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Soybean Oil as a Green Solvent for the Recovery of Carotenoids from Banana Peel: Evaluation of the Storage and Processing on Final Product

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Abstract: This study aimed to recover carotenoids from banana peel by employing a solid-liquid extraction using soybean oil as a green solvent. The oil with the highest total carotenoid content was evaluated for storage stability (30 °C/90 days) and thermal processing (100 and 200 °C/1–2 h). The results for changing temperature (33–67 °C), solid-liquid ratio (1:6–1:74 *w*/*w*), and agitation (132–468 rpm) were combined to evaluate the recovery of carotenoids from banana peel in extractions performed for 1 h. The highest total carotenoid concentration obtained from banana peel with 13% residual moisture was 756 µg of β-carotene/mL of oil at 50 °C with a solid-liquid ratio of 1:6 and 300 rpm agitation, resulting in a 55% recovery, which is superior to the extraction using acetone as the solvent (50%). Nutritionally, the carotenoid-rich oil can substantially increase vitamin A intake since a 13-mL serving can correspond to 63–117% of the daily intake of vitamin A for different groups. Regarding storage, no differences were observed in the fatty acid profile of the carotenoid-rich oil and the control (pure soybean oil) after 90 days ($p > 0.05$). The fatty acid profile also remained the same after thermal processing, regardless of temperature and exposure time, except for linolenic acid. 84% retention of total carotenoids was observed after storage. For thermal processing at 100 and 200 °C, regardless of the processing time, a 91 and 31% retention were observed, respectively. Therefore, the use of banana peel as a raw material to obtain carotenoids using soybean oil as a green solvent can add value to production chains, and it is aligned with Sustainable Development Goals 2 and 12 of the UN 2030 Agenda, which aims to end hunger, achieve food security, promote sustainable agriculture and ensure sustainable consumption and production patterns, respectively.

Keywords: *Dwarf cavendish* banana; solid-liquid extraction; storage and thermal processing

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1. Introduction

Brazil stands out in the production of bananas, a popular fruit on Brazilian tables, as either fresh or derived products. This is due to their sensory characteristics, practicality of consumption, and use in different food formulations. However, the agroindustrialization of bananas is responsible for generating a large number of peels that correspond to approximately 30% of the total mass of ripe fruit [1,2]. This abundant waste is a source of numerous bioactive compounds, such as carotenoids and flavonoids [2–4].

Carotenoids are pigments mostly found in foods of plant origin. They are known as pro-vitamin A, because they are precursors of retinol and are considered bioactive compounds due to their antioxidant activity and other biological effects [5]. Some studies

have reported the use of alcohol, acetone, and mixtures such as acetone/hexane, acetone/petroleum ether, and acetone/chloroform as solvents for carotenoid extraction. However, they all have the following disadvantages in common: they are harmful to human health due to their toxicity; with the exception of chloroform, all solvents are flammable, and the extraction cake can contain residual solvents [6–8]. Thus, research studies aim to develop extraction processes using greener and safer solvents such as supercritical and subcritical fluids (CO_2 and H_2O), natural deep eutectic solvents, and edible oils [9,10]. In this context, vegetable oils have been highlighted as green solvents to extract carotenoids from plant matrices. Baria et al. [11] evaluated the extraction of carotenoids from mango pulp using groundnut, sunflower, and flaxseed oil as solvents. Sharma and Bhat [10] employed corn oil in the recovery of carotenoids from pumpkin peel and pulp. Li et al. [12], on the other hand, extracted the carotenoids from carrots using sunflower oil.

Soybean oil, as described above, is able to perform the expected dispersant function in a solvent. In addition to characteristics such as being non-flammable, non-volatile, toxicologically harmless to human health during extraction, and easier to transport and store than traditional organic solvents, the obtained extract after extraction can be used directly in formulations without the refining or purification steps that are often required for traditional organic solvents. Also, it is important to highlight that Brazil is one of the world's largest producers of soybean oil. According to the Brazilian Association of Vegetable Oil Industries (ABIOVE, 2021), 9.9 million tons of this oil were produced in 2022, showing its importance to the country's economy [13,14].

