solution 2 (0.275 g/L Delvocid), and (c) solution (0.300 g/L Delvocid), compared with commercial paraffin coating (d) and uncoated cheese (e) at 0 day storage.

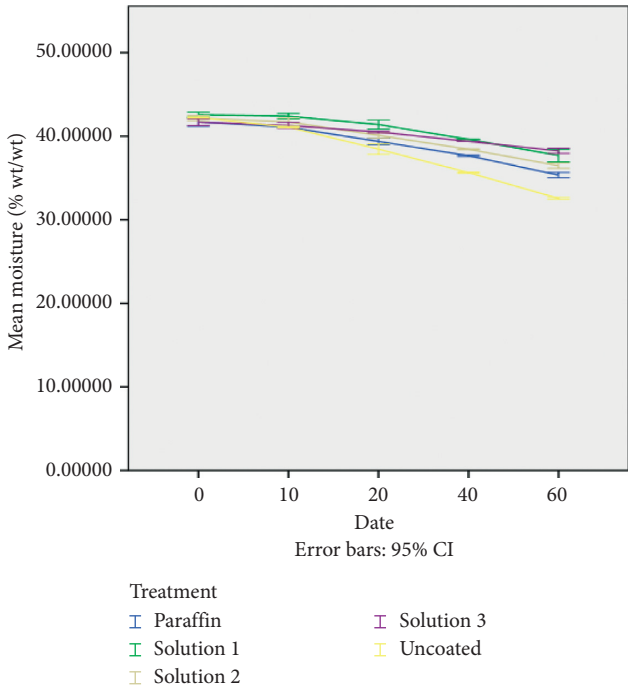

Figure 7: Values (means ± SD) of the moisture content of cheese coated with antimicrobial edible coating solutions—solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid)—compared with cheese coated with commercial coating and uncoated cheese throughout 60 d of storage at 10°C and 85% relative humidity.

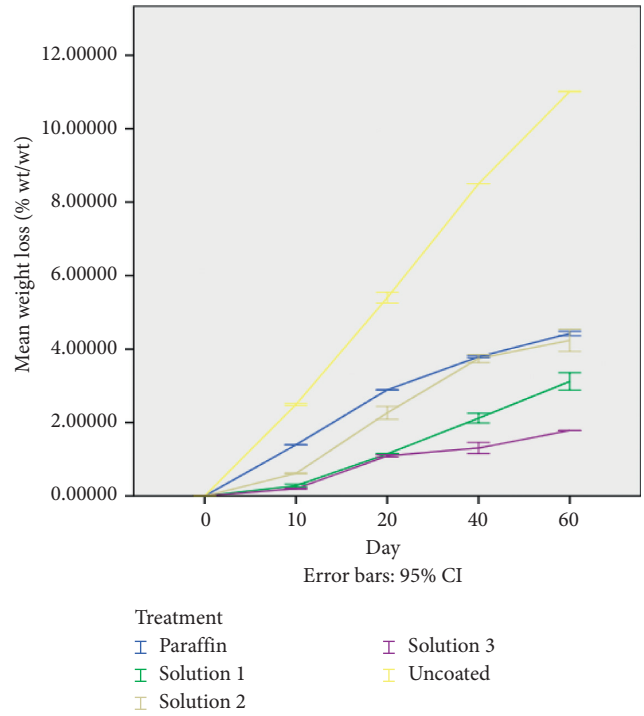

Figure 8: Values (means ± SD) of the weight loss of cheese coated with antimicrobial edible coating solutions—solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid)—compared with cheese coated with commercial coating and uncoated cheese throughout 60 d of storage at 10°C and 85% relative humidity.

According to the hardness changes (Figure 12), there was a statistically significant difference ($p < 0.05$) in hardness among the same cheese categories. Results of the hardness assay showed that the uncoated cheeses were more prone to hardening that coated cheeses. Antimicrobial edible coating solution 3 had the lowest hardness value, indicating that it was most effective in preventing cheese from hardening. Hardness of cheeses are directly linked to its moisture content. Therefore, the low hardening exhibited by antimicrobial edible solution-coated cheeses are a result of their low moisture permeability. On the contrary, the significant hardening of uncoated cheese demonstrates the absence of a moisture barrier.

