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Investigation of the Polyphenol Recovery of Overripe Banana Peel Extract Utilizing Cloud Point Extraction

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Abstract: Consuming fruits and vegetables necessitates discarding the inedible parts, which raises issues such as waste management and contamination of the environment. Numerous studies have been conducted in recent years in an effort to identify alternatives that reduce the negative effects of food and agricultural waste. This study aims to investigate the polyphenol recovery and the antioxidant capacity of overripe banana peel through cloud point extraction (CPE), which is a green method. The optimal conditions of the CPE were three steps of CPE with 10% *w*/*v* lecithin, which was used as surfactant, pH 7, and a salt concentration of 15% at 45 °C for 20 min. The total polyphenol content (TPC) was determined to be 541.25 mg GAE/L, the total flavonoid content (TFC) was determined to be 226.38 mg RtE/L, and FRAP and DPPH assays were found to be 2.52 and 2.91 mmol AAE/L, respectively. According to the results, the antioxidant compounds from banana peels can effectively be extracted with the proposed CPE procedure. The as-prepared extracts can potentially be used as food additives to improve human well-being and even as feed additives for a similar purpose.

Keywords: *Musa* spp.; micelle formation; polyphenols; flavonoids; surfactant; high-performance liquid chromatography

Citation: Athanasiadis, V.; Chatzimitakos, T.; Mantiniotou, M.; Kalompatsios, D.; Bozinou, E.; Lalas, S.I. Investigation of the Polyphenol Recovery of Overripe Banana Peel Extract Utilizing Cloud Point Extraction. *Eng* **2023**, *4*, 3026–3038. https://doi.org/10.3390/eng4040170

Academic Editor: James McGregor

Received: 31 October 2023
Revised: 5 December 2023
Accepted: 14 December 2023
Published: 18 December 2023

1. Introduction

Banana plants are classified under the *Musaceae* family. They come from three genera, namely *Musa*, *Ensete*, and *Musella*, all belonging to the same genus [1]. However, it is important to note that most banana plants are classified under various species within the *Musa* genus. The majority of known banana cultivars can be identified through two diploid species, specifically *Musa acuminata* (genome A) and *Musa balbisiana* (genome B) [2]. The cultivation of bananas dominates in numerous tropical and subtropical regions. The banana fruit is a highly nutritious source of energy and minerals, commonly consumed both fresh or after processing, on a small or industrial scale to make a variety of products. Such products are chips, flour, ice cream, smoothies, powder, bread, jam, wine, and functional food ingredients [3,4]. The banana peel contributes 35% of the total fruit weight and is commonly regarded as waste [5]. Given the global annual production of bananas up to 102 million tons, it is imperative to consider the industrial utilization of banana waste biomass, as it could benefit both the environment and industries [6]. Despite being profitable, eating bananas also produces over 26 million tons of dry matter residue annually, primarily as a result of discarding the peels [7]. According to some earlier studies, banana peels are a rich source of polyunsaturated fatty acids, essential amino acids and protein, potassium ions, and dietary fiber that is both water-soluble and water insoluble. These nutrients are important for human feed and food factories [8]. Banana peel has been used for centuries owing to its supposed therapeutic and preventative effects on a plethora of

ailments, including burns, anemia, inflammation, and depression [6]. Furthermore, banana peel is rich in polyphenolic compounds, thus promoting its antioxidant, antibacterial, and antibiotic activities [2]. Yet, banana peel waste, especially when overripe, is usually dumped at production sites or disposed of in landfills, and it is regularly converted into organic fertilizer or used as animal feed [9].

Waste in the food processing industry could be reduced if the by-products were utilized as additives for new products [10]. When compared to the peels of other fruits, banana peels have greater radical scavenging activity and reducing ability [11]. Additionally, they also contain significantly higher concentrations of polyphenols, which is an important secondary metabolite [3,12]. Therefore, banana peels may be used as a natural preservative to increase the duration of the life span of the food without compromising its nutritional value, given its potent antioxidant and antimicrobial properties. The polyphenols of banana peels, including ferulic acid, dopamine, and caffeic acid, are potential food preservatives due to their antioxidant and antimicrobial properties [5]. Banana peel is appealing due to its antioxidant properties, which can lead to the development of novel products [13]. Such products could be either foods for human consumption that could enhance the well-being of the human body or animal feed with similar properties [12].

Although the beneficial properties of banana peel extracts have been studied thoroughly using various extraction methods, more eco-friendly extraction techniques, like cloud point extraction (CPE), are lacking in the existing literature. The employment of CPE in the recovery of bioactive compounds derived from plant sources is a viable and environmentally conscious extraction technique [14]. This extraction method could be implemented in numerous sectors, including the pharmaceutical and food sectors. Utilizing surfactants, CPE is a simple and cost-effective technique for extracting bioactive compounds from liquid matrices [15]. In summary, the experimental protocol entails the introduction of a surfactant and a salt to a liquid sample, the regulation of the cloud-point temperature, the application of centrifugal force, and the eventual separation of the surfactant from the water phase of the sample [16–18]. CPE is a singular extraction method that has the potential to be replicated to improve the efficiency of bioactive compound recovery [19]. Utilizing surfactants that meet food-grade requirements permits the extraction of specific compounds, thereby facilitating their direct incorporation into food products [20]. When the concentration of molecules in aqueous solutions reaches a critical threshold, micelles are occurring, and these micelles exist in dynamic equilibrium with the monomers in the surrounding aqueous solution [21]. By associating hydrophobic and hydrophilic molecules with these structures through hydrogen bonds and dipole–dipole interactions, separation is achieved [22]. Utilizing various surfactants, including Tween 80, Genapol X-080, Triton X-100 and lecithin has enabled the successful isolation of bioactive compounds [19].