Thus, the use of soybean oil as a green solvent to extract carotenoids from agro-residues such as banana peel is an alternative to traditional organic solvents and is a route to its enrichment with these compounds, which can support the prevention of nutritional deficiencies by increasing the intake of vitamin A. Meléndez-Martínez [15] reported that β-carotene, a major carotenoid in banana peel [16], has a pro-vitamin A function, being associated with eye health and the prevention of certain types of cancer. Furthermore, oil-dispersed carotenoids have a six times higher conversion efficiency into retinol equivalent compared to carotenoids in vegetable matrices [17].

In addition to the advantages mentioned above, the present study aligns with the sustainable development goals of the UN 2030 Agenda. The 2030 Agenda was adopted by all United Nations Member States in 2015. It provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. For that, 17 sustainable development goals are proposed. Among them, goals 2 and 12 have as their aims, by 2030, to end hunger, achieve food security, promote sustainable agriculture, and ensure sustainable consumption and production patterns, respectively [18].

Therefore, the objective of this study was to recover carotenoids from banana peel using soybean oil as a green solvent to obtain a product with enhanced nutritional quality and evaluate its chemical stability with regard to storage and thermal processing.

2. Materials and Methods

2.1. Materials

In this study, we used bananas of the Dwarf Cavendish variety, at ripening stage 6 [3], acquired from the local market of Rio de Janeiro, Brazil. The bananas were cleaned using a 100 ppm sodium hypochlorite solution. The peels, obtained manually, were dried at 50 °C for 48 h to obtain flour by grinding in a food processor (total carotenoid content of 3012 μg/100 g flour presenting a 13% residual moisture, and 87% of particles smaller than 0.4 mm). Soybean oil was also acquired from the local market of Rio de Janeiro, Brazil, from the same production batch. The choice of soybean oil brand for this study was based on the list of ingredients, and the one with the fewest ingredients was chosen. Thus, the selected oil was composed of genetically modified soybean oil and citric acid, according to the packaging label.

2.2. Extraction

For the recovery assays of carotenoids from banana peel, the influence of temperature (33–67 °C), solid-liquid ratio (1:6–1:74 *w*/*w*), and agitation (132–468 rpm) on the content of total carotenoids (µg/mL) and the percentage recovery of these bioactive compounds was evaluated with 17 trials (Table 1). An extraction using acetone as solvent was performed in order to compare the extractive solvents. The recovery percentage was calculated using the ratio between the carotenoid content extracted from the peel flour using soybean oil as solvent or acetone and the total carotenoid content of the same flour exhaustively extracted according to an analytical method [5].

Table 1. Operational conditions and results for recovery of carotenoids from banana peel using soybean oil as a solvent.

Trial	Temperature (°C)	Solid–Liquid Ratio (g/g)	Agitation (rpm)	Carotenoid Concentration (µg/mL)	Recovery of Carotenoids (%)
1	40	1:20	200	70.03	51
2	40	1:20	400	73.17	54
3	40	1:60	200	25.20	56
4	40	1:60	400	30.46	67
5	60	1:20	200	85.20	61
6	60	1:20	400	80.71	60
7	60	1:60	200	29.02	64
8	60	1:60	400	30.97	69
9	33	1:40	300	31.98	47
10	67	1:40	300	40.97	61
11	50	1:06	300	755.95	55
12	50	1:74	300	26.31	72
13	50	1:40	132	36.90	54
14	50	1:40	470	39.36	57
15	50	1:40	300	40.12	59
16	50	1:40	300	39.10	57
17	50	1:40	300	40.20	58

Results obtained for banana peel with 13% residual moisture.

2.3. Storage

The carotenoid-rich soybean oil and the control sample (pure soybean oil) were inserted into glass jars and stored for 90 days at 30 °C, resulting in the following samples: SO_T0 (soybean oil, 0 days of storage), SO_T90 (soybean oil, 90 days of storage), SOC_T0 (carotenoid-rich soybean oil, 0 days of storage), and SOC_T90 (carotenoid-rich, 90 days of storage). After storage, the samples were kept at –18 °C until analysis.

