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Decolorization of Lactose-6-Phosphate Solutions Using Activated Carbon

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Abstract: Sugar phosphorylation has many applications that can be used to develop dairy and food products. During the phosphorylation process, the color of the solution turns into a dark color. The dark color causes many challenges and limitations in using phosphorylation products. The dark color could cause unpleasant color changes in the products, so it is important to remove that color. Activated carbon has been utilized for decades to remove the dark color and improve the appearance of solutions such as sugar syrup and wastewater. This methodology is cheap and environmentally friendly. The objectives of this study were to develop a method to phosphorylate α-lactose monohydrate and milk permeate and to remove the dark color of solutions. The compositional characteristics of the solution, such as pH, total solids, and color parameters (L*—lightness; a*—redness; and b*—yellowness), were examined at different stages (seven stages) of washing the solutions. α-lactose monohydrate and MPP solutions were diluted with distilled water with a ratio of 1:2.2. Activated carbon was mixed with the solutions and left for 5 min at room temperature. Subsequently, the solutions were filtered. These steps were repeated seven times until there was a transparent (colorless) solutions. The experiment was repeated using three different batches of lactose and milk permeate solutions. Both solutions' pH and total solids decreased with an increase in the number of washings with activated carbon. The International Commission on Illumination (CIE) L*a*b* scale was studied. The L* of the initial solutions was lower than that of the final solutions. However, the a* and b* of the initial solutions were higher than the final solutions. The total color difference (ΔE) was calculated for both solutions. ΔE decreased with an increase in the number of washings with activated carbon in both solutions. We conclude that activated carbon can be used to remove the dark color that results from the phosphorylation process.

Keywords: phosphorylation; lactose; milk permeate; activated carbon; lactose-6-phosphate; pH

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1. Introduction

Sugar phosphorylation has many applications that can be used to develop dairy and food products. Increasing the hydrophilicity of starch through phosphorylation is a common chemical modification method that produces products useful for the food, paper, glue, textile, and pharmaceutical industries [1,2]. Previous studies' findings demonstrated that the phosphorylation approach had been successfully used to enhance the attributes of mung bean, rice, corn, wheat, sago, and other starches [3–6].

Lactose, a disaccharide carbohydrate ($C_{12}H_{22}O_{11}$), is the mean carbohydrate in milk. Whey permeate, a byproduct of cheese and fractionation casein from skim milk, is used to make lactose commercially. It is widely used in food and pharmaceutical industries because it is a cheap ingredient, a source of low sweetness, and a filler [7]. Lactose is also significant for its economic worth and contributions to the sensory and functional aspects of dairy products. Lactose is a cheap dairy ingredient that could increase the profit of dairy products, but it could increase some chemical reactions in these products. High concentrations of lactose in those products could result in lactose crystal formation and a non-enzymatic browning reaction.

Lactose-6-phosphate (LP) is naturally present in milk and milk products with low concentrations [8,9]. LP was initially identified in bovine milk [10] and caprine milk [11] in low concentrations. Due to the similar structure of LP to lactose, it is hard to fractionate and purify it. LP is an organic molecule that replaces lactose's hydrogen with monophosphate. A phosphate group is connected to the lactose galactose portion of most LP molecules. Approximately 90% of LP is linked to galactose in pharmaceutical-grade lactose, while 10% is bound to glucose [12].

LP could be made using lactose and sodium cyclo-triphosphate at alkali conditions using sodium hydroxide [13]. The reaction causes color changes and byproducts such as carbon dioxide, carbon, and water. Under the alkali condition, the lactose could contain lactulose, lactitol, gluconic, other acids, lactosylurea, N-substituted amino sugars, polymers, and other reactions, such as esterification and acetylation [14]. The amount of sugar could be reduced due to the chemical reaction between the monosaccharides and hydrolyzed disaccharides with sodium hydroxide [15]. In addition, the degradation of lactose under alkali conditions has been noted [16]. A study on hemicellulose sugar shows that the alkali conditions release acetyl, acidic groups, and organic acids that lead to lower pH [17].

