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Evaluation of oxidative stability of soybean biodiesel using ethanolic and chloroform extracts of *Platymiscium floribundum* as antioxidant

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ABSTRACT

The objective of this work was to evaluate the effect of *Platymiscium floribundum* ethanolic and chloroform extracts on the oxidative stability of soybean biodiesel using the Rancimat and DSC methods. The soybean biodiesel was obtained by transesterification. The antioxidant activity of the extracts was also evaluated by the free radical scavenging (DPPH) method and the total phenolic content by the Folin-Ciocalteu method. Both extracts showed antioxidant activity, reducing the DPPH by about 90%, and the total phenolic content of the ethanolic and chloroform extracts were 2.87 and 3.10 mg GAE/100 mg of extract, respectively. The extracts showed to be very efficient in retarding the oxidation of soybean biodiesel since the induction period increased from 4.53 h to 18.09 h (PF–EtOH, 10000 mg/kg) and 17.58 h (PF–$CHCl_3$, 10000 mg/kg). Both extracts showed high thermal stability with Ton-e of 405.76 °C (PF–$CHCl_3$) and 396.79 °C (PF–EtOH). The presence of the extracts increased the activation energy of the samples between 12.3% and 37.0%. The increase of the activation energy represents an improvement of the oxidative stability of biodiesel. All results confirmed the action of the antioxidants present in the extracts on controlling the oxidation reactions in biodiesel.

1. Introduction

Biodiesel is a renewable fuel composed of a mixture of alkyl monoesters of vegetable oils produced by transesterification reactions. This process consists of the reaction between triglycerides constituting the oils and animal fats and short-chain alcohol, preferably methanol or ethanol, catalyzed by base or acid [1–4].

The percentage of biodiesel added to fossil diesel has been increasing in recent years. However, as a disadvantage, biodiesel is susceptible to oxidation because it is a mixture of esters of saturated and unsaturated fatty acids [5,6]. This composition can contribute to biodiesel oxidation (auto-oxidation, photo-oxidation, thermo-oxidation, hydrolytic reactions, and enzymatic oxidation). These reactions are the main ones responsible for the formation of oxidation products, the elevation of the acidity index, and consequently nonconformities [7–9].

Therefore, it is necessary to use compounds with antioxidant properties that preserve the biodiesel properties [10–12]. Phenolic compounds (synthetic and natural) are reported as having antioxidant activity on the interception of peroxide radicals on the

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oxidative process [13–16]. Natural antioxidants are reported as additives of vegetable oils and biodiesel. These compounds present antioxidant potential attributed to their chemical structures. The antioxidant action is described for a variety of compounds from different plant and animal species [17,18].

The use of extracts selected from plants can be a viable, inexpensive, and environmentally friendly alternative as a source of antioxidants. Rial [19] reported the use of ethanolic extract the leaves of cagaita (*Eugenia dysenterica*) in soybean methyl biodiesel showing to be efficient in retarding the oxidation of biodiesel, the samples with 800 ppm or more had the induction period higher than that recommended by EN 14214. In another study, Rial [20] demonstrated that soybean methyl biodiesel containing extract of ginger rhizomes (*Zingiber officinale* Roscoe), presented oxidative stability with values higher than the minimum regulated by Brazilian National Agency for Petroleum, Natural Gas and Biofuels (ANP).

Another interesting natural product that had its oxidizing action tested in the presence of soy biodiesel was the extracts of macerated barley waste and leaves of *Moringa oleifera*. The biodiesel produced was stored for about 6.5 months, with no loss of quality due to oxidative processes [21]. Several studies reported in the literature using plant extracts [17,19–25] have demonstrated the use of vegetable matrices as antioxidants.

The purpose of the present paper is to evaluate the antioxidant effect of ethanolic and chloroform extracts of *P. floribundum* on soybean biodiesel. This species is popularly known as “sacambu” and “jacaranda-do-litoral” and is used by the local population as an anti-inflammatory agent [25]. Previous phytochemical studies within our research group of this species revealed *P. floribundum* as a prolific source of phenolic compounds such as flavonoids and coumarins [25,26]. Knowing the chemical composition of this plant, the authors report in this work the antioxidant effect of extracts of *P. floribundum* on the oxidative stability of soybean biodiesel.