2.4. Thermal Processing

The carotenoid-rich soybean oil and the control sample were subjected to heating for 1 and 2 h at 100 and 200 °C, respectively, to simulate cooking and deep-frying conditions. The temperature was monitored and maintained throughout the processing. After processing, the samples were kept at −18 °C until analysis. The samples were identified as SO_Control (soybean oil without processing), SO_100C_1h, SO_100C_2h, SO_200C_1h, SO_200C_2h, and SOC_Control (carotenoid-rich soybean oil without processing), SOC_100C_1h, SOC_100C_2h, SOC_200C_1h, and SOC_200C_2h.

2.5. Analytical Methods

2.5.1. Total Carotenoids

The total carotenoid content of the oils obtained after extraction with soybean oil was determined by direct reading of the oil in a UV-Vis spectrophotometer at 453 nm, using pure soybean oil as the equipment blank. For quantification, a calibration curve was

constructed using a standard solution of β-carotene in soybean oil, in which the coefficient of determination (r^2) was 0.9967, and the concentrations of the curve points ranged from 31.66 to 132.84 μg/mL. When necessary, samples were properly diluted with pure soybean oil before reading. Results were expressed as μg β-carotene/mL oil obtained from banana peel with 13% residual moisture.

2.5.2. Preparation of Fatty Acid Methyl Esters for GC-MS Analysis

The samples from the storage and processing evaluation were hydrolyzed for the preparation of the methyl esters. For the hydrolysis of each sample, 0.4 g of oil was added into a 25-mL flask, and 6 mL of 0.5 N sodium hydroxide solution in methanol was added. The flask was heated at 50 °C for 5 min to dissolve the oil. Next, 8 mL of 20% boron trifluoride solution in methanol was added for methylation of the fatty acids. The mixture was heated for 2 min by water vapor. After cooling to room temperature, 3 mL of hexane was added to the flask, with the subsequent addition of 10 mL of saturated sodium chloride solution. The volumetric flask was closed and thoroughly shaken. After resting, the organic phase (top layer) was collected for fatty acid profile analysis [2].

2.5.3. Determination of the Fatty Acid Profile by GC-MS

The fatty acid profile of the samples was determined using GC-MS (6890–5975 system, Agilent Technology). The injection was performed in split mode with a split ratio of 1:200 at 250 °C. Helium was used as the carrier gas, and the injected sample volume was 1 μL. The oven temperature was maintained at 160 °C for 1 min initially, and then the temperature was increased at the rate of 4 °C/min to 250 °C; this was maintained for 5 min. The HP-5MS column (5% diphenyl and 95% dimethylpolysiloxane) was used with a flow rate of 1.0 mL min^{-1}. The transfer line temperature to the mass spectrometer was 250 °C, and mass spectra were obtained in the range of 20–500 m/z. Fatty acid identification was performed by comparing the mass spectra of samples with the data available in the Willey7Nist05 digital library of mass spectra. The composition was obtained by the area normalization method, in which the percentage indicated for each component is the contribution of each peak area to the total area of all peaks [2].

2.5.4. Infrared Spectroscopy Analysis

The samples were analyzed using Fourier transform infrared (FTIR) spectroscopy in a Thermo Nicolet spectrometer (model Nexus 470, Thermo Fisher Scientific, Waltham, MA, USA). The analyses were performed using the capillary liquid film method between NaCl cell windows, with a scanning range of 4000–400 cm^{-1}, 32 scans, and a resolution of 4 cm^{-1}.

2.6. Statistical Analysis

The data were statistically analyzed using Statistica software version 13 (Dell Inc., Tulsa, OK, USA), performing analysis of variance (ANOVA) and Tukey's test to check for differences between means at a 95% confidence level. The experiments were performed in duplicate, and the results were presented as mean ± standard deviation.

3. Results

3.1. Carotenoid Recovery

Table 1 presents the results of the total carotenoid content of soybean oil after the extraction process. Values between 25 and 756 μg β-carotene/mL of oil were obtained. These results demonstrate that the processing variables affect the concentration of these bioactive compounds. Regardless of the operational conditions, soybean oil was able to recover carotenoids from banana peel in each condition and add nutritional value to the oil. The highest concentration of total carotenoids was achieved at 50 °C with a solid-liquid ratio of 1:6 and 300 rpm agitation (trial 11).