The objective of this study is to explore the recovery of antioxidants, polyphenols and flavonoids from overripe banana peels via the CPE method. The results were evaluated through the quantification of the total polyphenol content (TPC) through the Folin–Ciocalteu method, the total flavonoid content (TFC), and the antioxidant capacity of the extracts through Ferric-Reducing Antioxidant Power (FRAP), and DPPH$^{\bullet}$ scavenging activity. High-Performance Liquid Chromatography coupled with a diode array detector (HPLC-DAD) was implemented to identify and qualify specific polyphenols from the banana peels.

2. Materials and Methods

2.1. Materials, Chemicals and Reagents

Hydrochloric acid, methanol, ethanol, sodium hydroxide, iron chloride (hexahydrate), L-ascorbic acid, Tween 20, Genapol X-080, Span 80, 2,4,6-tris(2-pyridyl)-*s*-triazine (TPTZ), DPPH$^{\bullet}$ (1,1-diphenyl-2-picrylhydrazyl), and all chemical standards used for HPLC-based analysis (all of which were at least HPLC grade) like ferulic acid, neochlorogenic acid, chlorogenic acid, catechin, epicatechin, quercetin 3-D-galactoside, rutin, narirutin and rosmarinic acid were obtained from Sigma-Aldrich (Steinheim, Germany). Gallic acid,

Folin–Ciocalteu reagent, and anhydrous sodium carbonate were all purchased from Penta (Prague, Czech Republic). Tween 80 and Tween 40 were from Panreac (Barcelona, Spain). PEG 8000 was bought from Alfa Aesar (Karlsruhe, Germany). Merck (Darmstadt, Germany) provided the anhydrous citric acid. Triton X-100 was obtained from Scharlau (Bayern, Germany). Lecithin soya (>97%) was from ABS Food (Vignoza PD, Italy). Sodium chloride was purchased from Carlo Erba (Milano, Italy). Deionized water was used throughout all the experiments, and it was generated from a deionizing column.

Overripe banana samples were purchased from a local market in Larissa, Greece. It was the Grand Nain banana variety. The fruit was left to ripe naturally, and when it was overippe, the peels were removed manually with a knife. The peels were cut into smaller parts and placed in a Biobase BK-FD10P (Jinan, China) lyophylizer to reduce the presence of water. Lyophilization took place at cold trap temperature ≤ -58 °C and vacuum degree $\leq$10 Pa for 24 h. After the freeze-drying procedure, the samples were grounded. The powder was stored at −40 °C pending further analysis. The pH values were measured in the peel extracts utilizing a pH meter (XS Instruments, PC 60 VioLab with XS 201T DHS digital electrode, Carpi, Modena, Italy).

2.2. CPE Procedure

An electronic analytical digital scale balance (Kern PLS 3100-2F (Kern & Sohn GmbH, Balingen, Germany) was used to measure the weight of the fruit. Banana peel powder was combined with deionized water in a solid-to-liquid ratio of 1:40 and was stirred (Heidolph MR Hei-Standard, Schwabach, Germany) at ambient temperature (25 °C) and 800 rpm for 1 h. Next, the sample was centrifuged at 4500× *g* for 5 min in a NEYA centrifuge (Remi Elektrotechnik Ltd., Palghar, India). The supernatant (i.e., banana peel extract) was used for further steps. The CPE method employed in this study was as follows. Briefly, 20 mL of the banana peel extract was combined with 10% *w*/*v* of a surfactant. A magnetic stirrer was used to maintain a steady temperature in the mixture while it was heated and stirred. The sample was stirred at 800 rpm for 20 min at 45 °C. Next, the sample was centrifuged for 5 min at 4500× *g*. All recovery values presented in this study are derived from the mean of three extraction experiments conducted independently.

2.3. Polyphenol Recovery

Utilizing a polyphenol mass balance, the recovery of polyphenols was measured. Using a previously established method [23] and Equation (1) provided below, the surfactant recovery was estimated:

$$\text{Recovery } (\%) = \frac{C_s \cdot V_s}{C_0 \cdot V_0} \times 100 = C_0 \cdot V_0 - \frac{C_w \cdot V_w}{C_0 \cdot V_0} \times 100 \quad (1)$$

where C_s stands for the polyphenol concentration in the surfactant phase volume V_s, C_0 refers to the initial sample polyphenol concentration in the initial sample volume V_0 (10 mL), and C_w is the polyphenol concentration in the water phase volume V_w.

The Folin–Ciocalteu method (*vide infra*) was employed to determine the average concentration of each phase, which was then expressed as mg GAE/L. The method is described below.

2.4. Quantification of Total Polyphenol Content

The total polyphenol content (TPC) was determined photometrically using a slightly altered Folin–Ciocalteu methodology [24]. Following the combination of 100 µL of the sample extract with 100 µL of the Folin–Ciocalteu reagent for a duration of 2 min, an additional 800 µL of a sodium carbonate solution 5% *w*/*v* was added. After a 20-min incubation period at 40 °C, devoid of any exposure to light, the absorbance of the solution was quantified at 740 nm utilizing a Shimadzu spectrophotometer (UV-1700, Shimadzu Europa GmbH, Duisburg, Germany). The results were reported as mg gallic acid equivalents (GAE) per liter.