2. Materials and methods

2.1. Plant material

P. floribundum was collected in Acarape, state of Ceará – Brazil, and identified by the botanist Dr. Edson Paula Nunes. A voucher specimen (number #31502) was deposited in the Herbarium Prisco Bezerra of Biology Department, the Federal University of Ceara, Brazil.

2.2. Preparation of extracts

The dried trunk heartwood (0.8 kg) was extracted exhaustively by chloroform and ethanol. The extracts were obtained by removal of the solvents under vacuum and denominated PF-$CHCl_3$ (76.0 g) and PF-EtOH (23.0 g), respectively.

2.3. Determination of the total phenolic content and evaluation of free radical scavenging activity of PF-$CHCl_3$ and PF-EtOH extracts

Samples of PF-$CHCl_3$ and PF-EtOH extracts (200 μL, 0.49–0.52 mg/mL) were added to 250 μL of folin–ciocalteu reagent, 3 mL of aqueous Na_2CO_3 (10%) and 4 mL of ultrapure water. After 20 min at room temperature (25 °C), the absorbance was measured at 785 nm [27]. The calibration curve was prepared with standard gallic acid at concentrations ranging from 1 to 6 μg/mL. The analyses were realized in triplicate and the results (milligrams of equivalent gallic acid (mg GAE)/100 mg of extract) are expressed as mean and coefficient variation.

The antioxidant effect of PF-$CHCl_3$ and PF-EtOH extracts were assessed based on their scavenging activity of the DPPH free radical [28]. An aliquot (0.1 mL) of extracts (10; 25; 50; 100; 200 μg/mL) or ascorbic acid (50 μg/mL) was mixed with 3.9 ml of DPPH (0.3 mM in a 1:1 methanol/ethanol solution). The mixture was vortexed for 1 min, left standing at room temperature for 30 min, and the absorbance was read spectrophotometrically (Beckman Instruments Inc., EUA) at 515 nm. The percentage of inhibition was calculated according to the following equation: % radical scavenging activity = $[Ao - (Ac/Ao)] \times 100$, where Ao was the absorbance of the control (without extract) and Ac was the absorbance in the presence of extracts. Control extracts were maintained in the dark. Absorbance ($\lambda = 515$ nm) was measured in both illuminated and not illuminated extracts and the differences between the absorbances were used for determining the scavenging activity.

The results related to antioxidant activity were expressed as means ± standard error of the mean (SEM). Data were analyzed by a one-way ANOVA using Turkey's test as *post hoc* test to assess differences between means. A significant difference was considered when $p < 0.05$. The data were analyzed by Microsoft Excel and GraphPad Prism software 6.0 (USA).

2.4. Production of soybean biodiesel (SB)

Soybean biodiesel was produced by transesterification. First, 1.18 g of KOH 85% was dissolved in 27.5 mL CH_3OH forming the catalyst solution. Then, this solution was added to a three-neck round-bottom flask containing 100.0 g of soybean oil and connected to a reflux condenser. The reaction was carried out for 60 min under reflux at 60 °C. The molar ratio of oil to methanol was maintained at 1:6. The reaction mixture was put in a separating funnel to obtain the methyl ester (biodiesel) and glycerol. The ester phase was washed with distilled water to remove impurities. This process was done until the wash water reaches a neutral pH. At sequence, the ester phase was dried under vacuum and filtered using sodium sulfate anhydrous to remove moisture residual.

2.5. Preparation of the soybean biodiesel/extracts formulations of P. floribundum

The extracts PF-$CHCl_3$ and PF-EtOH were solubilized in 1 mL of ethyl acetate and added to SB in the concentrations of 1000, 5000, and 10000 mg/kg. The authors used the formulation of ethyl acetate (1 mL)/SB as control.

2.6. Characterization of the soybean biodiesel

The acidity of samples was measured according to AOCS method Cd 3d-63. The kinematic viscosity and density were performed on digital Viscometer Anton Paar – SVM 3000 - Stabinger (Austria), according to ASTM D-7042.