Moreover, the Maillard reaction could occur when the carbonyl compounds in sugar combine with the amino acids to generate an unstable Schiff base. Then, via double bond migration and rearrangement activities of the Schiff base, the reduction efficiency may be increased during the development of relatively stable Amadori or Heyns rearrangements [18]. The intermediate step of the Maillard reaction entails Amadori product degradation, notably sugar dehydration and deamination, Strecker degradation, and sugar fragmentation [19].

The color produced during LP production is complicated to determine due to the chemical structure of some of these coloring materials. The most important colored substances that form during sugar processing fall into three categories: (a) melanins, (b) melanoidins, and (c) caramels [20]. Using the phosphorylation products as a food additive could affect the color of the final product. This could lead to limitations in the use of this product. Thus, decolorization of the solution is significant in food additive processes. Different methodologies have been examined to decolorize solutions, including microorganism-mediated treatment [21–23] and physicochemical methods [24,25]. Adsorption on activated carbon is a popular physicochemical treatment method for color removal due to its large surface area, microporous structure, high adsorption capacity, and high degree of surface reactivity [26]. Because of its unique properties, the usage of activated carbon has been expanded to include decolorization, gas separation and polluted air treatment, heavy metal recovery and food processing with no hazard, and wastewater treatment [27–32].

This work aimed to develop a method for phosphoryl α-lactose monohydrate (LaP1) and phosphorylating milk permeate powder (LaP2) and to investigate the removal of color-causing components from LP solutions by activated carbon adsorption, as well as measure the colored products using the International Commission on Illumination (CIE) L*a*b* values from colorimetry. Also, the effect of washing with activated carbon on the pH and total solids (TS) at different stages was studied.

2. Materials and Methods

2.1. Lactose-6-Phosphate Preparation

LP was prepared using the methodology reported by Inoue et al. [13], with some modifications. Two different solutions were prepared using lactose and milk permeate powder (MPP). The first solution (LaP1) was prepared by mixing 1 mol of α-D-(+) lactose monohydrate ($C_{12}H_{22}O_{11}\cdot H_2O$: Fisher chemical; L5-500) with 0.5 mol of sodium cyclo-triphosphate (Frontier Scientific, Newark, DE, USA; Cat # 343031). The second solution (LaP2) was prepared by mixing MPP obtained from Idaho Milk Products (Jerome, ID, USA) and sodium phosphate dibasic (DSP) (Fisher Scientific, Fair Lawn, NJ, USA) in distilled water at the ratio of 28.32 and 1.41%, respectively. The pH of both solutions was adjusted using sodium hydroxide to obtain a pH of 12. The solution was stirred for 3 d at room temperature and then stored at 4 °C for 24 h. The solutions were separated into two layers, and the bottom layers were used in the study.

2.2. Decolorization of Lactose-6-Phosphate Solution

The decolorization of LaP1 and LaP2 solutions was prepared using the methodology reported by Zhang et al. [33,34], with some modifications. These solutions were decolorized using activated carbon (Darco G60,-100 mesh, powder, Aldrich Chemical Company, St. Louis, MO, USA). The bottom layer was diluted with distilled water with a ratio of 1:2.2 into a 1000 mL glass Erlenmeyer flask. A total of 25 g of activated carbon was added to 250 mL of the lower portion of solutions, mixed well, and set for 5 min at room temperature. The mixture was filtered through filter paper (Cat No. 1001 125, Whatman, Maidstone, UK). The mix and filtration steps were repeated seven times until the solutions became transparent (colorless). Up to 25% of the volume of the solution might be lost during the preparation.

