Article

Application of Oil Extracted from Cashew Nut Peel (*Anacardium occidentale*) as an Antioxidant for Biodiesel

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The present work aims to extract and test cashew nut peel oil as a natural antioxidant in the oxidative stabilization of biodiesel. Therefore, determinations of the ideal time of Soxhlet and thermal extractions, Fourier transform infrared spectroscopy (FTIR) analyses, and evaluation of the oxidative stability by Rancimat method were carried out. FTIR analyses revealed that the 3rd cycle of extraction was sufficient to extract all the oil, with an average yield of 30.0%. For the thermal extraction of the laboratory technical cashew nut peel oil, the best extraction, based on statistical analysis, was 60 min, yielding 20.0%. The FTIR analysis of the extracted cashew nut peel oil showed characteristic peaks of phenolic groups and organic acids, showing differences in the intensities of the absorption bands. The oxidative stability showed induction period of 8 h 40 min for the hydraulic press extraction, 10 h 35 min for the Soxhlet extraction, and 10 h 65 min for the industrial technical extraction of the cashew nut peel oil. All values were below the 12-h limit established by the National Agency for Petroleum, Natural Gas and Biofuels (ANP). The technical cashew nut peel oil extracted in the laboratory presented an induction period of 11 h 12 min, close to that recommended by ANP, proving to be a promising natural antioxidant. Cardanol presented satisfactory results with 25 h 22 min, double that suggested by ANP. Thus, cashew nut peel oil showed important and promising results as a natural antioxidant for biodiesel.

Keywords: *Anacardium occidentale*, cashew nut, natural antioxidant, biodiesel, cardanol, induction period

Introduction

The continued population and economic growth over the years have caused an imminent energy search to meet the needs of different areas, mainly in the transport sector. Technological advances have also contributed to the advancement of energy demands, which are expected to increase by 50% or more by the year 2030.[1,2] Therefore, it is estimated that in the next 50 years, human society must find solutions to multiple challenges due to its growth, especially regarding fossil fuels, mainly due to the increase in the price of oil, environmental damage, and consequently, health-related problems.[3] Such aggravating factors are becoming relevant and require short-term solutions.[3]

The main source of the energy matrix is still found in fossil fuels, a source classified as non-renewable and exhaustible, in which 88% of the energy consumed by society in general comes from these sources.[4] In this sense, it is clear that energy is essential, and its control has allowed the growth and evolution of humanity. However, the advent of environmental and economic problems with the use of oil, highlighting the emissions of greenhouse gases (GHGs) responsible for global warming - a factor that is aggravated in large urban centers - are one of the reasons for the search for environmentally viable energy sources. On the other hand, several countries seek to minimize the effects of burning fossil fuels, prioritizing efforts to seek renewable and sustainable energy sources that can help reduce carbon emissions on Earth.[5,6] In this way, biodiesel has stood out as a promising sustainable energy matrix for the use of diesel. It offers environmental advantages including sulfur-free, emitting fewer particulates, being

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non-toxic, and producing lower greenhouse gas emissions compared to conventional fuels.[7]

Despite the environmental and economic advantages presented, biodiesel presents a problem regarding oxidation due to its chemical composition, such as a high content of unsaturated methyl esters, thus affecting its long-term storage and fuel quality.[8-10] This oxidative susceptibility is primarily caused by the presence of some elements, such as air, light, high temperatures, and humidity, in addition to the processing conditions, the environment, and the form of storage, all significant conditions for oxidation. Therefore, producing quality biodiesel and preserving characteristics during storage has been a considerable concern for producers and suppliers.[11,12]

Peroxides and hydroperoxides are the main oxidation products of biodiesel, contributing to the formation of other compounds such as acids, aldehydes, ketones, and alcohols. These compounds can alter important characteristics, such as increased acidity, risk of corrosion, and decreased flash point, thus causing clogging of pipes and fuel pumps.[10,13,14] Therefore, preserving the quality of biodiesel for more extended periods of storage is a broad concern for fuel producers and suppliers.[12,15] In this context, additives with antioxidant properties are essential since they act to inhibit the oxidative process and preserve the characteristics of biodiesel. Therefore, antioxidants are compounds that, in low concentrations, control the auto-oxidation processes of substrates and the generation of unwanted by-products.[16] Antioxidants can be of synthetic or natural origin. Synthetic compounds are generally phenolic compounds derived from petroleum,[17] and are commercially the most used by the biodiesel industry. Despite their efficiency, most of these antioxidants have low biodegradability, high toxicity, and high cost. Natural antioxidants, on the other hand, come from plant extracts, exhibiting antioxidant activities similar to synthetic ones, being the reason for the development of many studies. Rosemary, oregano, and basil are some examples that have antioxidant activities due to their ability to inhibit free radicals, minimizing the oxidative effects.[18-20]