Soybean biodiesel and its formulations with PF-$CHCl_3$ and PF-EtOH at concentrations of 1000 mg/kg, 5000 mg/kg, and 10000 mg/kg were evaluated by the Rancimat method - equipment 843 – Metrohm (Switzerland). All measurements were carried out in duplicate, according to EN 14112 standard (110 °C and airflow of 10 L/min).

2.7. Differential scanning calorimetry

The Differential scanning calorimetry (DSC) assays were conducted at a Mettler Toledo instrument (USA) using a cell DSC 1500 2624 under synthetic air atmosphere. Experimental conditions: samples of 6.0 mg; airflow of 50 mL/min; temperature range of 303–723 K, and heating rate of 5 K/min. The instrument was

calibrated with indium and zinc. Soybean biodiesel (SB) and its formulations with PF-$CHCl_3$ and PF-EtOH at concentrations of 1000 mg/kg, 5000 mg/kg, and 10000 mg/kg were evaluated.

The enthalpy variation (Δh), the extrapolated onset temperature (Ton-e), and the peak temperature (Tpeak) were determined according to ASTM E537-12. The Borchardt-Daniels method, described in ASTM E2041-13, was used to evaluate the activation energy, Arrhenius pre-exponential factor, the reaction rate, and the reaction order.

2.8. Kinetic parameters by Borchardt-Daniels method

The determination of the kinetic parameters was performed for the first thermal event, which corresponds to the beginning of the thermo-oxidative degradation, the moment that the biodiesel reaches a non-conformity profile. These parameters were obtained by the Borchardt-Daniels method based on the dependence of the reaction rate and amount of sample present (ASTM E2041-13), see Eq. (1)

$$\frac{d\alpha}{dt} = k(T)(1-\alpha)^n \quad (1)$$

where dα/dt = reaction rate [min^{-1}]; α = fraction reacted [dimensionless]; k(T) = rate constant at temperature T [min^{-1}], and n = reaction order [dimensionless].

The model also makes use of the Arrhenius equation to describe the relationship between reaction rate and temperature (Eq. (2)).

$$k(T) = Ze^{-\frac{Ea}{RT}} \quad (2)$$

where Z = Arrhenius pre-exponential factor [min^{-1}]; Ea = activation energy [J/mol]; T = absolute temperature [K]; and R = gas constant (8.314 J/mol.K).

Eq. (3) corresponds to a combination of the logarithm forms of Eqs. (1) and (2).

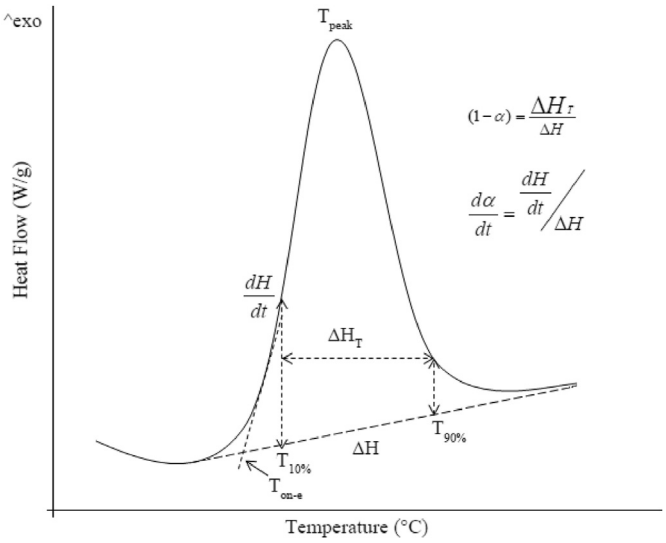
$$\ln\left[\frac{d\alpha}{dt}\right] = \ln[Z] + n\ln[1-\alpha] - \frac{Ea}{RT} \quad (3)$$

Equation (3) has the form of z = a + bx + cy, where z ≡ *ln*[dα/dt]; a ≡ ln[Z]; b ≡ n; x ≡ *ln*[1-α]; c ≡ Ea/R, and y ≡ 1/T. The data treatment used to solve Eq. (3) was carried out through the multiple linear regression process (ASTM E1970). Then, this equation was linearized aiming to obtain the plot of *ln* [k(T)] *versus* [1/T(K)], and consequently, the angular coefficient (-Ea/R) and the linear coefficient [ln (Z)]. The calculation procedure to determine dα/dt, (1-α), and T were obtained by the DSC curve (see Fig. 1).