Color analysis, based on color change, showed that all cheeses significantly changed their color ($p < 0.05$) throughout the storage, with uncoated cheeses exhibiting the highest color change and antimicrobial edible solution-coated cheeses showing the least changes (Figure 13). Interestingly, the color change among the cheese samples with antimicrobial edible coating was lower than the color change observed in paraffin-coated cheeses. Among the cheeses coated with antimicrobial edible solutions, those coated with solution 3 showed the least color change. According to literature, the acidulant power of lactic acid reduces color changes in cheese [13]. Therefore, we believe that the high lactic acid content in solution 3 may have induced a protective effect against color change. In addition, coatings prevent the cheese from oxidation as a result of lower oxygen permeability and damages from direct light. Color change may also be related with the rate of cheese dehydration, which was lower in coated cheese and thus produced a less dry and less dark, cheese rind [13].

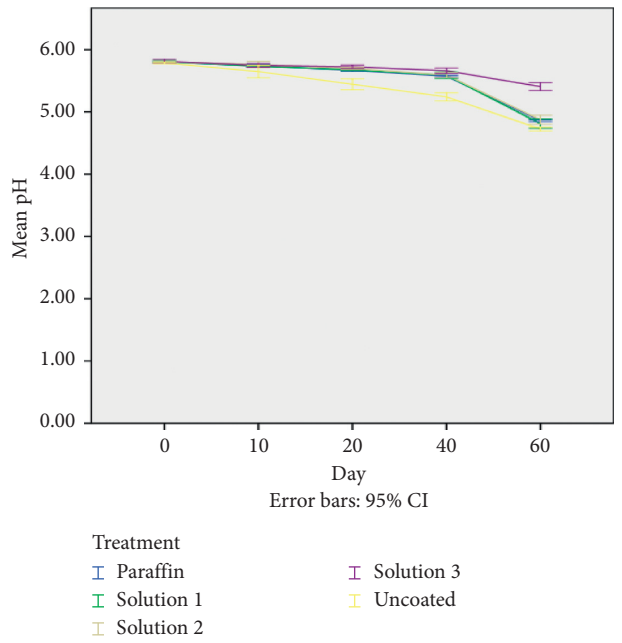

Figure 9: Values (means ± SD) of the pH of cheese coated with antimicrobial edible coating solutions—solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid)—compared with cheese coated with commercial coating and uncoated cheese throughout 60 d of storage at 10°C and 85% relative humidity.

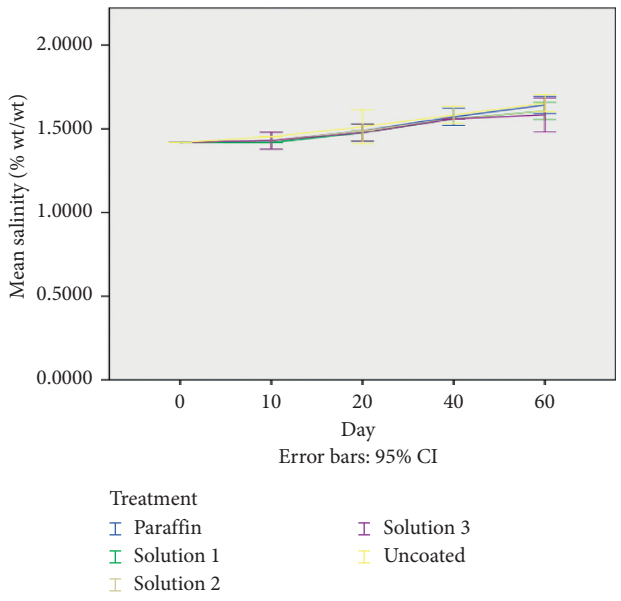

Figure 11: Values (means ± SD) of the salinity of cheese coated with antimicrobial edible coating solutions—solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid)—compared with cheese coated with commercial coating and uncoated cheese throughout 60 d of storage at 10°C and 85% relative humidity.