The present work is justified by the importance of developing, testing, and using natural antioxidants, such as cashew nut oil, as an additive to biodiesel to replace synthetic antioxidants. Cashew nut oil is a biodegradable and non-toxic, in addition to enabling another commercialization route, adding value to a by-product. Furthermore, the availability of raw materials in our country and the low cost are essential and feasible for companies in the sector.

Experimental

Obtaining samples

The samples of the cashew nuts came from Prata Settlement, located in the municipality of Porto Nacional, 35 km from the capital Palmas (Tocantis (TO) State); this area is classified as Cerrado Zone. Part of the nuts were collected randomly on-site, while the other part was acquired from residents. The industrial technical cashew nut oil used in this work was provided by Companhia Brasileira de Resinas (RESIBRAS®), located in Fortaleza (Ceará State, Brazil). The company provided two samples of the material available, accompanied by a product quality certificate.

Preparation of samples for natural cashew nut oil extraction

Two extraction techniques were employed to extract natural oil: via solvent (Soxhlet, Marconi®, São Paulo, Brazil) and via mechanical method (hydraulic press, Shree Hydraulic Press Industries®, USA), according to the methodologies of the Association of Official Analytical Chemistry.[21] For the laboratory technical oil extraction, thermal extraction at 180-200 °C was used, being similar to the industrial process. The Cardanol extraction was conduct according to the methodology adapted from Tyman *et al.*[22] The preparation of the sample for extraction was carried out as follows: initially, the nuts were sorted in order to remove those that presented undesirable physical characteristics, subsequently washed and subjected to drying in a circular air oven. Then, the fruit components were separated, using a transversal blade, cutting the nut in half in order to remove the almonds. In order to increase the contact surface and obtain the highest yield in solvent extraction, the cashew nut peels were fragmented in the following ways: cut into small pieces with the aid of pruning shears and crushed in a blender.

Cashew nut peel oil extraction

By Soxhlet and hydraulic press

For the extraction of natural oil by Soxhlet, an extractor was used consisting of a 500 mL flat-bottom flask, a horn, a condenser, and a horn siphon with a capacity of 200 mL. Small filter paper cartridges were made with 15 g of crushed bark, where three cartridges were inserted for each extraction cycle. The flask was filled with 350 mL of solvent and heated on a heating blanket until the boiling temperature of hexane PA (69 °C). After extraction, it was taken to the rotary evaporator at 40-45 °C to remove and recover the solvent.

For extraction by hydraulic press, a Forest brand hydraulic press with a capacity of 100 tons was used. Approximately 50 to 60 g of peel cut in half were weighed and added to a disc, adjusted to a pressure of 40 MPa.

By technical extraction

For the laboratory technical oil extraction, conditions similar to the industrial process were employed. This involved heat treatment, decarboxylation of anacardic acid occurs, and production of technical oil. In this extraction, a drying oven was used ranging from 180 to 200 °C for 60 to 120 min. 30 g of chestnuts were used, cut in half, and added to a sieve to facilitate the drainage of the oil. A porcelain evaporation capsule (with a capacity of 100 mL) was used to collect the oil from the extraction.

Cardanol extraction

For cardanol extraction, 100 mg of natural oil extraction by Soxhlet and 3 mg of calcium hydroxide were used as a catalyst. This mixture was kept stirring in an oil bath with a closed system at 140 ºC for 2 h. Subsequently, the mixture remained at room temperature for cardanol extraction using hexane with solvent. Finally, the product was filtered with filter paper and concentrated to remove the solvent. For this extraction, the methodology adapted from Tyman *et al.*[22] was used.