2.5. Evaluation of Total Flavonoid Content (TFC)

A previously established method [25] was followed, according to which 100 µL of diluted sample (1:5) was mixed with 40 µL of a reagent containing 5% w/v aluminum chloride and 0.5 M sodium acetate and 860 µL of aqueous ethanol (35% v/v). After keeping the mixture for 30 min at room temperature, the absorbance at 415 nm was obtained. Based on a rutin (quercetin 3-*O*-rutinoside) calibration curve (30–300 mg/L in methanol), the total flavonoid concentration was determined. The TFC was expressed as mg rutin equivalents (RtE) per liter.

2.6. Ferric-Reducing Antioxidant Power (FRAP) Assay

The FRAP investigation was conducted according to a previously employed method [26]. An amount of 50 µL of the sample was mixed with 50 µL of $FeCl_3$ solution (4 mM in 0.05 M HCl) in an Eppendorf tube. Then, the resulting mixture was incubated at 37 °C for 30 min. Afterwards, 900 µL of TPTZ solution (1 mM in 0.05 M HCl) was added, and after a 5-min wait, the absorbance was obtained at 620 nm. The ferric-reducing power (P_R) was assessed by employing a calibration curve, which was established utilizing ascorbic acid dissolved in 0.05 HCl. The quantities of ascorbic acid ranged from 0.05 to 0.5 mmol/L. The P_R of the samples was measured in terms of mmol of ascorbic acid equivalents (AAE) per liter.

2.7. Evaluation of Antiradical Activity (DPPH• Assay)

A previously described assay [26] for DPPH• scavenging was employed. First, 25 µL of diluted sample extract (1:5) was combined with 975 µL of DPPH• solution (100 µmol/L in methanol), and the absorbance at 515 nm was measured immediately ($A_{515(i)}$) and 30 min later ($A_{515(f)}$). The DPPH• radical scavenging capacity was expressed as described in Equation (2):

$$\text{Inhibition } (\%) = \frac{A_{515(i)} - A_{515(f)}}{A_{515(i)}} \times 100 \quad (2)$$

Antiradical activity (A_{AR}) was expressed as mmol ascorbic acid equivalents (AAE) per liter, using an ascorbic acid calibration curve.

2.8. HPLC–DAD Analysis

Shimadzu Europa GmbH, Duisburg, Germany supplied the liquid chromatograph (model CBM-20A) and diode array detector (model SPD-M20A) used in this study. A Phenomenex Luna C18(2) column (100, 5 m, 4.6 250 mm) from Phenomenex Inc. in Torrance, CA, USA was used to separate the compounds at 40 °C. The mobile phase included both a 0.5% formic acid aqueous solution (A) and a 0.5% formic acid in acetonitrile solution (B). The used gradient program went from 0% B to 40% B in 10 min, 50% B in 10 min, 70% B in 10 min, and then maintained at 70% for 10 min. The mobile phase was flowing at a rate of 1 mL/min. Calibration curves were used to determine the concentration range (from 0 to 50 µg/mL) of the compounds of interest by comparing the retention time and absorbance spectrum to those of pure chemical standards.

2.9. Statistical Analysis

All analyses were conducted thrice. The findings were presented as the mean values of three replicated measurements along with the standard deviation. The Kolmogorov–Smirnov test was employed to examine if the data were normally distributed. The one-way analysis of variance (ANOVA) with Tuckey's post hoc Test Calculator was utilized to analyze statistically significant differences, using IBM SPSS Statistics (Version 29.0) statistical software (SPSS Inc., Chicago, IL, USA). A significance level of $p < 0.05$ was applied to assess statistical significance.

3. Results and Discussion

3.1. Optimization of the CPE Procedure

3.1.1. Surfactant Selection

This study aimed to assess the optimal conditions for maximizing polyphenol recovery from overripe banana peels. As such, at first, the optimum surfactant was selected after evaluating their performance. Eight surfactants, namely Tween 80, Tween 40, Tween 20, Triton X-100, PEG 8000, Span 80, lecithin, and Genapol X-080 were tested. Polyphenol recovery percentage was used to assess the effectiveness of all surfactants. Figure 1 shows the results of the recovery achieved by each surfactant.