2.3. Color Measurements

The color measurements of LaP1 and LaP2 solutions were prepared using the methodology reported by Hammam et al. [35,36], with some modifications. The color of the LaP1 and LaP2 solutions was measured using a Minolta Spectrophotometer (CM-508d, Minolta Camera Co., Ltd., Osaka, Japan). Color differences were recorded in the CIE L*a*b* scale in terms of lightness (L*) and color (a*—redness; b*—yellowness) for both solutions. Color measurement was recorded in triplicate, and the average value was recorded. The instrument was calibrated (Y = 85.7, x = 0.3236, and y = 0.3236) with a white calibration plate (CR-210, Konica Minolta, Tokyo, Japan) before being used. Samples were placed in Petri dishes (100 mm × 15 mm) with an optically clear bottom. A reference sample was obtained using distilled water in the Petri dishes with clear bottoms. Additionally, the total color difference (ΔE) was calculated using Formula (1):

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (1)$$

where $\Delta L^2 + \Delta a^2 + \Delta b^2$ are differences in the L*, a*, and b* values between the reference sample and the test sample, respectively.

2.4. Total Solids and pH

TS were measured using a forced draft oven [37], and pH was determined using the Hanna pH meter (Hannah Edge Blu, Woonsocket, RI, USA).

2.5. Statistical Analysis

Statistical analysis was performed to study the difference between treatments in terms of pH, TS, and color. The ANOVA test was carried out using R software (R×64-3.3.3, R Foundation for Statistical Computing). Mean separation was carried out using the least significant difference (LSD) test at $p < 0.05$.

3. Results and Discussion

3.1. pH and TS of Solutions

Table 1 shows the effect of activated carbon on the pH and TS of LaP1 solutions. The pH of the seven stages was 11.64, 11.61, 11.51, 11.32, 11.05, 10.91, and 10.86, respectively. The pH of solutions slightly decreased ($p < 0.05$) with an increase in the number of washings. A significant difference was detected between the fourth, fifth, sixth, and seventh stages and the diluted solution before washing with activated carbon (11.72). The pH of the solutions has a critical effect on the decolorization solution using the activated carbon technique.

A study on sugar syrup shows that a pH between 4.5 and 6.7 led to easy decolorization compared to acidic and alkali conditions [38]. As the solutions were in alkali conditions, this could lead to activated carbon treatment having poor efficiency. This could be related to the hydroxide ions in the solutions, which are competitive ions during color removal [39]. The pH adjustment of solutions before decolorization is recommended to improve the efficiency of activated carbon [40]. However, this adjustment of pH could affect the structure of LP.

Table 1. Mean (n = 3) composition of lactose solution (LaP1) after washing at different times with activated carbon.

Treatments [1]	pH	Total Solids (%)
Bottom layer	11.70 [a]	27.92 [a]
Dilated solution	11.72 [a]	12.61 [b]
1st stage	11.64 [ab]	8.43 [c]
2nd stage	11.61 [ab]	7.78 [c]
3rd stage	11.51 [b]	6.89 [d]
4th stage	11.32 [c]	6.11 [de]
5th stage	11.05 [d]	5.91 [e]
6th stage	10.91 [de]	5.33 [e]
7th stage	10.86 [e]	6.03 [de]

[1] Treatments: Bottom layer = the bottom layer of lactose solution after the phosphorylation process; dilated solution = the bottom layer of lactose solution after the phosphorylation process and being dilated with distilled water with a ratio of 1:2.2; 1st stage = lactose solutions after washing 1 time with activated carbon; 2nd stage = lactose solutions after washing 2 times with activated carbon; 3rd stage = lactose solution after washing 3 times with activated carbon; 4th stage = lactose solutions after washing 4 times with activated carbon; 5th stage = lactose solutions after washing 5 times with activated carbon; 6th stage = lactose solutions after washing 6 times with activated carbon; 7th stage = lactose solutions after washing 7 times with activated carbon. [a–e] Means in the same row not sharing a common superscript are different at $p < 0.05$.