Yield

For the yield percentage of natural and laboratory technical oil, 5 replications were used and determined by the ratio between the masses of the extract obtained plus mass of raw material (dry basis) and presented as mean and standard deviation, according to the methodology proposed by the Association of Official Analytical Chemistry (AOAC),[21] using equation 1.

$$\text{Yield (\%)} = \frac{(P2 - P1)}{P} \times 100 \qquad (1)$$

where P is grams of the sample, P1 is mass of the beaker, and P2 is mass of the beaker plus oil.

Determination of the extraction time of natural cashew nut oil by Soxhlet and laboratory technical

To determine the maximum extraction time of natural oil by Soxhlet, Fourier transform infrared spectroscopy (FTIR, Shimadzu®, São Paulo, Brazil) was used. The spectra were acquired after each extraction cycle, removing a 10 mL aliquot from the extractor and adding it to glass

vials until room temperature. The hexane spectrum was used as a standard to identify in which cycle only the solvent is present. The time for each cycle was determined taking into account the specific characteristics of the extraction method and apparatus used in the process, aiming to optimize the process. Table 1 presents the parameters used in the acquisition of the spectra.

To analyze the maximum extraction time, a completely randomized design was used, testing 3 treatments (with time of 60, 90, and 120 min) with five replications. The results were statistically analyzed using analysis of variance and mean test (Tukey's test, 5% probability) using the statistical program Sisvar 5.0.[23]

Table 1. Instrumentation and region investigated by Fourier transform infrared spectroscopy (FTIR) for acquiring spectral data of the studied samples (natural cashew nut oil)

Parameter	Condition
Spectral region / cm^{-1}	650-4000
Detector	detector with thermoelectric cooling (DTGS)
Beam splitter	KBr crystal
Number of scans	32
Resolution / cm^{-1}	4
Accessory	attenuated total reflection
Software	Resolutions Pro (Agilent)

Qualitative determination of natural, technical, and cardanol cashew nut oil by FTIR

The oil was transferred using a Pasteur pipette to the surface of the attenuated total reflectance (ATR) crystal to acquire the spectra. An Agilent Cary 630 FTIR spectrometer was used, with the following parameters: wavelength ranges from 650 to 4000 cm^{-1}, with a resolution of 4 cm^{-1}, and 32 scans *per* s. The Resolutions Pro software (Agilent) was used to process the data. The methodology adopted was based on the work of Santos *et al.*[24]

Determination of the cashew nut oil induction period using the Rancimat method

The determination of the efficiency of oil in the oxidative stability of biodiesel was evaluated according to the EN14112 method using the Rancimat (Metrohm® Equipment, São Paulo, Brazil). Approximately 3 g of the sample were weighed in a glass test tube under a constant airflow of 10 L h^{-1} at 110 °C. The volatile oxidation products formed during the oxidation experiment were collected in a container containing 50 mL of distilled water, and the conductivity of the water was measured continuously. The analyses were carried out in partnership

with Binatural-Biodiesel Company, located in the Goiás State. The biodiesel produced by the company itself was used (without the addition of other additives), and was obtained from various raw materials, known as blend (50% soybean oil, 20% cottonseed oil, 8% palm oil, 17% fat oil, and 5% pork fat oil). In the tests, concentrations between 1,000 and 10,000 mg L^{-1} were applied to verify the concentration, which meets the specifications of ANP Resolution No. 798/2019.[25]

Results and Discussion

Natural cashew nut oil by Soxhlet

Table 2 presents the results of the times in each Soxhlet extraction cycle. Under the conditions and characteristics of the extractor device used in this study, it was observed that the 1st cycle had the longest reflux duration; a slower boiling rate justifies this result due to the initial period of heating to its boiling point (69 °C). The other cycles had shorter reflux times. The total time of all cycles was approximately 135 min (2 h 15 min).

Table 2. Duration of the Soxhlet extraction cycles for the studied samples (natural cashew nut oil)

Extraction cycle	time / min
1st	35
2nd	26
3rd	25
4th	24
5th	25

To determine the end of the maximum extraction cycle (time), the FTIR spectrum of the aliquot after each cycle was compared with that of hexane. If the spectra coincide peak to peak, it shows that the samples are identical. Figure 1 shows spectrum of hexane and spectra obtained after extraction cycles (from 1st to 5th) for the studied samples (natural cashew nut oil). The FTIR spectrum of hexane used for oil extraction was carried out to identify the cycles in which oil is extracted, has greater extraction efficiency and finalizes the process.