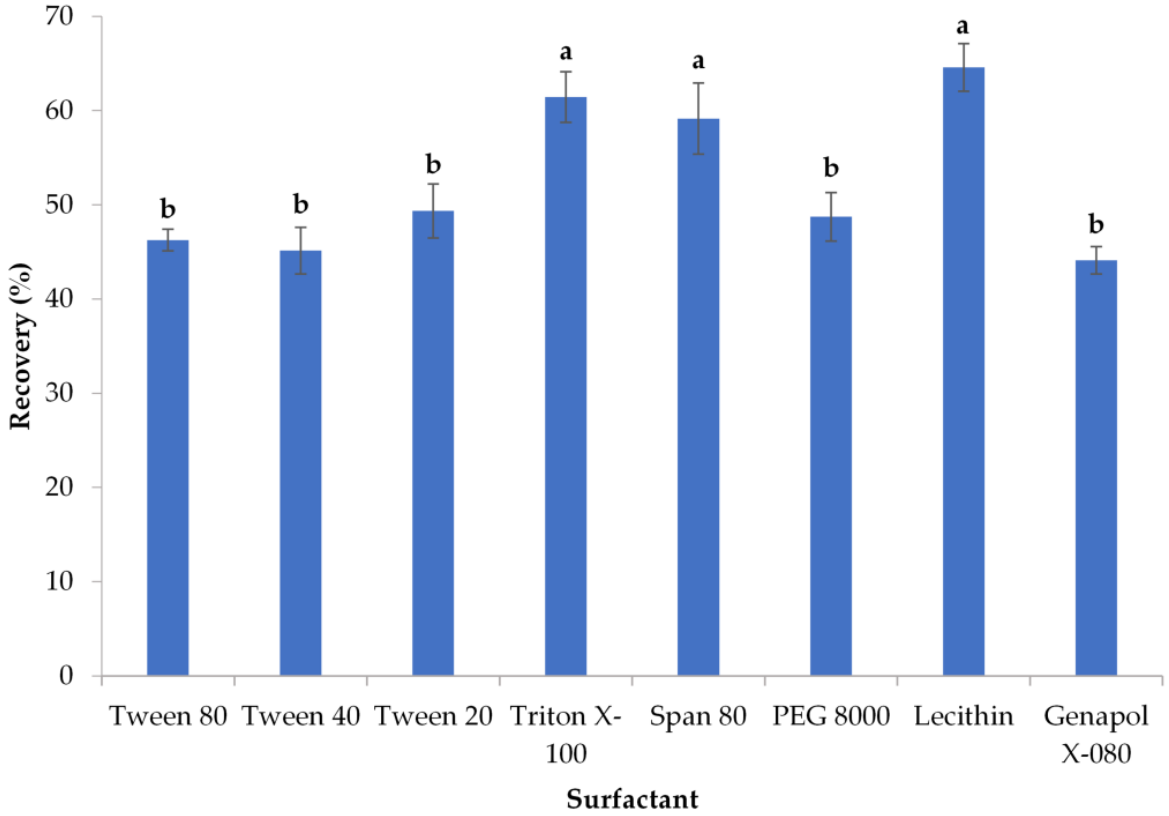

Figure 1. Impact of different surfactants on the polyphenol recovery from overripe banana peels; Standard deviations are depicted with error bars and the means with lowercase letters (e.g., a, b) that have statistically significant differences ($p < 0.05$).

As shown in Figure 1, the surfactants Span 80, Triton X-100, and lecithin are the ones achieving the highest polyphenol recovery, with no statistically significant difference ($p > 0.05$) among them, with lecithin yielding the highest recovery, at 64.57%. Thus, lecithin was chosen as the optimum surfactant for the CPE procedure. Lecithin is a zwitterionic surfactant of natural origin and low toxicity that can be used directly in foods [27]. Due to the fact that it is a non-toxic surfactant and it has a low price, it is widely accepted. Similarly, in the European Union, it is also permitted as a food additive (under the designation E322) and is typically classified as "quantum satis" (implying that it could be applied in any amount) [28]. All the above render lecithin a food-grade surfactant. There are numerous studies in the literature reporting the utilization of lecithin as a surfactant for CPE, such as for the isolation of polyphenols through CPE from olive-mill wastewater [29,30]. Similarly, Alibade et al. [28] employed CPE with lecithin surfactant in order to isolate antioxidants from winery wastes. Giovanoudis et al. [31] also utilized CPE with lecithin as a surfactant to isolate carotenoids from tomato liquid wastewater.

3.1.2. Determination of the Optimal pH

The pH of the sample is a crucial factor to consider for maximizing the recovery of the extraction process. Consequently, an investigation was conducted to assess the impact of various pH levels on the recovery of polyphenols. It was evident that the pH level exerts a significant influence on the extraction efficiency of polyphenolic compounds. As shown in Figure 2, the higher the pH value, the higher the recovery of polyphenols from the extract. The maximum recovery is at pH 7, where the recovery was 77.46%. At pH 8, the recovery of polyphenols was 73.18%, a value not statistically different from pH 7 ($p > 0.05$); however, pH 7 was chosen as it was closer to the original pH value of the sample (5.54). This result is in line with Zain et al. [32], who developed a green CPE method for the elimination of phenolic substances from aqueous samples.