The TS of the bottom layer solution was 27.92, which was dilated with distilled water with a ratio of 1:2.2 to obtain 12.61. The TS of the seven stages of washings were 8.43, 7.78, 6.89, 6.11, 5.91, 5.33, and 6.03%, respectively. The TS slightly decreased with an increase in the number of washings, except in stage number 7, which was slightly higher than stage number 6. No significant difference ($p > 0.05$) was found in the TS of LaP1 between the fourth, fifth, sixth, and seventh stages. Comparing the TS of the diluted solution with the final washing stage, it was significantly higher ($p < 0.05$). The loss of TS is related to removing the organic compounds from the solution by the adsorbent technique of activated carbon. It is not entirely clear how the adsorption of organic molecules on activated carbon in an aqueous media. Weber Jr and Morris [41] theorized that intraparticle diffusion is the critical step in the adsorption of several organic compounds on carbon. In a turbulent environment, several mechanisms are involved in the adsorption of organic compounds on activated carbon.

Table 2 presents the pH and TS of LaP2 solutions before and after being treated with activated carbon. The pH of LaP2 solutions was slightly decreased with the increasing number of washings. The pH of the seven stages was 11.48, 11.29, 11.17, 10.89, 10.35, 10.34, and 10.37, respectively. A significant difference ($p < 0.05$) was detected between the fifth, sixth, and seventh washing stages and the solution after being diluted with distilled water (11.54). This is related to the removal of organic compounds by adsorption techniques, leading to a decreased solution pH [42]. Similar results were found in Lubis et al. [43]. They purified water using activated carbon from natural sources. They found a decrease in water pH after being treated with activated carbon.

Increased ionization, solubility, and hydrophilicity are typically caused by higher pH [44]. The adsorption of organic compounds was also discovered to be affected by pH changes by modifying the adsorbents' surface properties and the adsorbate molecules' electronic properties in activated carbon [45,46]. Additionally, it has been demonstrated that the solution's pH, which affects the charge density of the activated carbon, significantly impacts the adsorption rate [47]. Mohan et al. [48] studied the commercial activated carbon's ability to be adsorbed in an aqueous phase. The results showed that the adsorption of activated carbon is highly dependent on the pH of the solution; as pH rises from 2.0 to 10.5, adsorption capacity decreases.

Table 2. Mean (n = 3) composition of milk permeate solution (LaP2) after washing at different times with activated carbon.

Treatments [1]	pH	Total Solids (%)
Bottom layer	11.66 [a]	30.12 [a]
Dilated solution	11.54 [ab]	8.83 [b]
1st stage	11.48 [ab]	8.17 [bc]
2nd stage	11.29 [abc]	6.78 [bcd]
3rd stage	11.17 [bc]	6.21 [cd]
4th stage	10.89 [c]	5.73 [d]
5th stage	10.35 [d]	5.76 [d]
6th stage	10.34 [d]	5.48 [d]
7th stage	10.37 [d]	4.93 [d]

[1] Treatments: Bottom layer = the bottom layer of milk permeate solution after the phosphorylation process; dilated solution = the bottom layer of milk permeate solution after the phosphorylation process and being dilated with distilled water with a ratio of 1:2.2; 1st stage = milk permeate solutions after washing 1 time with activated carbon; 2nd stage = milk permeate solutions after washing 2 times with activated carbon; 3rd stage = milk permeate solution after washing 3 times with activated carbon; 4th stage = milk permeate solutions after washing 4 times with activated carbon; 5th stage = milk permeate solutions after washing 5 times with activated carbon; 6th stage = milk permeate solutions after washing 6 times with activated carbon; 7th stage = milk permeate solutions after washing 7 times with activated carbon. [a–d] Means in the same row not sharing a common superscript are different at $p < 0.05$.