The analysis of the FTIR spectra (Figure 1) reveals that the oil extraction began in the 1st cycle, also being the most efficient in the extraction process. Comparing the spectrum of the aliquot obtained after the 1st cycle with the spectrum of the solvent, it is possible to visualize the appearance of peaks between the regions of 400 to 1650 nm^{-1} that are related to the oil. In addition to the significant increase in absorbance in the region from 400 to 3600 nm^{-1}, this

variation is more effective and relevant in the region from 400 to 1700 nm^{-1} being correlated to the high concentration of oil after the 1st cycle during the extraction process.

Another factor that proves the efficiency of this cycle is the presence of peaks in the FTIR spectrum in the region of 1550 to 1650 nm^{-1}, characteristic of C=C stretching of aromatic rings from molecular structure of anacardic acid, one of the main components of the natural oil. In the 3rd cycle, peaks were observed in the region of 400 to 1700 nm^{-1}, like in the 1st cycle, but with substantially lower absorbance, indicating the reduction in the oil extraction process. The evaluation of the FTIR spectra of the aliquots after the 4th and 5th cycles clearly indicates that the extraction process concluded after the 4th cycle since the both spectra are identical to the spectrum of hexane used in the oil extraction, in terms of absorbance values as well as wavenumber values. Demonstrating that from the 4th cycle onwards, only the presence of hexane occurs in the extraction process.

In view of what was observed, it was found that oil extraction began in the 1st cycle with a time of 35 min (peak) and ended entirely in the 3rd cycle with a time of 25 min, with the total time for complete extraction being 1 h 25 min according to spectra (Figure 1). The results of the yields of each extraction of natural oil by Soxhlet extraction can be seen in Table 3.

According to the results in Table 3, the yields showed a high oil content with an average percentage of 30.0%. Oliveira and Dweck[11] and Chatterjee *et al.*[26] obtained lower yields, 27.4 and 25.3%, respectively, for 24 h of extraction with hexane. It is worth mentioning that in the present work, complete extraction was carried out in less than 2 h, demonstrating that the sample preparation and extraction processes used in the study were efficient, considering that the oil content present in the cashew nut peel is approximately 30 to 35%.[27-29]