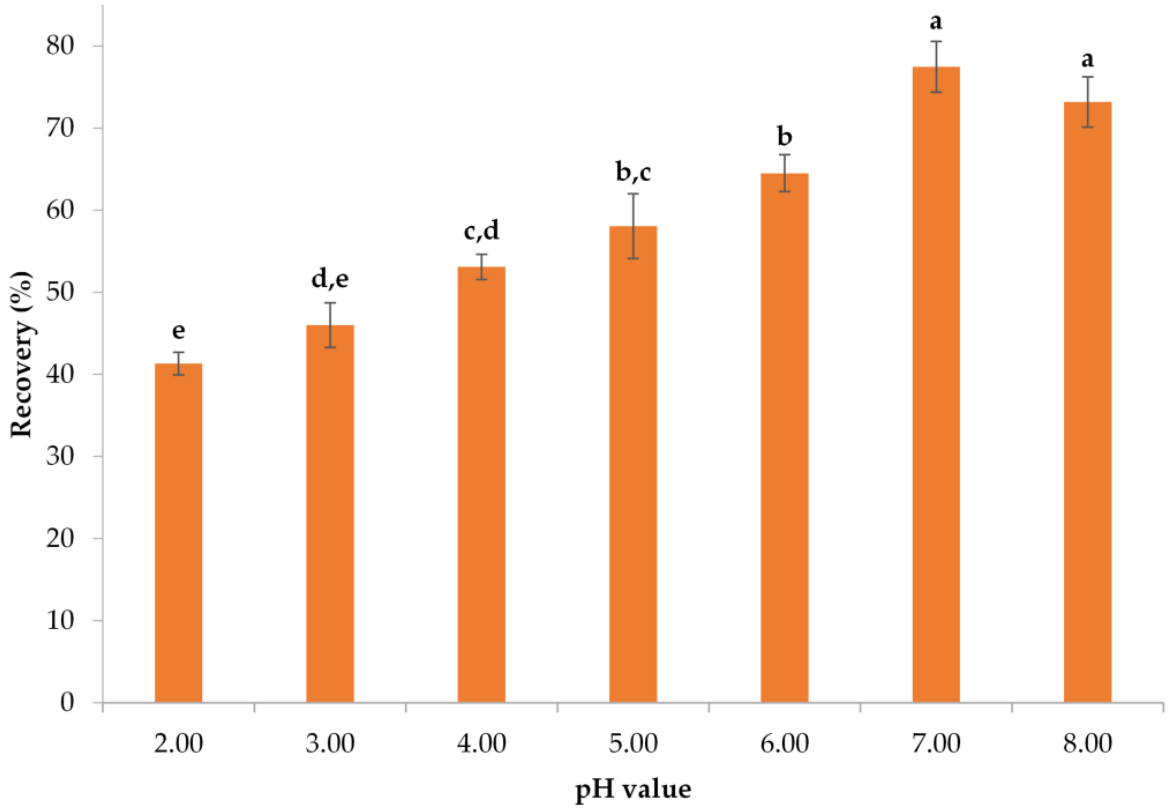

Figure 2. The effect of the pH on the recovery of polyphenols from overripe banana peels; standard deviations are depicted with error bars and the means with lowercase letters (e.g., a–e), which have statistically significant differences ($p < 0.05$).

3.1.3. Determination of the Optimal Salt Concentration

It is well known that the extraction efficiency of organic compounds is affected by the ionic strength of the solvent. In order to speed up the process of separating the different phases, sodium chloride was introduced into the sample to enhance the density of the aqueous phase. In addition, the ionic strength of this salt lowers the cloud-forming temperature [33]. When the ionic strength of a solution is increased, the solubility of organic compounds decreases, which is a phenomenon known as the salting-out effect. Thus, this effect helps during the extraction procedure [34,35]. In addition to the salting-out effect, salt has been shown to improve the extraction procedure by decreasing the cloud-point temperature and facilitating phase separation [17,36,37]. As a result, the impact of sodium chloride concentration on the polyphenol recovery was studied. As shown in Figure 3, the highest recovery of polyphenols was achieved at a concentration of 15% w/v salt, which was chosen as the optimal to conduct the rest of the experiments. Sun et al. [38]

also used 14% w/v sodium chloride in their attempt to optimize the polyphenol extraction from pomegranate peel via CPE. Once the salt concentration exceeded 15% w/v, there were no significant changes ($p > 0.05$) to the recovery, which was a result also reported by Ji et al. [39] in their study for the separation and determination of phenolic acids from dandelion through CPE. Nevertheless, the 15% w/v salt concentration was chosen as the optimal for reasons of lower cost.

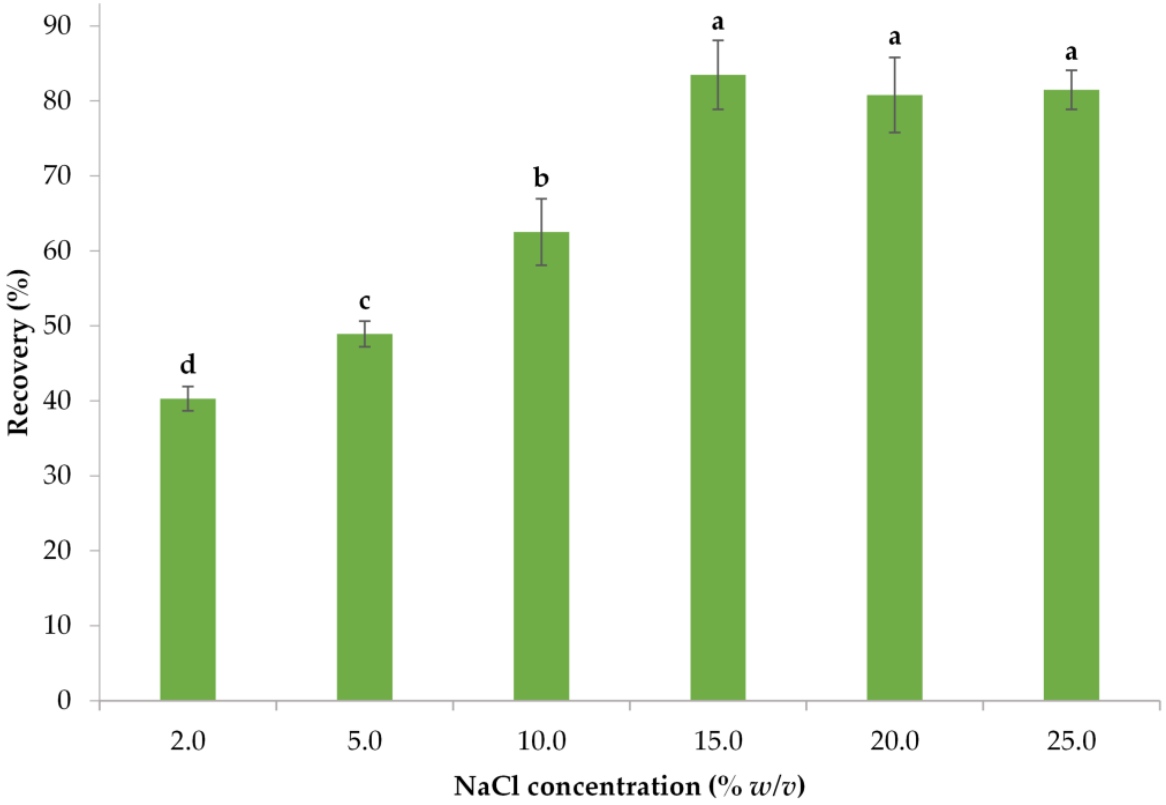

Figure 3. The effect of salt concentration on the recovery of polyphenols from overripe banana peels; standard deviations are depicted with error bars and the means with lowercase letters (e.g., a–d), which have statistically significant differences ($p < 0.05$).