The TS of the first, second, third, fourth, fifth, sixth, and seventh stages of washings were 8.17, 6.78, 6.21, 5.73, 5.76, 5.48, and 4.93%, respectively. TS slightly decreased with an increase in the number of washings. The solution of the first wash was significantly higher ($p < 0.05$) compared to the second, third, fourth, fifth, sixth, and seventh stages. However, there was no significant difference between the second, third, fourth, fifth, sixth, and seventh stages. It appears that the TS of both solutions decreased after being treated with activated carbon. Because of its non-polar nature, activated carbon is notably well-recognized for its ability to adsorb organic compounds [49]. It is effective in adsorbing different types of chemicals. This led to a decrease in the TS of solutions each time they were treated with activated carbon. Similar results have found that TS decreased for beet sugar after being treated with activated carbon [50].

3.2. Color Measurements

Table 3 shows the effect of washing numbers with activated carbon on the color parameters of the LaP1 solutions. The standard L*, a*, and b* were 89.53, −4.97, and 6.07, respectively. On the other hand, the L*, a*, and b* of the bottom layer of LaP1 were 33.49, 2.17, and −1.85, respectively. In terms of the first stage, it appears that the L* of the solution was significantly lower ($p < 0.05$) than in the seventh stage. The sixth stage (75.31) was slightly higher than the seventh stage (75.04), but there was no significant difference between those two stages. However, the a* of the first wash solution was significantly higher ($p < 0.05$) than the seventh wash. It slightly decreased until the fourth wash and then elevated with an increasing number of washings. Furthermore, the b* of the first stage was significantly higher ($p < 0.05$) than in other stages, which was expected. The a* and b* decreased as the number of treated solutions with activated carbon increased; however, L* increased on the other side. Januszewicz et al. [51] found similar results when treating wastewater with activated carbon. Januszewicz's study reported that the color was slightly removed from the water when it was washed multiple times with activated carbon, and this is due to the high surface area of adsorption.

Table 3. Mean (n = 3) variation of color parameters (L*, a*, and b*) of lactose-6-phosphate solutions made with lactose (LaP1) according to the number of washings with activated carbon.

Treatments [1]	Parameters [2]		
	L*	a*	b*
Standard	89.53 ± 0.31 [a]	−4.97 ± 0.03 [c]	6.07 ± 0.15 [g]
1st stage	64.98 ± 2.01 [e]	2.56 ± 0.17 [a]	44.28 ± 1.85 [a]
2nd stage	73.96 ± 1.93 [d]	−6.31 ± 0.17 [e]	32.99 ± 0.91 [b]
3rd stage	77.71 ± 1.37 [c]	−7.05 ± 0.14 [g]	16.95 ± 0.46 [c]
4th stage	81.48 ± 2.87 [b]	−6.71 ± 0.23 [f]	13.30 ± 0.58 [d]
5th stage	81.85 ± 1.86 [b]	−6.51 ± 0.07 [ef]	11.05 ± 0.56 [e]
6th stage	75.31 ± 1.52 [cd]	−5.71 ± 0.09 [d]	7.87 ± 0.35 [f]
7th stage	75.04 ± 1.56 [cd]	−5.44 ± 0.08 [d]	7.16 ± 0.16 [fg]
Bottom layer	33.49 ± 0.27 [f]	2.17 ± 0.32 [b]	−1.85 ± 0.12 [h]

[1] Treatments: Standard = distilled water into the Petri dish with clear bottom; 1st stage = lactose solutions after washing 1 time with activated carbon; 2nd stage = lactose solutions after washing 2 times with activated carbon; 3rd stage = lactose solution after washing 3 times with activated carbon; 4th stage = lactose solutions after washing 4 times with activated carbon; 5th stage = lactose solutions after washing 5 times with activated carbon; 6th stage = lactose solutions after washing 6 times with activated carbon; 7th stage = lactose solutions after washing 7 times with activated carbon; bottom layer = the bottom layer of lactose solution after the phosphorylation process. [2] Parameters: L* = black (0) to white (100); a* = green (−) to red (+); b* = blue (−) to yellow (+). [a–h] Means in the same row not sharing a common superscript are different at $p < 0.05$.