Technical cashew nut oil

To determine the extraction time, an analysis of variance was carried out, and Table 4 summarizes the results of analysis of variance for the three technical oil extraction times (60, 90, and 120 min). A significant difference was observed between the studied treatments, indicating that the experiments behave differently. Therefore, the mean comparison test (Tukey's test) is at a 5% probability level. The coefficient of variation (CV) was 5.5%, considered low, indicating good precision in experimental conduction. According to Lopes *et al.*,[30] the coefficient of variation measures the precision of the experiment and is classified as follows: low when less than 10%, medium when between
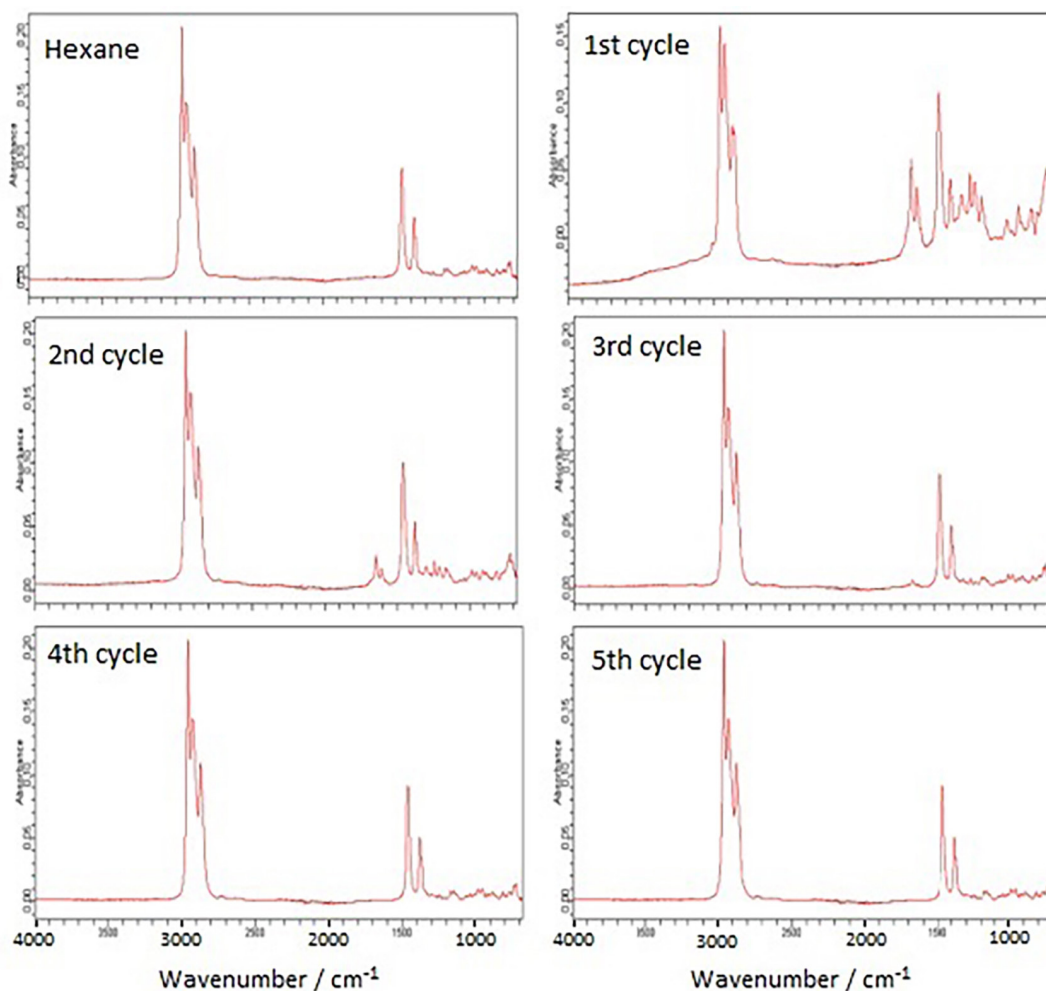
Figure 1. Comparison of the FTIR spectrum of hexane and spectra obtained after extraction cycles (from 1st to 5th) for the studied samples (natural cashew nut oil).

Table 3. The percent yield of natural cashew nut by Soxhlet extraction

Repetition	Average yield / %
1st	30.00
2nd	30.40
3rd	31.30
4th	28.50
5th	29.60
Overall mean ± standard deviation	29.96 ± 1.02

Table 4. Summary of analysis of variance for three technical oil extraction times (60, 90, and 120 min)

Source of variation	DF	MG
Treatment	2	8.798385[a]
Error	12	1.062862
Total	14	
CV / %	5.50	

[a]Significant at $p \leq 0.05$; CV: coefficient of variation; DF: degree of freedom; MG: mean square.

10 and 20%, high when between 20 and 30%, and very high when greater than 30%.

This significant difference observed between studied treatments is mainly due to the polarity of the non-polar solvent. This is due to that low polarity presents greater efficiency in oil extraction as the extraction yield depends on the different interactions between solute and solvent.[31,32] The types of lipids present, as well as the proportion of polar and non-polar lipids present in the raw material. The average technical oil contents at different extraction times are informed in Table 5.

Comparing the average contents obtained in the times analyzed, the 60 min period presented the best results for the performance variable, thus presenting a statistical difference from the other analyzed times ($p \leq 0.05$). Regarding times of 90 and 120 min, there were no significant differences between them, with concentrations of 17.45 and 18.30%, respectively. This result indicates that there was maximum extraction in the 60 min period and, at other times, stability with reduction in relation to the first.

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Table 5. Average contents obtained through the technical natural cashew nut for the three extraction times

Treatment	Average content / %
Extraction 30 min	20.03 ± 0.32[a]
Extraction 90 min	17.45 ± 0.53[b]
Extraction 120 min	18.30 ± 0.85[b]

Values expressed as mean ± standard deviation (n = 3); means followed by the same letter in the same column do not differ statistically using the Tukey's test at the level of $p \leq 0.05$.