The recovery percentage ranged from 47 to 72%. The highest recovery was achieved at 50 °C with a solid–liquid ratio of 1:74 and 300 rpm agitation (trial 12); however, the

concentration of carotenoids (26 µg β-carotene/mL) was much lower than the oil obtained in trial 11 (756 µg β-carotene/mL; 29-fold higher). Thus, although the recovery percentage of trial 11 was moderate (55%), this condition was chosen for subsequent tests, considering the need for a high carotenoid concentration based on the amount of soybean oil consumed.

Using the operating conditions of trial 11, replacing only soybean oil as a solvent for acetone, a recovery rate of 50 ± 0.9% was obtained, showing that the use of soybean oil as a solvent is superior to acetone under the conditions proposed in the current study. Furthermore, it is important to emphasize once again that soybean oil is a non-toxic, non-flammable solvent and can be used directly in food formulation without the need for refining, unlike acetone. Suo et al. [8] evaluated the green recovery of carotenoids from apricot flesh employing corn oil as a solvent. The carotenoid-rich oil was used as a color enhancer of French fries after deep-frying. The results were promising, since these potatoes presented higher a* values (yellow) than those fried in corn oil without carotenoids.

Table 2 presents the recommended dietary allowances (RDAs) of vitamin A for different groups and their respective contributions from the consumption of a 13 mL serving [19] of carotenoid-rich soybean oil (756 µg/mL), based on the National Institutes of Health from USA [20] and considering β-carotene as major carotenoid in the banana peel as described by Pereira and Maraschin [16]. This oil represents 63–117% of the daily intake of vitamin A for lactating and female adults. For men above 19 years old, a serving of soybean oil enriched with banana peel carotenoids can correspond to 91% RDA, showing the nutritional potential of the oil obtained after extraction.

Table 2. Recommended dietary allowances (RDAs) and percentage of the daily value (%DV) provided by a serving of soybean oil enriched with banana peel carotenoids (13 mL) in relation to vitamin A.

Population Group	RDA (µg) [20]	%DV per 13 mL Oil [19]
Pregnant	750–770	106–109
Lactating	1200–1300	63–68
General male (≥19 years)	900	91
General female (≥19 years)	700	117

3.2. Carotenoid-Rich Soybean Oil Storage

The fatty acid profiles of soybean oils with and without added carotenoids stored for 90 days at 30 °C are presented in Table 3. The fatty acids exhibiting an area percentage above 0.2% were monitored during the storage and thermal processing. They were palmitic acid (C16:0), stearic acid (C18:0), oleic acid (C18:1), linoleic acid (C18:2), and linolenic acid (C18:3).

Table 3. Fatty acid profile of the enriched soybean oil and the control after storage for 90 days at 30 °C.

Samples	Fatty Acids (%)				
	Palmitic (C16:0)	Stearic (C18:0)	Oleic (C18:1)	Linoleic (C18:2)	Linolenic (C18:3)
SO_T0	13.11 ± 0.01 ^{a}	4.64 ± 0.16 ^{a}	33.12 ± 0.40 ^{a}	48.87 ± 0.55 ^{a}	0.28 ± 0.01 ^{a}
SO_T90	13.19 ± 0.01 ^{a}	4.65 ± 0.02 ^{a}	33.28 ± 0.10 ^{a}	48.64 ± 0.08 ^{a}	0.24 ± 0.04 ^{a}
SOC_T0	12.96 ± 0.01 ^{a}	4.71 ± 0.09 ^{a}	33.24 ± 0.29 ^{a}	48.85 ± 0.15 ^{a}	0.24 ± 0.03 ^{a}
SOC_T90	13.25 ± 0.05 ^{a}	4.79 ± 0.00 ^{a}	33.23 ± 0.05 ^{a}	48.45 ± 0.01 ^{a}	0.28 ± 0.01 ^{a}

Equal superscript letters in the same column indicate that the results do not differ statistically ($p > 0.05$).