Table 4 illustrates the impact of the washing stages with activated carbon on the color of LaP2 solutions. It appears that the L* of the solution of the first wash (73.68) was significantly lower ($p < 0.05$) than in other washes (81.34 in the second wash vs. 90.21 in the seventh wash). However, the a* of the solution of the first wash (−0.41) was significantly higher ($p < 0.05$) than the seventh wash (−5.02). It decreased until the fourth stage (−6.34), then slightly increased. Furthermore, the b* significantly dropped ($p < 0.05$) from 45.29 in the first wash to 6.17 in the seventh wash when the solution was washed with activated carbon. When we compared the first stage with the seventh stage of both solutions, the lightness increased, and the redness and yellowness decreased in stage 7. It means that with an increase in the number of washes, the dark color slightly decreased, which was expected. A study was carried out on removing the color of wastewater using activated carbon at different ratios [52]. The study shows that the efficiency of color removal increased by increasing the dosage of adsorbents.

Table 4. Mean (n = 3) variation of technological parameters of lactose-6-phosphate solutions made with milk permeate (LaP2) according to the number of washings with activated carbon.

Treatments [1]	Parameters [2]		
	L*	a*	b*
Standard	89.53 ± 0.31 [a]	−4.97 ± 0.03 [b]	6.07 ± 0.15 [de]
1st stage	73.68 ± 5.69 [c]	−0.41 ± 3.72 [a]	45.29 ± 3.05 [a]
2nd stage	81.34 ± 1.49 [b]	−5.80 ± 0.15 [b]	23.70 ± 0.87 [b]
3rd stage	87.34 ± 1.34 [a]	−6.41 ± 0.39 [b]	16.17 ± 4.95 [bc]
4th stage	86.61 ± 1.20 [a]	−6.34 ± 0.23 [b]	14.22 ± 2.07 [cd]
5th stage	88.05 ± 0.67 [a]	−6.08 ± 0.27 [b]	11.02 ± 1.41 [cd]
6th stage	89.99 ± 0.32 [a]	−5.29 ± 0.27 [b]	7.36 ± 1.15 [cd]
7th stage	90.21 ± 0.38 [a]	−5.02 ± 0.08 [b]	6.17 ± 0.23 [de]

[1] Treatments: Standard = distilled water into the Petri dish with clear bottom; 1st stage = milk permeate solutions after washing 1 time with activated carbon; 2nd stage = milk permeate solutions after washing 2 times with activated carbon; 3rd stage = milk permeate solution after washing 3 times with activated carbon; 4th stage = milk permeate solutions after washing 4 times with activated carbon; 5th stage = milk permeate solutions after washing 5 times with activated carbon; 6th stage = milk permeate solutions after washing 6 times with activated carbon; 7th stage = milk permeate solutions after washing 7 times with activated carbon. [2] Parameters: L* = black (0) to white (100); a* = green (−) to red (+); b* = blue (−) to yellow (+). [a–e] Means in the same row not sharing a common superscript are different at $p < 0.05$.

Tables 5 and 6 present the color removal efficiencies of activated carbons with seven washes for both LaP1 and LaP2 solutions. It was clear that depending on the wash of activated carbon, the color removal efficiency varied widely among the solutions. Complete color removal was achieved with seven stages. ΔE of LaP1 solutions was 46.03, 31.13, 16.20, 10.96, 9.27, 14.35, and 14.54 for the first, second, third, fourth, fifth, sixth, and seventh stages, respectively. ΔE was slightly decreased with an increase in the number of washings with activated carbon. The fourth and fifth stages were slightly lower than the sixth and seventh stages. This could relate to the a* parameter being slightly lower ($p > 0.05$) in those stages. ΔE of the first wash was three times higher compared to the seventh stage. The bottom layer of solutions was 57.04, which is higher than that of the other stages. On the other hand, ΔE of LaP2 solutions was 42.57, 19.45, 10.43, 8.76, 5.28, 1.40, and 0.68 for the first, second, third, fourth, fifth, sixth, and seventh stages of washing, respectively. ΔE was slightly decreased with an increase in the number of washings. The LP decolorization performances of activated carbon are shown in Figures 1 and 2. The dark color of both solutions was slightly decreased after multiple washes with activated carbon. The color of solutions tended to be brownish (first and second stages), yellowish (third and fourth stages), clear (fifth and sixth stages), and transparent (colorless) solutions in the final stages.