Qualitative results of cashew nut oil by FTIR

As previously mentioned, the oil extraction from cashew nut peels showed varying yields depending on the duration, with the highest yield being found for the 60-min extraction, indicating that most of the compounds have high polarity and are removed in the first few hours of extraction. This is in accordance with work from Oliveira and Dweck[11] when studying the isolation of the constituents and tegument of the cashew nut peel and its potential evaluation as a natural antioxidant. Thus, the obtained mixtures, possibly composed of anacardic acids, were subjected to FTIR analysis and compared with spectra of oils obtained from extraction with mechanical mechanical press, Soxhlet, laboratory technical, industrial technical, and cardanol. Figure 2 presents a comparison of the FTIR spectra and the details of each functional group in the oil from the cashew nut peel by the different extraction methods.

From the FTIR spectra of the mixtures (Figure 2), it is observed the absorption bands at the interval of 1637-1645 cm^{-1} (νC=O) and at 2920 cm^{-1} (νO–H) that indicates the presence of carboxylic acids, directly associated with citric, benzoic, acetic and butyric acids. This gave to the mixtures an antioxidant character mainly due to the citric acid. These results were observed only for samples obtained through pressing and Soxhlet extractions. In the other samples, the non-appearance of such peaks in their structures may be associated with the extraction and storage method.[33] Similar results were reported by Nogueira *et al.*[34] when evaluating the antioxidant potential of anacardic acids in sunflower biodiesel. Low-intensity bands can be seen at 992 and 1152 cm^{-1}, with these values being compatible with the alkyl ether group. On the other hand, the existence of saturated carbons (–H) at 2923, 2924, and 2930 cm^{-1} can be observed in the spectra.

The absorption bands that remained around 1200-1300 cm^{-1} (νC–O) indicate the presence of the carbonic group linked to oxygen and may be related to the νC–O of the phenolic substituent or the carboxylic hydroxyl. As well as, it is possible to observe the absorption in the region of 3000 to 3100 cm^{-1} (νO–H) characteristic of alcohol or phenol hydroxyl, this effect may be due to intramolecular hydrogen bonding, which according to Xiao *et al.*[35] shifts the band towards lower frequencies (lower energy). These groups were verified in both samples, demonstrating that the phenolic bonds and groups were primarily responsible for the increase in the induction period of the oils being confirmed in the oxidative stability analysis using Rancimat method. It was also observed in all spectra the appearance of peaks in the region of 3500 to 3100 cm^{-1} due to the presence of humidity, making it impossible to attribute the signal to the νO–H of phenol.[35] In addition to this, researchers observed specific bands at 3330 cm^{-1} attributed to the stretching of the N–H type (primary and secondary amines), and a probable unsaturation, peaks at 1500 and 2800 cm^{-1}, indicative of the presence of methyl groups in organic structures.[36]

In general, we can verify that both oil press, Soxhlet, laboratory technical, and industrial technical samples presented characteristic peaks of phenol groups and organic acids that help in the antioxidant capacity of these oils. This is because that the only difference found between the spectra is the intensity of the bands/peaks, which directly reflects the Rancimat analysis and the sample induction periods (IP) (a fact that will be shown in the next section). The intensity peaks of the absorption band around 1754-1600 cm^{-1} due to C=O stretching confirmed the presence of a carboxylic group (–COOH) in the structure, while the peak around 3460 cm^{-1} denotes the existence of hydroxyl groups (–OH). The absorption band at 2924 and 2884 cm^{-1} was attributed to aliphatic and aromatic C–H stretching, respectively. The aromatic C=C bonds were confirmed by the band at 1560-1630 cm^{-1}. Furthermore, the ring-opening reaction of the epoxy group was confirmed to be completed by the absence of the absorption band at 909 cm^{-1} in the spectrum which is a characteristic C–O–C bond peak in the epoxy ring.[35,36]