3.1.4. Determination of the Optimal Surfactant Concentration

Lecithins are a group of naturally occurring amphiphilic molecules comprising of phosphatidylinositol, phosphatidic acid, phosphatidylcholine and phosphatidylethanolamine. They are common emulsifiers that are frequently employed within the food industry without any imposed limitations on their maximum permissible levels. Lecithins are a preferable alternative to synthetic compounds due to both agreement with regulations and positive effects of phospholipids on human health [40]. The examined concentrations of lecithin tested were 1.0, 2.5, 5.0, 7.5, and 10.0% w/v, and their recoveries are displayed in Figure 4. It is obvious that a 10% w/v lecithin concentration yields the highest recovery of polyphenols, about 84.73%, which is statistically significant ($p < 0.05$) from the lower concentrations. Lecithin concentrations higher than 10% w/v were not examined as it was observed in preliminary experiments that saturation was occurring in the solution. As a result, this concentration was chosen as the optimal one. It is expected that when multiple steps of CPE with 10% w/v are employed, the total recovery will be elevated.

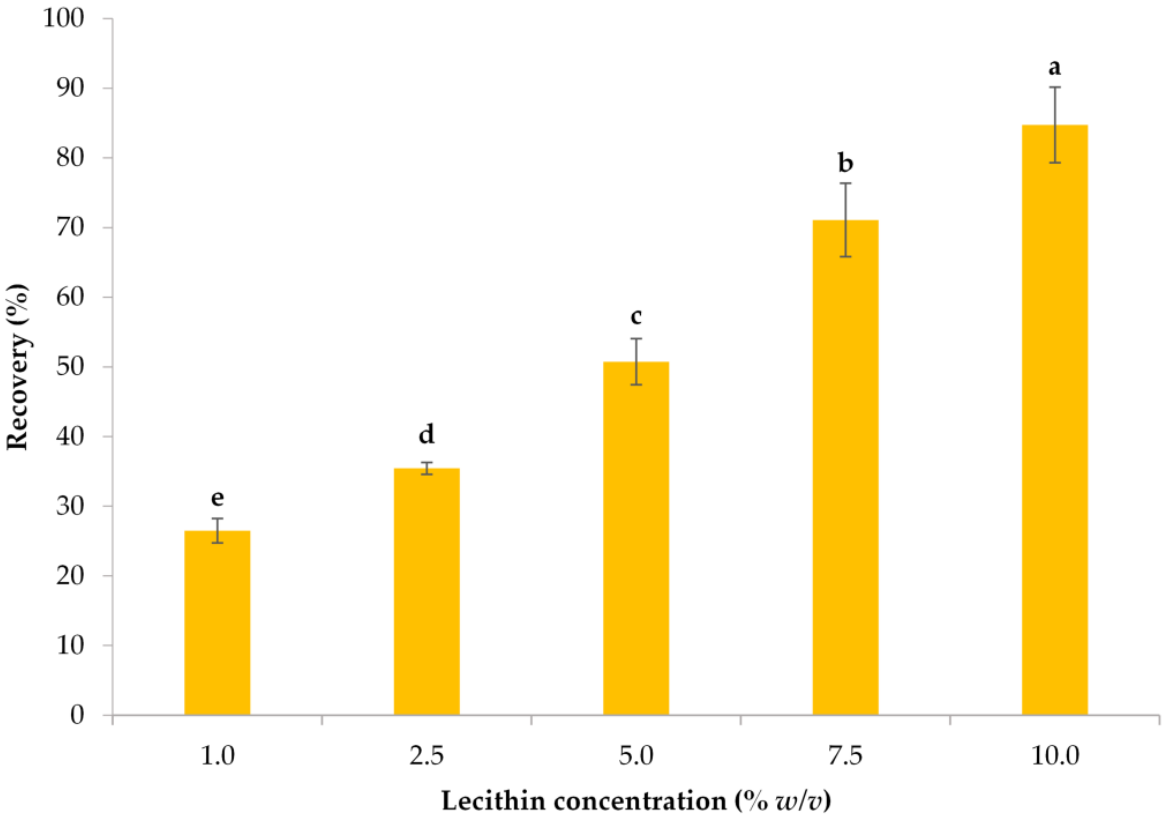

Figure 4. The effect of lecithin concentration on the recovery of polyphenols from overripe banana peels; Standard deviations are depicted with error bars and the means with lowercase letters (e.g., a–e), which have statistically significant differences ($p < 0.05$).