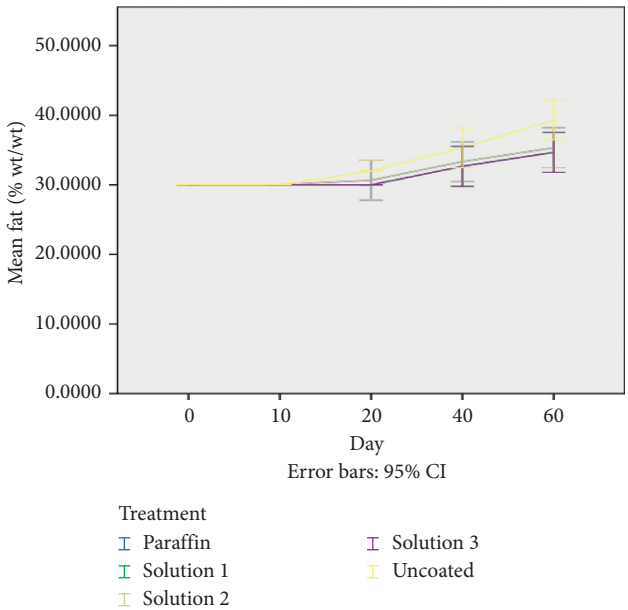

Figure 10: Values (means ± SD) of the fat content of cheese coated with antimicrobial edible coating solutions—solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid)—compared with cheese coated with commercial coating and uncoated cheese throughout 60 d of storage at 10°C and 85% relative humidity.

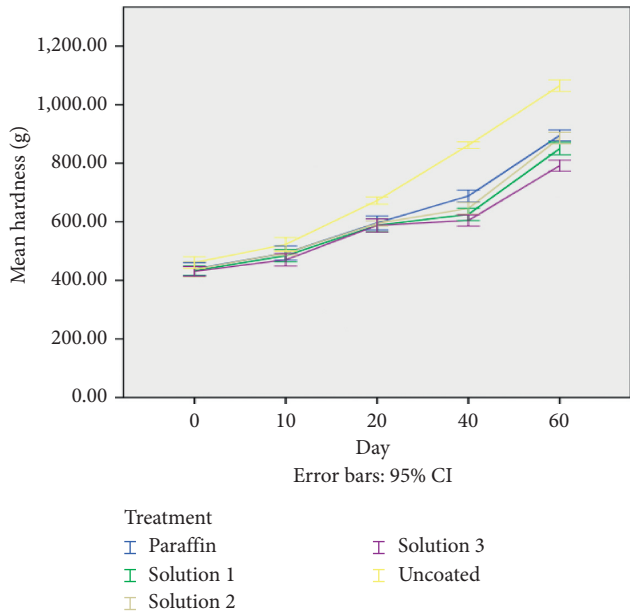

Figure 12: Values (means ± SD) of the hardness of cheese coated with antimicrobial edible coating solutions—solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid)—compared with cheese coated with commercial coating and uncoated cheese throughout 60 d of storage at 10°C and 85% relative humidity.