Use of cashew nut oil as an antioxidant

Accelerated oxidative stability analysis is routinely used on oil and biodiesel samples in a system under strictly controlled temperature programming (ΔT) and airflow. This oxidative stability, measured through accelerated tests by the Rancimat equipment, is basically divided into two stages. The first is categorized with the induction period occurring under slow oxidation of esters and, consequently, a low formation of volatiles; the second stage is classified as accelerated oxidation of high molecular weight esters, resulting in the formation of volatile products, saturating the system. The results obtained from Rancimat can be seen in Table 6, which shows the tests carried out with the blank (pure biodiesel) and oil biodiesel containing antioxidants.
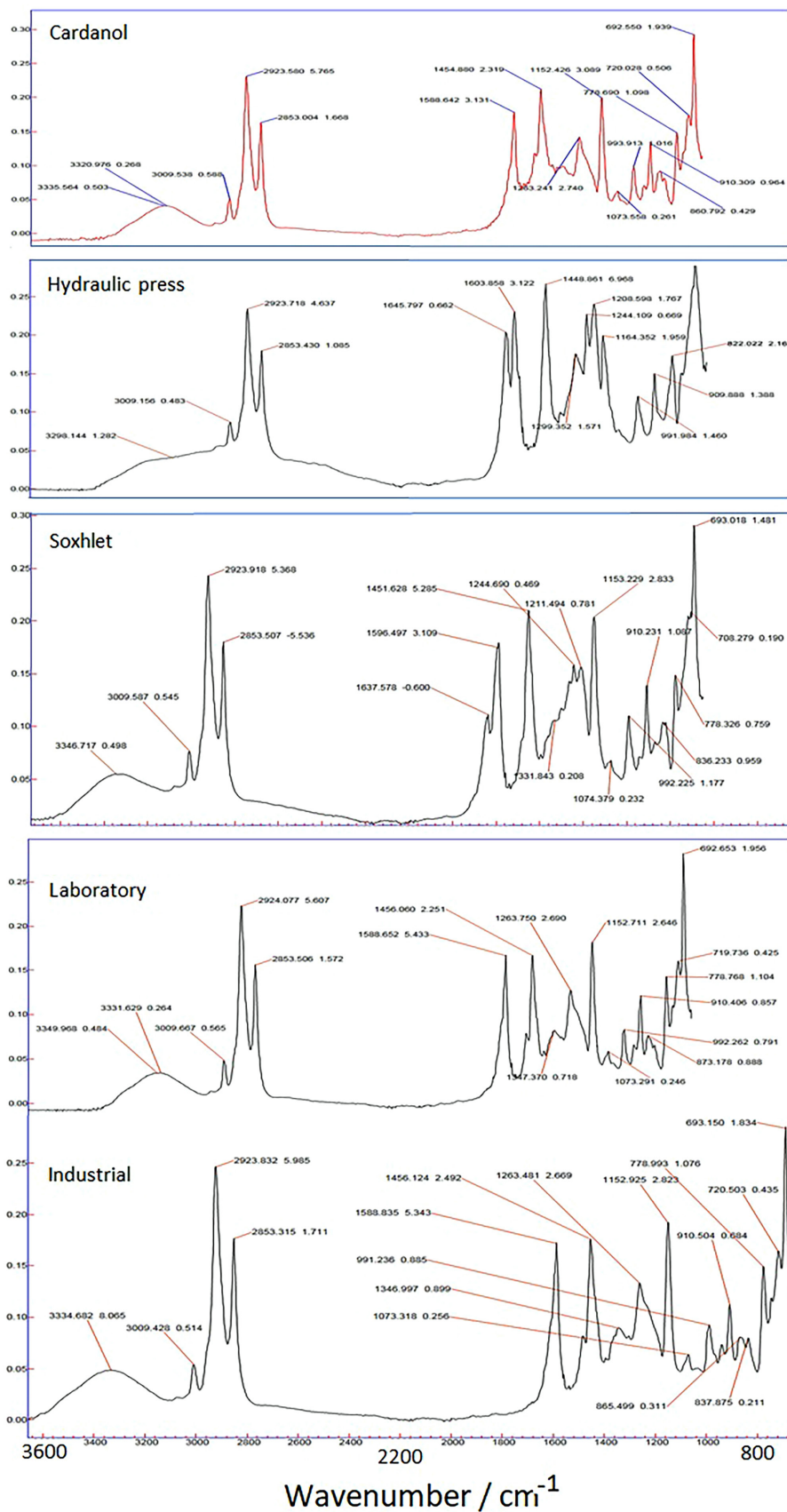
Figure 2. Infrared spectra of fractions obtained by different methods with the studied samples cashew nut oil: cadanol, Soxhlet, laboratory technical and industrial technical.