It was found that storage had no influence on the fatty acid profile of the evaluated oils ($p > 0.05$). However, the total carotenoid content was affected by storage, as after 90 days stored at 30 °C, there was a loss of 16% of the content of this pigment in the oil evaluated. The total carotenoid retention observed in the present study (84%) is similar to that reported by Borguini et al. [17]. They evaluated soybean oil enriched with carotenoids from carrots, which was stored at room temperature for 150 days. After that, a loss of 20% was reported.

Thus, the approach proposed in the present work could be an alternative for developing nutritious and stable products, observing the operational conditions investigated here.

3.3. Carotenoid-Rich Soybean Oil Processing

The fatty acid profiles of soybean oils after thermal processing (with and without carotenoids) are shown in Table 4. Thermal processing, regardless of temperature and exposure time, had no significant influence on the fatty acid profile of the samples, except for the percentage of linolenic acid ($p < 0.05$). The linolenic acid concentration in the oils showed no clear trend; hence, the statistical difference may be due to errors during the analytical evaluation and integration of the chromatographic peaks.

Table 4. Fatty acid profile of the enriched soybean oil and the control after thermal processing.

	Fatty Acids (%)				
Samples	**Palmitic (C16:0)**	**Stearic (C18:0)**	**Oleic (C18:1)**	**Linoleic (C18:2)**	**Linolenic (C18:3)**
SO_control	4.70 ± 0.07 ^{a}	12.82 ± 0.00 ^{a}	33.24 ± 0.05 ^{a}	48.96 ± 0.13 ^{a}	0.28 ± 0.00 ^{b}
SO_100C_1h	4.68 ± 0.11 ^{a}	12.92 ± 0.02 ^{a}	33.09 ± 0.41 ^{a}	49.05 ± 0.26 ^{a}	0.26 ± 0.03 ^{b}
SO_100C_2h	4.70 ± 0.06 ^{a}	12.97 ± 0.01 ^{a}	33.14 ± 0.12 ^{a}	48.95 ± 0.18 ^{a}	0.25 ± 0.00 ^{b}
SO_200C_1h	4.84 ± 0.02 ^{a}	13.27 ± 0.03 ^{a}	33.29 ± 0.14 ^{a}	48.34 ± 0.12 ^{a}	0.26 ± 0.03 ^{b}
SO_200C_2h	4.81 ± 0.04 ^{a}	13.35 ± 0.03 ^{a}	33.38 ± 0.19 ^{a}	48.20 ± 0.10 ^{a}	0.25 ± 0.08 ^{a,b}
SOC_control	4.74 ± 0.01 ^{a}	13.18 ± 0.00 ^{a}	33.12 ± 0.48 ^{a}	48.68 ± 0.45 ^{a}	0.28 ± 0.02 ^{b}
SOC_100C_1h	4.81 ± 0.04 ^{a}	13.15 ± 0.06 ^{a}	33.20 ± 0.10 ^{a}	48.54 ± 0.07 ^{a}	0.29 ± 0.01 ^{b}
SOC_100C_2h	4.76 ± 0.05 ^{a}	13.19 ± 0.09 ^{a}	33.23 ± 0.15 ^{a}	48.56 ± 0.03 ^{a}	0.27 ± 0.01 ^{b}
SOC_200C_1h	4.85 ± 0.03 ^{a}	13.27 ± 0.06 ^{a}	33.17 ± 0.40 ^{a}	48.39 ± 0.47 ^{a}	0.33 ± 0.02 ^{a}
SOC_200C_2h	4.81 ± 0.03 ^{a}	13.33 ± 0.02 ^{a}	33.22 ± 0.10 ^{a}	48.33 ± 0.08 ^{a}	0.32 ± 0.01 ^{a}

Equal superscript letters in the same column indicate that the results do not differ statistically ($p > 0.05$).