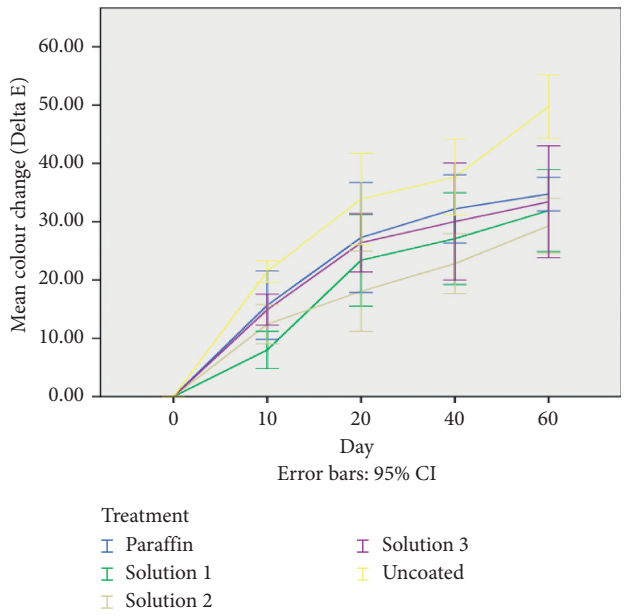

Figure 13: Values (means ± SD) of the color change of cheese coated with antimicrobial edible coating solutions—solution 1 (0.250 g/L Delvocid), solution 2 (0.275 g/L Delvocid), and solution 3 (0.300 g/L Delvocid)—compared with cheese coated with commercial coating and uncoated cheese throughout 60 d of storage at 10°C and 85% relative humidity.

3.4. Microbiological Analyses. Microbial counts (*Coliform*, yeast, and mold counts) of cheeses coated with 3 different antimicrobial edible solutions were compared with that of paraffin-coated cheese and uncoated cheese to determine the antimicrobial effect of the developed coating. Results of the microbiological analyses are demonstra in Figures 14–16.

As shown in Figure 14, all cheeses showed no *Coliform* growth during storage. As such the *Coliform* count for all cheeses were within the levels accepted as safe for consumption (<1 CFU/g) by the Sri Lankan Standard SLS 773: 1987.

Results of yeast counts (Figure 15) showed that both uncoated and paraffin-coated cheeses showed elevated levels of yeast growth during storage, which exceeded the acceptable level for the consumption within the first 10 days of storage (<100 CFU/g, SLS 773:1987). Among the antimicrobial edible solution-coated cheeses, solution 1-coated cheeses exceeded the acceptable level for consumption over 40 days of storage, while yeast counts for solution 2-coated and solution 3-coated cheeses remained within the acceptable range.

In terms of mold count, all antimicrobial edible solution-coated cheeses exhibited the acceptable mold count level for consumption (<100 CFU/g, SLS 773:1987) throughout the storage period, whereas paraffin-coated cheeses and uncoated cheeses exceeded the acceptable level subsequently over the 20 days of storage and over the 0 day of storage.

3.5. Sensory Analyses. Sensory profiles of antimicrobial edible solution-coated cheeses, paraffin-coated cheeses, and uncoated cheeses were obtained during the storage period with a 10-day interval period to determine if each of the cheeses showed significant variations in their sensory properties. Results of sensory analyses of all cheese varieties throughout the storage are shown in Table 1.

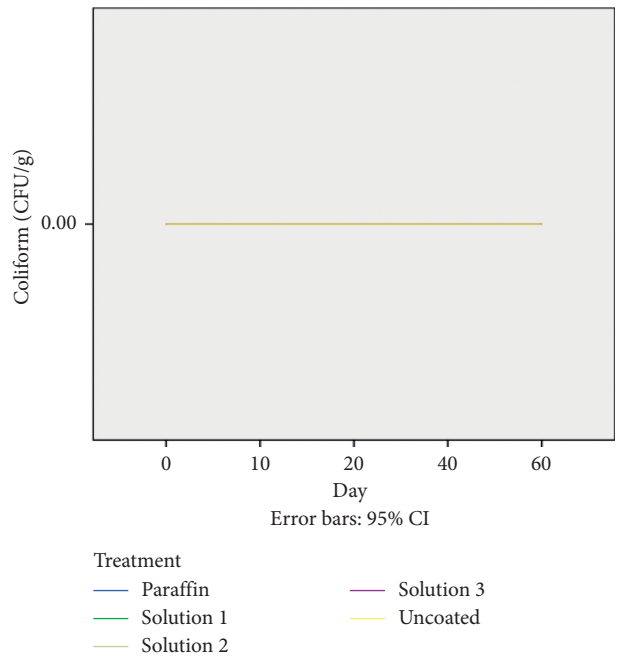

Figure 14: Coliform count (means ± SD) of cheese coated with antimicrobial edible coatings compared with cheese coated with commercial coating and uncoated cheese throughout 60 d of storage at 10°C and 85% relative humidity.