In the DSC curve, after obtaining ΔH (mJ) by the integration of the total peak area, the temperatures correspondent to approximately 10% ($T_{10\%}$) and 90% ($T_{90\%}$) of the total peak area should be identified. This area should be divided into, at least, ten equal parts (*in our study, we divided it into twenty*). Then, for each subdivision, dH/dt (mW), T (K), and ΔH_T (mJ) should be determined, as shown in Fig. 1. The data statistical treatment was realized according to ASTM E1970.

3. Results and discussion

The content of total phenolic compounds of the PF–$CHCl_3$ and PF–EtOH were 3.10 (1.30%) and 2.87 (1.34%) mg GAE/100 mg of extract, respectively. The content was calculated by the regression equation of the calibration curve y = 0.1118x+0.0367 with a correlation coefficient of r = 0.9738. Both extracts showed antioxidant activity comparable to ascorbic acid with higher radical scavenging activity, reducing the DPPH by about 90%. However, the free radical scavenging activity of the PF–$CHCl_3$ extract (10 μg/mL), at low concentration, was significantly higher than the PF–EtOH extract (10 μg/mL). It is possible that the free radical scavenging activity related to the presence of phenols in these plant extracts [29].



Source: Adapted from ASTM E2041.

Fig. 1. Idealized DSC curve, including parameters used in the Borchardt and Daniels Method.
Source: Adapted from ASTM E2041.

The results of the physicochemical properties of the soybean biodiesel (SB) are described in Table 1. All parameters evaluated, except the oxidative stability at 110 °C, obey the limits established by Brazilian National Agency for Petroleum, Natural Gas and Biofuels (ANP) – Resolution nº. 45/2014 and nº. 798/2019 [30].

Oxidative stability at 110 °C for pure SB (without antioxidant) showed results below the limit established by the RANP 798/2019, however, our results corroborate with the literature [21]. The high content of unsaturated fatty acids esters, e. g. linoleic acid justifies the susceptibility to oxidation of the SB [17,21].

The induction period of the SB and its formulations (soybean biodiesel + extracts of *P. floribundum*) are in Table 2. The influence of the ethyl acetate solvent on the oxidative stability of the samples was also evaluated. The results indicated that 1 mL of ethyl acetate used in the solubilization of the samples, not interfered in the oxidative induction period.

All formulations presented an induction period higher than the minimum established by RANP 798/2019 except the soybean biodiesel + PF–CHCl3 1000 mg/kg and soybean biodiesel + PF–EtOH 1000 mg/kg. The addition of the PF–CHCl3 extracts promoted increments in the order of 71.30% (1000 mg/kg), 261.81% (5000 mg/kg), and 288.08% (10000 mg/kg) compared to SB without antioxidant. Regarding the PF–EtOH extracts, the SB induction period increased in the order of 91.17% (1000 mg/kg),

Table 1
Physicochemical properties of the soybean biodiesel (SB).

Parameter	Results	[a]RANP 45/2014, RANP 798/2019
Acid number	0.21 mg KOH/g	0.50 mg KOH/g, max.
Kinematic viscosity at 40 °C	4.22 mm^2/s	3–6 mm^2/s
Density at 20 °C	882.6 kg/m^3	850–900 kg/m^3
Oxidative stability at 110 °C	4.53 h	12 h, min.

[a] RANP = ANP Resolution.

Table 2
Oxidative induction period of the soybean biodiesel (SB) and its formulations.