When analyzing the data in Table 6, the biodiesel added with oil natural press and oil natural Soxhlet at concentrations of 6,000 mg L^{-1}, we can verify that the samples obtained IP of 8.40 and 10.35 respectively. Thus, the sample added with the natural oil press method was analyzed in Rancimat and the received response shows a result of 8.40 h, which does not correspond to the expected value and is outside the parameters recommended by ANP.[25] In this context, this decrease in the induction period may be correlated mainly due to some contamination of the oil. A similar result was reported by Mazzetto *et al.*[37] when studying the oil extracted from cashew nuts as an antioxidant for biodiesel at a concentration of 3,000 mg L^{-1}, obtaining an IP of 4.60 h, being entirely outside the limits of the current resolution.

Table 6. Cashew nut oil induction period, study of the oxidative stability of biodiesel samples

Biodiesel sample	Induction period (IP) / h
Cardanol (10,000 mg L^{-1})	25.22
Control	10.08
Oil Press (6,000 mg L^{-1})	8.40
Oil Soxhlet (6,000 mg L^{-1})	10.35
Laboratory technical oil (6,000 mg L^{-1})	11.12
Industrial technical oil (6,000 mg L^{-1})	10.65

On the other hand, the oil sample extracted in the Soxhlet also presented unsatisfactory results with an induction period of 10.35 h (IP), however, higher than that reported by the control sample (10.08 h), demonstrating that the oil Soxhlet is an additive important and a promising alternative to preventing the oxidation process in biodiesel, being close to the minimum limit required by ANP.[25] A viable and profitable alternative would be to increase the dosage of oils. In this sense, according to Pateiro *et al.*,[38] additives are natural or synthetic molecules of great importance, being commonly used to confer specific beneficial attributes to the original product. Thus, in general, and in different concentrations, oils have been presenting important results, as they have given biodiesel excellent induction periods, directly reflecting on the stability of the biodiesel and consequently on its helpful life during storage, ensuring that it does not suffer from commonly reported oxidative processes.

Analyzing the results from Table 6, we can verify that the samples added with technical oils (laboratory and industrial) generally obtained better IP results than the samples added with natural oils (press and Soxhlet). However, regardless of the method of obtaining and extraction, both samples do not comply with current legislation.[25] Analyzing Table 6 again, we can note that

the only oil that reached the minimum recommendation required by the ANP[25] was the one that contained extracted cardanol in its mixture, presenting an induction period of 25.22 h. This result is justified mainly due to the large number of phenolic acids present in the sample and its higher dosage, 10,000 mg L^{-1}, which directly contributes to its antioxidant and retardant action against oxidation. These results confirm the possibility of using oil obtained from cashew nut peels as a promising antioxidant for the Brazilian biodiesel industry, guaranteeing a promising product, with unique characteristics and greater oxidative stability, especially when using cardanol as an antioxidant agent. Thus, there are several approaches that must be taken into consideration when using oil as an antioxidant, the low cost of the product, and the conditions that the country has to meet the demand for biodiesel production, due to the great availability of oils and their raw materials.

Conclusions

In this context, we can conclude that the cashew nut peel oils evaluated in the present work showed promise as antioxidants for the oxidative stabilization process of biodiesel. The use of a concentration of 6,000 mg L^{-1} proved to be unsatisfactory since all oils tested at this concentration did not present induction periods longer than those recommended by the National Petroleum Agency (ANP), which is 20 h. However, the sample added with cardanol gave meaningful and satisfactory results since its induction period of 25.22 h was twice as long as that recommended by ANP.[25] New studies must be developed in order to verify the optimal concentrations (mg L^{-1}) of oils from cashew nut peels to maximize the retardant effect of biodiesel oxidation.

Acknowledgments

Author Contributions

Fabrício de Oliveira Ramos was responsible for conceptualization, methodology, validation, formal analysis, original draft, investigation; Patrícia Martins Guarda for resources, supervision, project administration; Emerson Adriano Guarda for conceptualization, resources, supervision, project administration, review, and editing; Rosinete Nogueira de Sousa for formal analysis; Danylo Bezerra

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