However, after thermal processing, a change in the coloration of the carotenoid-rich soybean oil was observed, especially for the sample processed at 200 °C for 2 h (Figure 1), varying from an intense yellow to a yellow-brown color. Since the fatty acid profile was not changed after processing, this change in the oil color is related to the degradation of carotenoids. This behavior is confirmed by the results presented in Table 5, where it can be seen that enriched oil was more stable at 100 °C regardless of the processing time compared to that subjected to 200 °C. At this temperature, regardless of the processing time, there was a loss of ~70% of the carotenoids extracted from the banana peel using soybean oil as a solvent. As reported by Murador et al. [21], carotenoids are susceptible to degradation by physical and chemical factors, including elevated temperature, light, oxygen, and pH. Depending on the cooking conditions, the carotenoids can be more or less affected by these factors, as observed in the current work. Thus, the use of carotenoid-rich soybean oil in cooking or frying processes would not be recommended. However, it can be used as table oil, such as olive oil, as the oils are not heated, and its high carotenoid concentration contributes to a nutritional increase in the products.

Table 5. Effect of the processing on carotenoid retention of the enriched soybean oil.

Samples	**Carotenoid Retention (%)**
SOC_control	100 ± 0.0 ^{a}
SOC_100C_1h	91.17 ± 2.48 ^{b}
SOC_100C_2h	91.45 ± 0.89 ^{b}
SOC_200C_1h	31.36 ± 1.24 ^{c}
SOC_200C_2h	31.89 ± 0.30 ^{c}

Equal superscript letters indicate that the results do not differ statistically ($p > 0.05$).

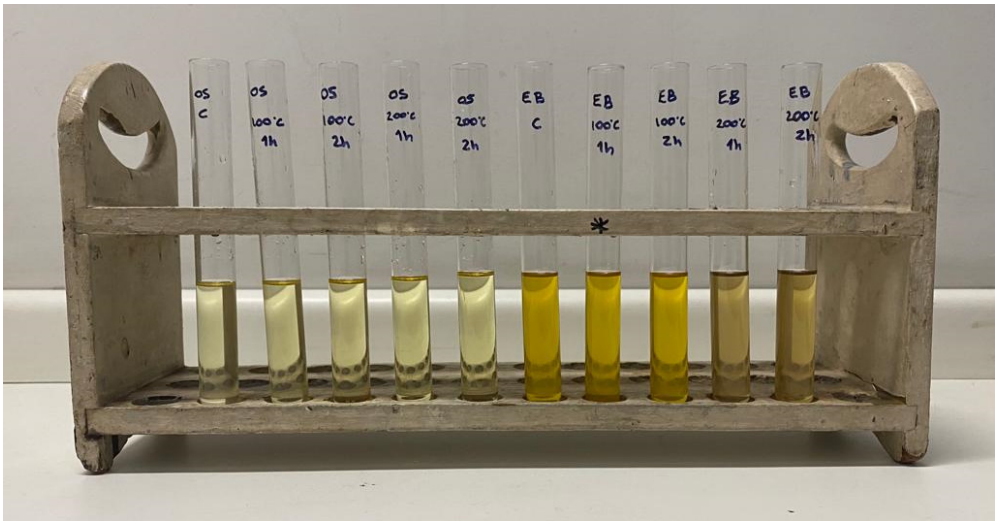

Figure 1. Soybean oil samples with and without carotenoids subjected to thermal processing and their controls (From left to right: Soybean oil not subjected to thermal processing; soybean oil processed at 100 °C for 1 and 2 h; soybean oil processed at 200 °C for 1 and 2 h; carotenoid-rich soybean oil not subjected to thermal processing; carotenoid-rich soybean oil processed at 100 °C for 1 and 2 h; and carotenoid-rich soybean oil processed at 200 °C for 1 and 2 h).