3.2. Analysis of the Optimal Extract

The objective of this research was to determine the recovery of polyphenols from banana peel extract via CPE. The method was optimized, and the optimal conditions were a three-stepped CPE at pH 7, with 15% w/v salt concentration and 10% w/v lecithin concentration. Each extraction step took place at 45 °C for 20 min. In Figure 5, the TPC recoveries from both the surfactant (micellar) phase (SP) and the water phase from the three steps of CPE and the recovery from the initial sample are presented. The first step of the extraction resulted in an 84.39% recovery of TPC on the surfactant phase, while the second and the third step yielded 6.48% and 3.63% recoveries, respectively. The total recovery on the surfactant phases from all steps of CPE was up to 94.51%. The sum of the TPC from each distinct step of the CPE is 543.34 mg GAE/L, which is a value that is not far from the one evaluated on the final sample (the combined three micellar phases), which confirms the success of the extraction step.

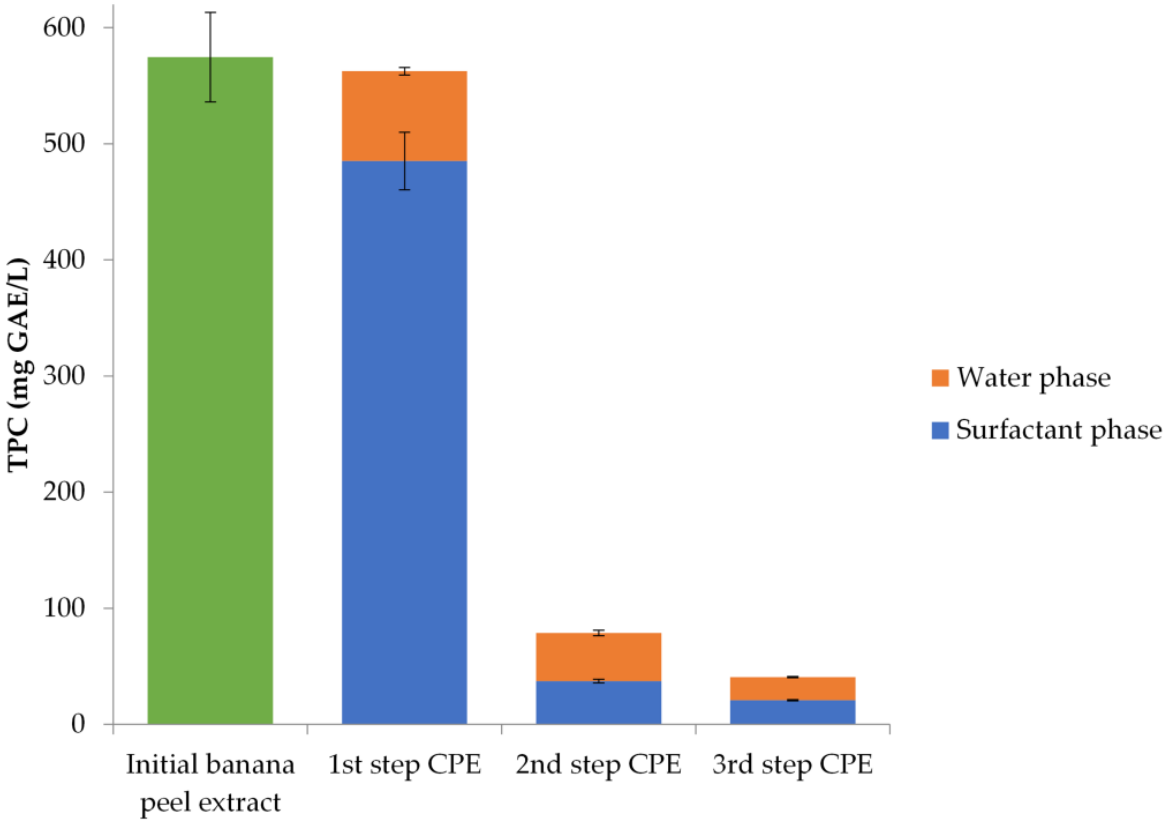

Figure 5. Recovery (%) of polyphenols from overripe banana peel extract with 10% *w*/*v* lecithin, 15% *w*/*v* NaCl, stirring at 800 rpm, at 45 °C for 20 min; standard deviations are presented with error bars.

All analyses were performed on the final sample, which consisted of the combination of the surfactant phases of the three CPE steps. The results are presented in Table 1. Measurements were performed on both the initial sample (before any treatment) and the final sample (the combined three micellar phases). Moreover, a series of preliminary experiments were conducted to investigate the potential antioxidant properties of lecithin and its influence on the antioxidant properties of the extract. The results indicated that lecithin did not possess any antioxidant properties. Consequently, it can be concluded that lecithin lacks any obvious influence on the antioxidant properties of the extract. It was observed that in the final sample, after CPE, there was a 6.21% reduction in TPC, but there was no statistically significant difference ($p < 0.05$) between them. This may be due to the fact that some polyphenols may be highly hydrophilic and thus remained in the aqueous phase. The SP TPC is 541.25 mg GAE/L, which is an amount ~35% higher than the one reported by Toh et al. [41] on mature banana peels extract. Additionally, the TPC determined in our study is 75% higher than the one determined by Bilgin et al. [42] on overripe banana fruit extract. The TFC was determined as 226.38 mg RtE/L, which is about 8.86% less than the TFC of the initial sample, but once again, no statistically significant difference ($p < 0.05$) between the values was observed. The FRAP value was found to be 2.52 mmol AAE/L, which was 4.36% lower of the initial sample, but no statistically significant difference ($p < 0.05$) was observed. Likewise, the DPPH$^{\bullet}$ value was 2.91 mmol AAE/L, which is 8.93% lower than the one determined in the initial sample, again, with no statistically significant difference ($p < 0.05$) between the values. Rodríguez-Solana et al. [43] also reported an FRAP value (2.56 mmol AAE/L) close to the one we determined on liqueur that was macerated along with *Ceratonia siliqua* L. Several polyphenols were identified and quantified through HPLC-DAD. Catechin is the one found in abundance at a quantity of 45.66% of the total polyphenols identified through HPLC-DAD on the SP. Catechin recovery on the SP phase was 4.40% lower than that of the initial sample, which was statistically non-