Table 5. Mean (n = 3) color determinants and total changes in the color of lactose solutions (LaP1).

Treatments [1]	ΔL^2	Δa^2	Δb^2	ΔE
1st stage	602.70	56.70	1460.26	46.03
2nd stage	242.53	1.79	724.87	31.13
3rd stage	139.71	4.33	118.45	16.20
4th stage	64.86	3.03	52.27	10.96
5th stage	58.98	2.36	24.77	9.27
6th stage	202.21	0.55	3.23	14.35
7th stage	210.15	0.22	1.19	14.54
Bottom layer	3140.12	50.97	62.72	57.04

[1] Treatments: 1st stage = lactose solutions after washing 1 time with activated carbon; 2nd stage = lactose solutions after washing 2 times with activated carbon; 3rd stage = lactose solution after washing 3 times with activated carbon; 4th stage = lactose solutions after washing 4 times with activated carbon; 5th stage = lactose solutions after washing 5 times with activated carbon; 6th stage = lactose solutions after washing 6 times with activated carbon; 7th stage = lactose solutions after washing 7 times with activated carbon; bottom layer = the bottom layer of lactose solution after the phosphorylation process.

Table 6. Mean (n = 3) color determinants and total changes in the color of milk permeate solutions (LaP2).

Treatments [1]	ΔL^2	Δa^2	Δb^2	ΔE
1st stage	251.33	23.36	1538.21	42.57
2nd stage	67.13	0.69	310.82	19.45
3rd stage	4.81	2.06	102.08	10.43
4th stage	8.55	1.87	66.42	8.76
5th stage	2.21	1.23	24.47	5.28
6th stage	0.21	0.10	1.66	1.40
7th stage	0.45	0.00	0.01	0.68

[1] Treatments: 1st stage = milk permeate solutions after washing 1 time with activated carbon; 2nd stage = milk permeate solutions after washing 2 times with activated carbon; 3rd stage = milk permeate solution after washing 3 times with activated carbon; 4th stage = milk permeate solutions after washing 4 times with activated carbon; 5th stage = milk permeate solutions after washing 5 times with activated carbon; 6th stage = milk permeate solutions after washing 6 times with activated carbon; 7th stage = milk permeate solutions after washing 7 times with activated carbon.

The numbered pictures represent various doses of activated carbon: 1st = lactose solutions after washing 1 time with activated carbon; 2nd = lactose solutions after washing 2 times with activated carbon; 3rd = lactose solution after washing 3 times with activated carbon; 4th = lactose solutions after washing 4 times with activated carbon; 5th stage = lactose solutions after washing 5 times with activated carbon; 6th = lactose solutions after washing

6 times with activated carbon; 7th = lactose solutions after washing 7 times with activated carbon; bottom layer = the bottom layer of lactose solution after the phosphorylation process; dilated solution = the bottom layer of lactose after the phosphorylation process and being dilated with distilled water with a ratio of 1:2.2.