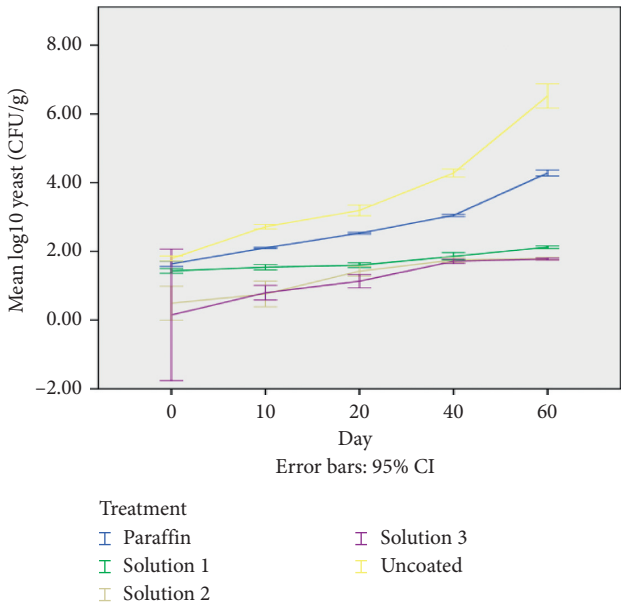

Figure 15: Yeast count (means ± SD) of cheese coated with antimicrobial edible coatings compared with cheese coated with commercial coating and uncoated cheese throughout 60 d of storage at 10°C and 85% relative humidity.

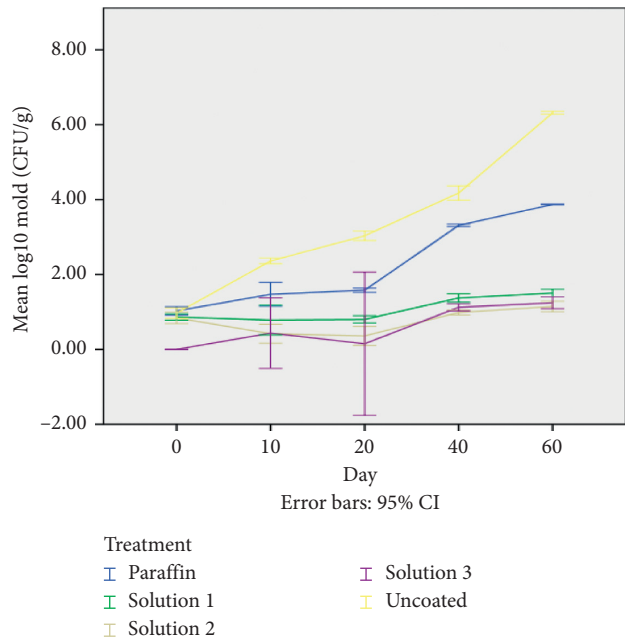

Figure 16: Mold count (means ± SD) of cheese coated with antimicrobial edible coatings compared with cheese coated with commercial coating and uncoated cheese throughout 60 d of storage at 10°C and 85% relative humidity.

Table 1: Sensory evaluation results of cheeses throughout the storage.