3.4. Mid-Infrared Spectroscopic Analysis of Oils during Storage and Thermal Processing

The FTIR spectra of the samples from storage (Figure 2) and thermal processing (Figure 3) provided important information for their elucidation with emphasis on the main absorption bands: bands in region 1 are attributed to the axial deformation vibrations of symmetric and asymmetric C-H bonds of the methyl (CH_3) and methylene (CH_2) functional groups at 2980 to 2800 cm^{-1} and =C-H bonds at 3100 cm^{-1}, indicating the presence of saturated and unsaturated aliphatic hydrocarbons, respectively. In region 2 (1800–1600 cm^{-1}), the largest bands are near 1750 and 1660 cm^{-1}. The band near 1750 cm^{-1} corresponds to axial vibrations of ester carbonyl groups (C=O), while the band around 1650 cm^{-1} indicates C=C bonds present in unsaturated fatty acids. In region 3 (1600–1390 cm^{-1}), the C-H bond angular deformation vibrations in methylene groups (CH_2) are observed in the region of 1445–1440 cm^{-1}. Region 4 (1300–700 cm^{-1}) shows the absorption bands corresponding to the axial deformation vibration of the C-O bond of esters (=C-O-C and C-O-C). The range of 900–800 cm^{-1} indicates the bands for out-of-plane vibration of the olefins C-H bond, corroborating the absorption band near 1650 cm^{-1} for the C=C stretching bond of olefins present in unsaturated fatty acids and esters. Finally, the absorption band at 720 cm^{-1} is attributed to the symmetric stretching vibration of $(CH_2)n$ groups for n higher than 4, indicating the presence of long hydrocarbon methyl chains [22]. Figures 2 and 3 confirm that there was no change in the spectroscopic profile of the samples based on the fatty composition of oil, regardless of the type of processing and storage. This result was consistent with the fatty acid profiles obtained by GC-MS.

In general, the carotenoids from banana peel had no considerable effect on the intensity of the functional groups' bands of the evaluated oils [22,23]. However, it is clear, based on Figure 1 and the results shown above, that there was degradation of these pigments after processing at 200 °C. As carotenoids act as antioxidants in food systems, they oxidize first, ensuring the integrity of the fatty acids in soybean oil, mainly those unsaturated, oleic and linoleic acids. It was reported by Lui et al. [23] when evaluating the chemical stability of carotenoid-rich oil at different temperatures (25–45 °C). The half-life values decreased with the increased storage environment temperature. Similar behavior was observed in the present study, when carotenoid-rich oil was processed at 200 °C for 1 and 2 h, the drastic conditions.

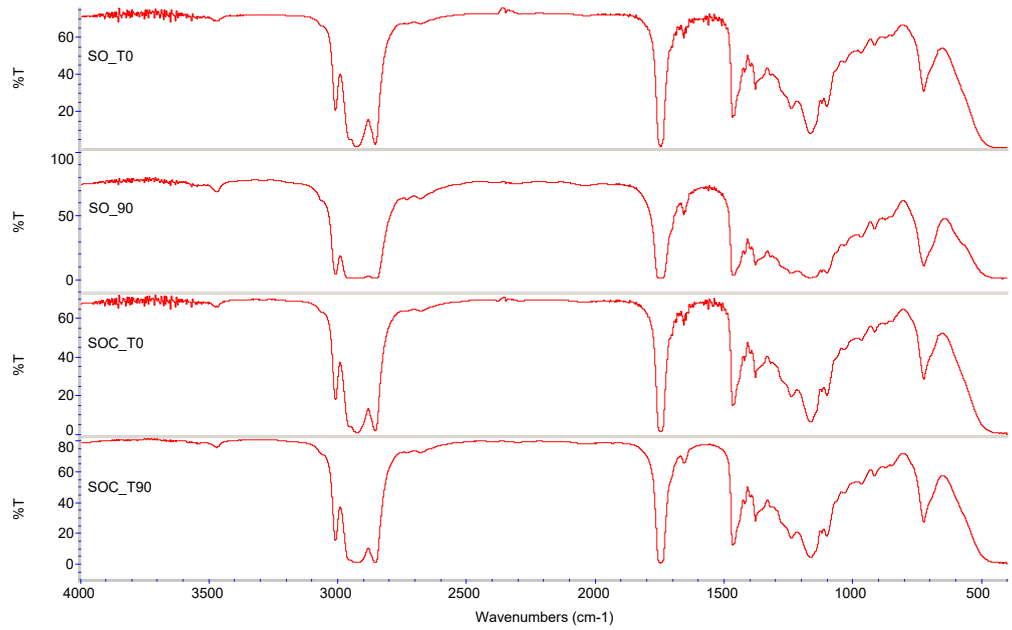

Figure 2. FTIR spectra of soybean oil samples with and without carotenoids stored for 0 days and 90 days.