Samples	Oxidative induction period (h)
SB	4.53 ± 0.12
SB – ethyl acetate	4.66 ± 0.35
SB PF–$CHCl_3$ 1000 mg/kg	7.76 ± 1.29
SB PF–$CHCl_3$ 5000 mg/kg	16.39 ± 0.98
SB PF–$CHCl_3$ 10000 mg/kg	17.58 ± 0.14
SB PF–EtOH 1000 mg/kg	8.66 ± 0.88
SB PF–EtOH 5000 mg/kg	16.02 ± 0.38
SB PF–EtOH 10000 mg/kg	18.09 ± 0.07

253.64% (5000 mg/kg), and 299.34% (10000 mg/kg). The oxidative induction periods are shown in Figs. 2 and 3.

The extracts of *P. floribundum* showed a better antioxidant performance when compared to natural extracts reported in the literature [21]. The extract of curcumin (1000 mg/kg) reported by Sousa [17] promoted an increase of 61.5% on the oxidative stability of the soybean biodiesel. Pitaro [31], who studied the influence of ethanolic extracts of fresh basil and dried oregano, did not find results higher than 111.65%.

According to the previous work of our research group [25], the compounds isolated from *P. floribundum* include flavonoids and coumarins. These phenolic compounds are considered primary antioxidants that eliminate the free radicals formed in lipid autoxidation reactions. In the antioxidant mechanism, the hydrogen atom of the hydroxyl linked to the aromatic ring is donated to the lipid molecule, being converted into thermodynamically stable free radicals [32]. This stabilization depends on the phenol structure, such as the presence of additional hydroxyl groups and the ability of intramolecular hydrogen bonding [33].

The flavonoids and coumarins isolated from *P. floribundum* (**1**–**8**, see Fig. 4) have centers that favor the antioxidant action [25,26]. The possible mechanisms of the antioxidant action of flavonoid **7** and coumarin **8** are described in Fig. 4. Flavonoid **7** is resonance-stabilized and forms an intramolecular hydrogen bond, and coumarin **8** has an electron-donor moiety ortho to hydroxyl, lowering the dissociation energy of the phenolic –OH bond, thus releasing the hydrogen atom to the free radical, being stabilized by resonance. All these factors may explain the antioxidant activity of the extracts of *P. floribundum*, where the substances might be acting synergistically.

The thermo-oxidative stability of the PF–CHCl3 and PF–EtOH extracts were evaluated by Differential Scanning Calorimetry (DSC), as shown in Fig. 5.

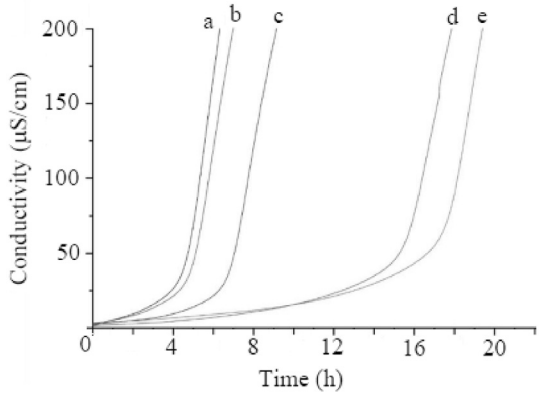


Fig. 2. Rancimat curves of the Pure SB and its formulations with chloroform extracts. a. Pure SB; b. SB Ethyl Acetate; c. SB PF-$CHCl_3$ 1000 mg/kg; d. SB PF-$CHCl_3$ 5000 mg/kg; and e. SB PF-$CHCl_3$ 10000 mg/kg.

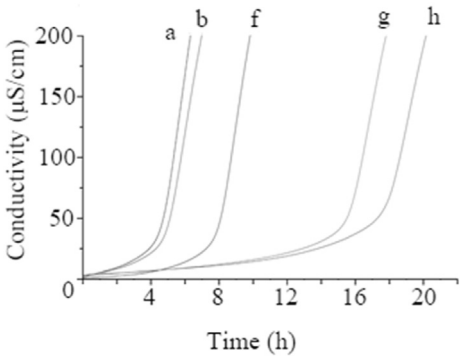


Fig. 3. Rancimat curves of the Pure SB and its formulations with ethanolic extracts. a. Pure SB; b. SB Ethyl Acetate; f. SB PF-EtOH 1000 mg/kg; g. SB PF-EtOH 5000 mg/kg; and h. SB PF-EtOH 10000 mg/kg.