Day	Cheese sample	Odor	Color	Surface shininess	Hardness	Taste	Overall acceptability
0	Solution 1	5.10 ± 0.74^{a}	5.40 ± 0.52^{a}	4.90 ± 0.99^{a}	4.90 ± 1.45^{a}	4.10 ± 1.91^{a}	4.70 ± 1.42^{a}
	Solution 2	4.40 ± 1.90^{a}	5.50 ± 0.53^{a}	5.10 ± 0.99^{a}	4.30 ± 1.77^{a}	3.50 ± 1.78^{a}	4.70 ± 1.64^{a}
	Solution 3	4.90 ± 1.20^{a}	5.50 ± 0.85^{a}	4.90 ± 1.52^{a}	5.50 ± 1.51^{a}	4.20 ± 1.40^{a}	4.70 ± 1.34^{a}
	Paraffin	5.10 ± 1.10^{a}	5.70 ± 0.82^{a}	5.20 ± 1.14^{a}	4.60 ± 1.23^{a}	4.70 ± 1.64^{a}	5.60 ± 1.17^{a}
	Uncoated	5.00 ± 0.94^{a}	5.60 ± 0.52^{a}	5.50 ± 0.97^{a}	5.40 ± 1.78^{a}	4.80 ± 1.03^{a}	5.20 ± 1.14^{a}
10	Solution 1	4.80 ± 1.32^{a}	5.10 ± 0.99^{a}	5.00 ± 1.16^{a}	4.90 ± 1.10^{a}	5.40 ± 1.43^{a}	4.90 ± 0.88^{a}
	Solution 2	4.20 ± 1.32^{a}	5.60 ± 1.43^{a}	5.50 ± 1.51^{a}	5.30 ± 1.77^{a}	5.60 ± 1.35^{a}	5.10 ± 1.79^{a}
	Solution 3	4.20 ± 1.03^{a}	5.30 ± 1.64^{a}	5.30 ± 1.77^{a}	5.10 ± 1.52^{a}	4.80 ± 1.93^{a}	4.90 ± 1.60^{a}
	Paraffin	5.30 ± 1.06^{a}	5.30 ± 0.95^{a}	5.40 ± 0.97^{a}	5.00 ± 1.89^{a}	-	5.40 ± 1.08^{a}
20	Solution 1	4.90 ± 1.10^{a}	5.40 ± 1.17^{a}	4.80 ± 1.03^{a}	4.90 ± 1.10^{a}	4.40 ± 0.45^{a}	4.30 ± 1.49^{a}
	Solution 2	5.40 ± 1.17^{a}	5.30 ± 1.16^{a}	5.40 ± 1.17^{a}	5.50 ± 1.18^{a}	5.00 ± 0.39^{a}	$4.90 \pm 1.37^{a,b}$
	Solution 3	5.40 ± 1.27^{a}	6.10 ± 0.74^{a}	5.80 ± 0.79^{a}	5.80 ± 1.03^{a}	5.30 ± 1.34^{a}	6.10 ± 0.74^{b}
	Paraffin	5.50 ± 1.08^{a}	$5.\ 80 \pm 1.32^{a}$	5.20 ± 1.23^{a}	5.70 ± 1.06^{a}	-	5.70 ± 0.68^{b}
40	Solution 1	5.20 ± 1.23^{a}	$5.80 \pm 0.63^{a,b}$	$5.40 \pm 0.52^{a,b}$	5.30 ± 0.82^{a}	4.70 ± 1.16^{a}	$5.00 \pm 0.82^{a,b}$
	Solution 2	5.70 ± 1.16^{a}	6.20 ± 0.63^{b}	6.00 ± 0.67^{b}	5.30 ± 0.68^{a}	5.60 ± 0.70^{a}	$5.80 \pm 0.79^{b,c}$
	Solution 3	5.80 ± 0.63^{a}	$6.00 \pm 0.47^{a,b}$	$5.60 \pm 0.52^{a,b}$	5.70 ± 0.68^{a}	5.60 ± 0.84^{a}	5.90 ± 0.57^{c}
	Paraffin	5.30 ± 1.16^{a}	5.10 ± 1.23^{a}	5.10 ± 0.99^{a}	5.20 ± 0.79^{a}	-	4.70 ± 0.68^{a}
60	Solution 1	4.80 ± 1.03^{a}	5.10 ± 1.10^{a}	5.40 ± 0.84^{a}	5.10 ± 0.74^{a}		4.60 ± 1.08^{a}
	Solution 2	5.40 ± 0.97^{a}	$5.80 \pm 0.79^{a,b}$	5.50 ± 0.97^{a}	5.70 ± 0.95^{a}	5.10 ± 0.74^{a}	$5.50 \pm 0.85^{a,b}$
	Solution 3	5.30 ± 0.95^{a}	6.10 ± 0.32^{b}	5.80 ± 0.79^{a}	5.60 ± 0.84^{a}	5.70 ± 0.82^{a}	5.80 ± 0.79^{b}
	Paraffin	5.30 ± 0.95^{a}	$5.70 \pm 0.48^{a,b}$	5.50 ± 0.53^{a}	5.30 ± 0.68^{a}	-	$5.10 \pm 0.57^{a,b}$