significant ($p < 0.05$). Pramote et al. [44] also determined catechin in banana peel extracts in a range from 2.1 to 17.7 mg/L in the ripe peel extracts, which is significantly lower than the one determined in our study. Another polyphenolic compound that was found in excess in the overripe banana peel extract was rosmarinic acid. The quantity identified was 48.89 mg/L, which was 58.73% higher than that reported by Zorić et al. [45], who determined 30.8 mg/L of rosmarinic acid in *Origanum majorana* L. extract. Querctin 3-D-galactoside was determined at an amount of 17.93 mg/L, which is 576.6% higher than that found in most samples by Hernanz et al. [46]. Chlorogenic acid was measured in a quantity of 9.23 mg/L, which is a value close to the one reported by Mascarin et al. [47] on crude *Cymbopogon citratus* extract. Neochlorogenic acid, chlorogenic acid, rutin, ferulic acid, and narirutin were the polyphenols that exhibited statistically significant ($p > 0.05$) differences between the initial sample and the final sample. More specifically, neochlorogenic acid was 31.67% lower in the final sample, while chlorogenic acid was 78.11% lower. Rutin recovery was also decreased in the total SP phase by 40.49%. Finally, ferulic acid and narirutin were 93.48% and 15.98% lower than the initial sample, respectively. The SP was stable, as the same analyses were repeated one week and one month later, and no differences in measured values were observed.

Table 1. Parameters and polyphenolic compounds on the initial banana peel extract and the surfactant phase (SP) under optimal CPE conditions.

Parameters	Initial Banana Peel Extract	Optimal Total SP
TPC (mg GAE/L)	574.86 ± 12.07 [a]	541.25 ± 21.19 [a]
TFC (mg RtE/L)	246.44 ± 16.76 [a]	226.38 ± 12.46 [a]
FRAP (mmol AAE/L)	2.63 ± 0.08 [a]	2.52 ± 0.13 [a]
DPPH (mmol AAE/L)	3.17 ± 0.1 [a]	2.91 ± 0.16 [a]
Polyphenolic compounds (mg/L)		
Neochlorogenic acid	2.12 ± 0.11 [a]	1.61 ± 0.07 [b]
Catechin	387.94 ± 24.05 [a]	371.58 ± 13.01 [a]
Chlorogenic acid	16.44 ± 0.54 [a]	9.23 ± 0.37 [b]
Epicatechin	2.56 ± 0.13 [a]	2.42 ± 0.08 [a]
Rutin	24.01 ± 0.6 [a]	17.09 ± 0.68 [b]
Ferulic acid	12.17 ± 0.88 [a]	6.29 ± 0.41 [b]
Quercetin 3-D-galactoside	17.93 ± 1.27 [a]	17.93 ± 1.22 [a]
Narirutin	9.58 ± 0.24 [a]	8.26 ± 0.51 [b]
Rosmarinic acid	51.08 ± 3.73 [a]	48.89 ± 3.08 [a]
Total identified	523.83 ± 31.55 [a]	483.3 ± 19.42 [a]

Within each row, statistically significant differences ($p < 0.05$) are denoted with lowercase letters (e.g., a, b).

4. Conclusions

In the current study, CPE was applied to overripe banana peels in order to evaluate the recovery of polyphenols and its antioxidant capacity. The initial goal was to optimize the method, which was followed by evaluations of the recoveries. The optimal conditions were defined as a three-stepped CPE at 45 °C for 20 min, utilizing 10% w/v lecithin, a quantum satis and food-grade emulsifier as a surfactant. Those enriched with bioactive compounds from the banana peels extract surfactant exhibited great stability in the content of those compounds. The optimal pH value was 7, and 15% w/v sodium chloride was added in order to provoke the salting-out effect. The TPC measured was up to 94.51% at the surfactant phases of all three steps of CPE, while the TFC was measured as 226.38 mg RtE/L. FRAP and DPPH$^{\bullet}$ values were close, measuring 2.52 and 2.91 mmol AAE/L, respectively. The findings of this study indicate that overripe banana peels have the potential to be utilized as food additives for human consumption as they hold antioxidant capacity and significant quantities of polyphenols, such as catechin, rutin, neochlorogenic and rosmarinic acids that may improve the antioxidant properties of food products. They can also be used as animal feed for similar purposes. In addition, it is imperative to investigate the feasibility

of simultaneously extracting flavorings from banana peels and encapsulating them within the surfactants. This would enhance the flavor profile of food products, thereby increasing their appeal to consumers.

Author Contributions: Conceptualization, V.A., T.C. and S.I.L.; methodology, V.A. and T.C.; software, V.A.; validation, V.A. and T.C.; formal analysis, V.A. and T.C.; investigation, M.M., D.K., V.A., T.C. and E.B.; resources, S.I.L.; data curation, M.M. and V.A.; writing—original draft preparation, M.M. and D.K.; writing—review and editing, M.M., V.A., T.C., D.K., E.B. and S.I.L.; visualization, V.A.; supervision, S.I.L.; project administration, V.A. and T.C.; funding acquisition, S.I.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

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