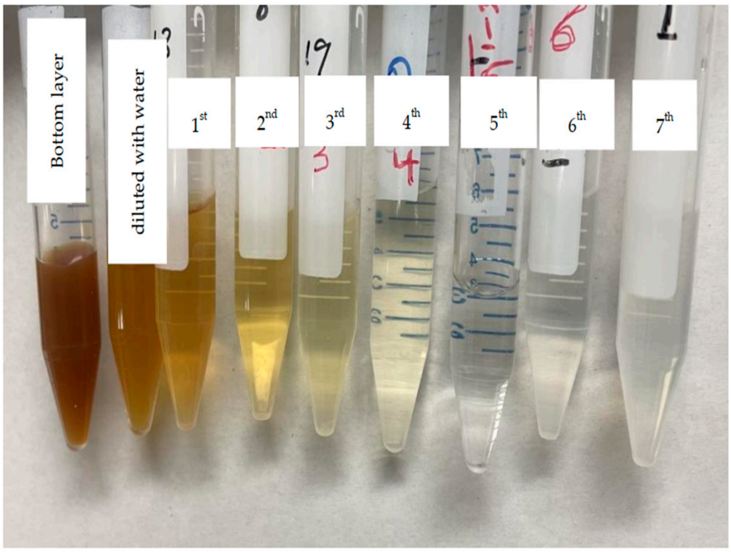

Figure 1. Discoloration of the lactose solution (LaP1) by the application of the activated carbon.

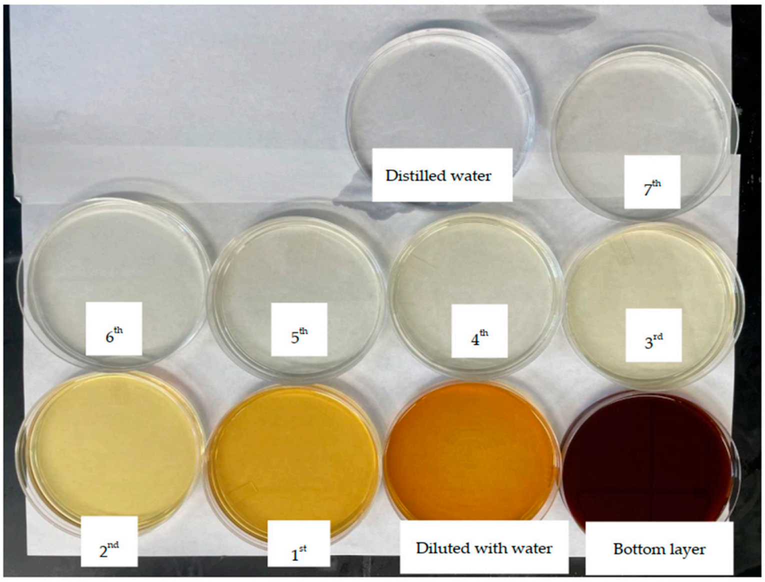

Figure 2. Discoloration of the milk permeate solution (LaP2) by the application of the activated carbon.

The numbered pictures represent various doses of activated carbon: 1st = milk permeate solutions after washing 1 time with activated carbon; 2nd = milk permeate solutions after washing 2 times with activated carbon; 3rd = milk permeate solutions after washing 3 times with activated carbon; 4th = milk permeate solutions after washing 4 times with activated carbon; 5th = milk permeate solutions after washing 5 times with activated carbon; 6th = milk permeate solutions after washing 6 times with activated carbon; 7th = milk permeate solutions after washing 7 times with activated carbon; bottom layer = the bottom layer of milk permeate solution after the phosphorylation process; dilated solution = the bottom layer of milk permeate solution after the phosphorylation process and being dilated with distilled water with a ratio of 1:2.2.

4. Conclusions

The activated carbon was successfully used to remove the dark color from the LaP1 and LaP2 solutions. Both solutions' pH and TS were significantly decreased with an increase in the number of washings with activated carbon. When comparing parameters (L*, a*, and b*) of stages, we found that the parameters a* and b* decreased, but L* increased. ΔE decreased with an increase in the number of stages for both solutions. The phosphorylation products could be used as a food additive. The decolorization of the solution is a significant process that could be used when making food additives. The next step would be to use the phosphorylation products as ingredients in making processed cheese to replace emulsifying salts. We assume that activated carbon can be used to remove the dark color that results from the phosphorylation process.

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