a, b, c, Values in the same column at the same day with different superscripts are significantly different at $p < 0.05$.

According to the above results, all cheeses showed no significant difference ($p > 0.05$) in odor, color, surface shininess, hardness, taste, and overall acceptability at 0 day storage. There was a significant difference ($p < 0.05$) in overall acceptability among cheeses at the 20 days of storage, while color, surface shininess, and overall acceptability significant differed ($p < 0.05$) in all cheeses by day 40. A significant difference in color and overall acceptability was observed at day 60 of storage.

Sensory assessments were not performed for uncoated cheese after day 0 of storage due to extensive growth of yeast (>100 CFU/g). It also showed visible, largely expanded fungus growth and thus was not suitable for consumption and external sensory attributes evaluation. In addition, taste evaluation for paraffin-coated cheeses were not conducted after 0 day of storage because it showed relatively larger growth of yeast (>100 CFU/g). As such, the results only contain external attributes of paraffin-coated cheese.

According to the panelist, the characteristics odor and flavor of sunflower oil in antimicrobial edible solution-coated cheese somewhat affected the taste and odor profiles. This could be due to the unfamiliarity of sunflower oil to Sri Lankan consumers. However, results from the sensory analyses showed that the antimicrobial solution 3-coated cheeses showed better external attributes than both paraffin-coated cheeses and other antimicrobial edible coated cheeses from 20 days of storage. In addition, it showed better taste profiles from 20 days of storage until end of the shelf life. Interestingly, solution 2-coated cheeses showed a better taste profile in comparison to solution 1- and solution 3-coated cheeses at day 10 of storage.

Results showed that the external attributes of paraffin-coated cheeses showed better external attributes than antimicrobial edible solution-coated cheeses at day 10 of storage. According to the overall results of sensory attributes, the paraffin-coated cheeses showed better taste profiles at day 0 and external attributes at the 0 day and 20 days of storage. After 20 days of storage, antimicrobial edible solution-coated cheeses showed better external attributes.

4. Conclusion

This study determined the effectiveness of an antimicrobial edible coating prepared from sweet whey base to improve the physicochemical, microbiological, and sensory attributes of Swiss cheese throughout 60 days of storage, as a substitute for commercial nonedible paraffin coatings. Our study showed that this novel, edible coating showed the optimum antimicrobial function at 0.300 g/L Delvocid concentration. Analyses of physiochemical (weight, moisture, fat content, salt content, pH, hardness, and color), microbial (*Coliform*, yeast, and mold counts), and sensory properties (odor, color, surface shininess, hardness, taste, and overall acceptability) revealed that the antimicrobial edible coating exceeded the performance of commercially available, paraffin-coated cheese, indicating that this novel coating could be used as a more successful alternative to nonedible paraffin coatings. In addition, this coating added a commercial value to a common dairy by-product, sweet whey. Color of the edible coating solution was very similar to the color of Swiss cheese. Our results indicated that this antimicrobial edible coating minimized the moisture loss and maintained the preferable hardness. In addition, it also presents the consumer convenience of not requiring to remove the outer layer, while minimizing the weight loss of the product and wastage. Therefore, this antimicrobial edible coating is a novel, preferable, and economical innovation.

Data Availability

The data that support the findings of this study are available from the corresponding author on request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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