The DSC curves of the PF–CHCl3 and PF–EtOH extracts showed Ton-e of 405.76 °C and 396.79 °C, respectively. These Ton-e values were identified through the peaks of their respective derivatives curves. Indeed, the extracts showed good thermo-oxidative stability and these results corroborate with the results of oxidative stability of the formulations (biodiesel + extract) evaluated by the Rancimat method. The Ton-e and thermal behavior of the extracts are compatible with thermal results for flavonoids [34,35].

Regarding the oxidative stability criteria for lipid compounds (including biodiesel), the region of interest is just the first exothermic peak, since the other peaks refer to thermal degradation [36,37]. Thus, the oxidative stability parameters for the SB curve are shown in Fig. 6. In the region of interest, the enthalpy variation (Δh, J/g), extrapolated onset temperature (Ton-e), and peak temperature (Tpeak) is depicted.

Fig. 7 and Table 3 present the parameters for the SB and its formulations at 1000 mg/kg and 5000 mg/kg of PF-$CHCl_3$ and PF-EtOH.

According to the thermal profiles presented in Fig. 7, all formulations showed Ton-e higher than soybean biodiesel (SB), this result agrees with the trend obtained by the Rancimat. Table 3 shows the enthalpic variations of the degradation processes and the peak temperatures. All peak temperatures of the formulations were higher than Tpeak of the SB, also indicating the higher stability of these formulations compared to the pure biodiesel.

Finally, the kinetic evaluation was adopted in the first exothermic peak of each sample (interest region). The activation energy, reaction order, natural logarithm of Arrhenius, and the reaction rate at 383 K, the same temperature used in the Rancimat test, are shown in Table 4. As mentioned, the kinetic parameters were obtained through the multiple linear data treatment, just as determined by the ASTM E1970 standard (see Supplementary Material section - Borchardt and Daniels Method Data).

The presence of the PF–CHCl3 and PF–EtOH extracts increased the activation energy (Ea) of the soybean biodiesel between 12.3% and 37.0%. The increase of the activation energy represents an improvement in the oxidative stability of the biodiesel, which agrees with the trend observed in the Rancimat method. The formulation SB PF–CHCl3 5000 mg/kg showed the highest activation energy, 188.12 ± 1.92 kJ/mol. Gregorio et al. [38] also observed a significant increase in the activation energy of the soybean biodiesel when mixed with extracts of pepper, sage, coffee leaves, and bacupari. Similar results were also observed by Borsato [39] in the study of the oxidation kinetics of the soybean biodiesel. This work showed that when TBHQ was added to soybean biodiesel, there was an increase of 1.8 times in the kinetic energy. This result agrees with

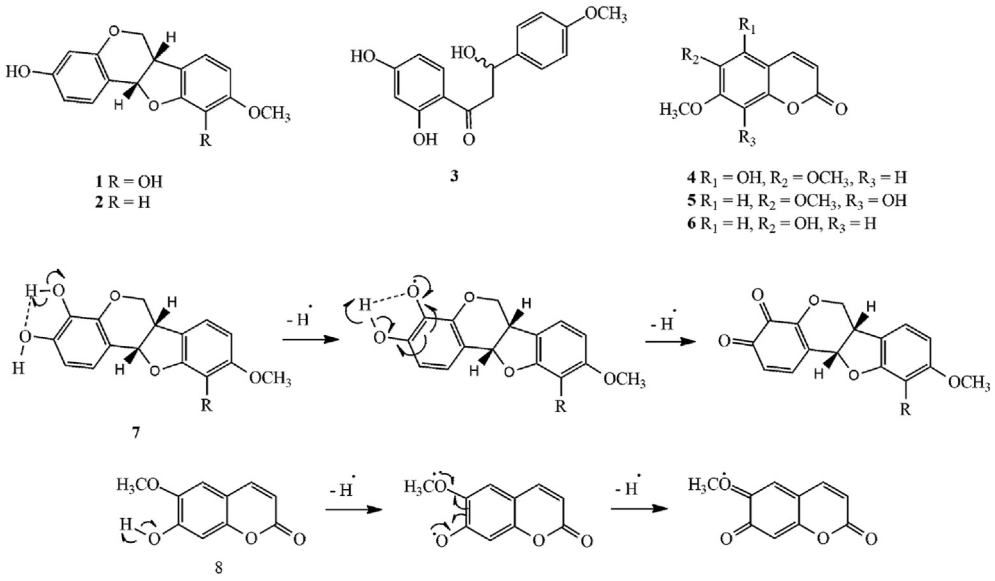


Fig. 4. Isolated compounds of *Platymiscium floribundum*.