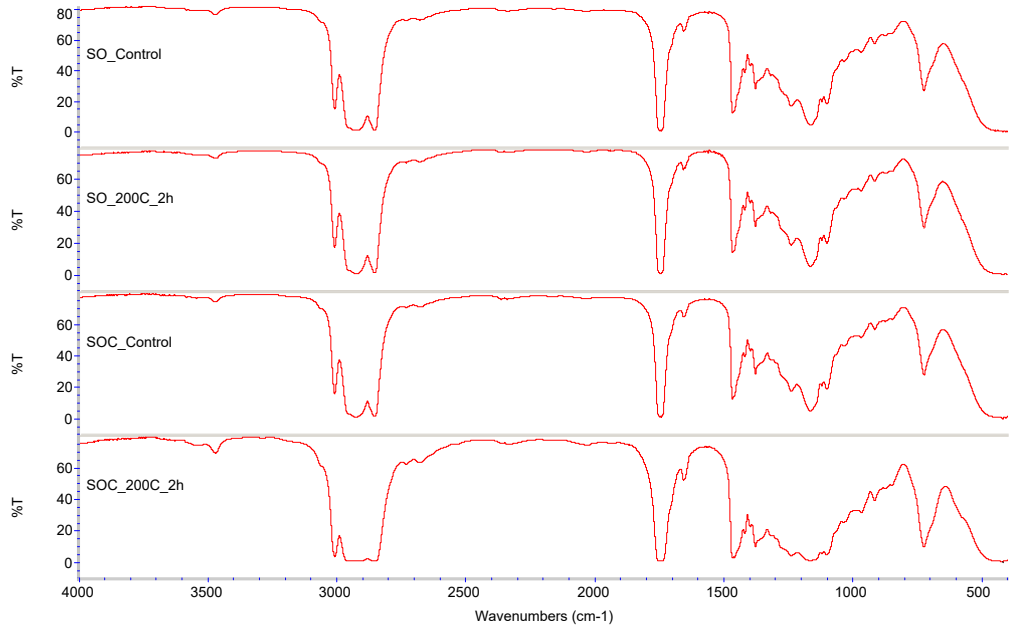

Figure 3. FTIR spectra of soybean oil samples with and without carotenoids subjected to thermal processing (200 °C/2 h).

4. Conclusions

Banana peel was shown to be a suitable raw material to obtain carotenoids. In the extraction processes using soybean oil as green solvent, the total carotenoid content ranged from 25 to 756 μg β-carotene/mL of oil from the banana peel with 13% residual moisture, with the highest concentration obtained at 50 °C, with 300 rpm agitation and a solid-liquid ratio of 1:6; the recovery percentage was 55%. The fatty acid profile of soybean oil with the highest concentration of carotenoids was not affected by storage at 30 °C for 90 days, and, with respect to thermal processing, only the percentage of linolenic acid was affected. However, storage and thermal processing affected carotenoid retention, changing the color of the carotenoid-rich product, especially when subjected to the harshest condition

(200 °C/2 h). Thus, using the product as table oil is a better strategy. From a nutritional point of view, the carotenoid-rich soybean oil provided 63–117% of the RDI of vitamin A from the ingestion of one portion of 13 mL of oil. Therefore, the proposed method can contribute to reducing agro-industrial waste generation and offer a product with better nutritional characteristics. Also, it can add value to the production chains of soybean and banana by enabling the production of more nutritious food through a greener extraction process using soybean oil as a solvent.

As an initial approach, we focused on obtaining carotenoids from banana peel using soybean oil as a green solvent in the extraction, as well as evaluating the effects of storage and processing on the chemical quality of the carotenoid-rich soybean oil. It provided promising results. However, future studies could include an evaluation of the efficiency of ultrasound- or microwave-assisted extractions, as well as the use of other green solvents, such as natural deep eutectic solvents. Furthermore, metabolomic analysis of the final product is required to reveal its phytochemical profile. Such findings will aid in choosing the best extraction method and expand the possibilities of applying the oil enriched with bioactive compounds.

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