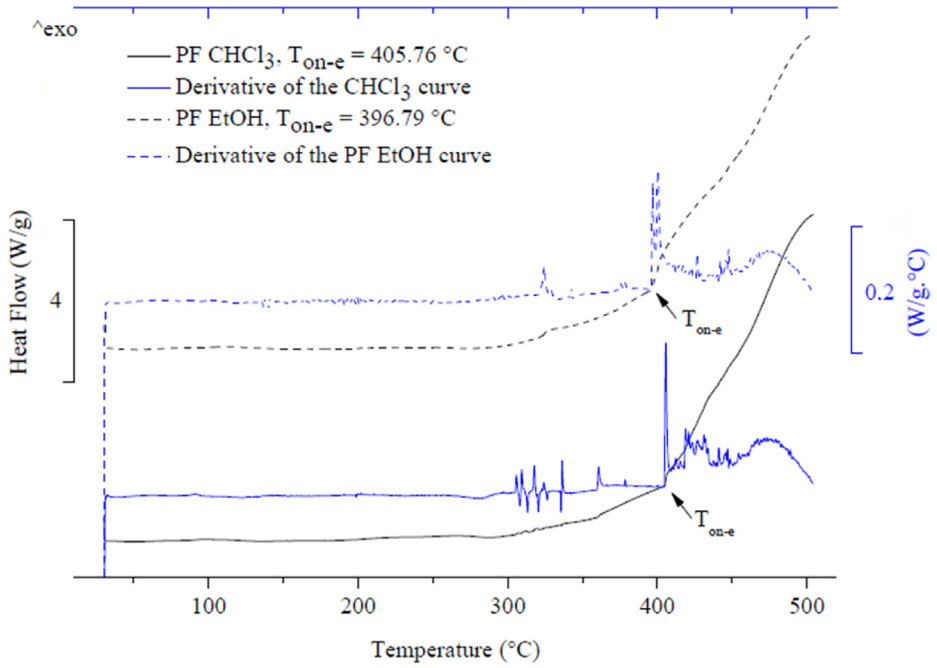


Fig. 5. DSC curves (black lines) and respective derivatives curves (blue lines) of PF-$CHCl_3$ (straight lines) and PF-EtOH (dashed lines) extracts, including Ton-e of each sample. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the antioxidant profile of the phenolic compounds.

Some authors report that the reaction rate is the most significant parameter to evaluate oxidative stability [38,40,41]. The results shown in Table 4 agree with this hypothesis once the highest value of *k* (110 °C) was for the soybean biodiesel. This result represents that the SB is more prone to oxidize. The addition of the extracts decreased the *k* (110 °C) values, and the SB PF-$CHCl_3$ 5000 mg/kg showed the lowest result indicating that this formulation is more resistant. Again, the trend observed in the Rancimat method was confirmed.

Therefore, according to DSC and Rancimat results, it may be inferred that PF-CHCl3 and PF-EtOH extracts increased the oxidative stability of the soybean biodiesel when added to this biofuel. Concluding the kinetic study, Fig. 8 shows the plot of ln[*k*(T)] *versus* 1/T.

According to the multiple linear regression was observed a linear trend for all samples (SB and its formulations), which represents a high reproducibility (R^2). The high values of R2 (see Table 4) indicate the efficiency of the Borchardt-Daniels method to evaluate the oxidative stability of soybean biodiesel [37].

4. Conclusion

The ethanolic and chloroform extracts of the *Platymiscium floribundum* (PF—EtOH and PF-CHCl3) showed to be potential additives to retard the oxidation of soybean biodiesel (BS). The best

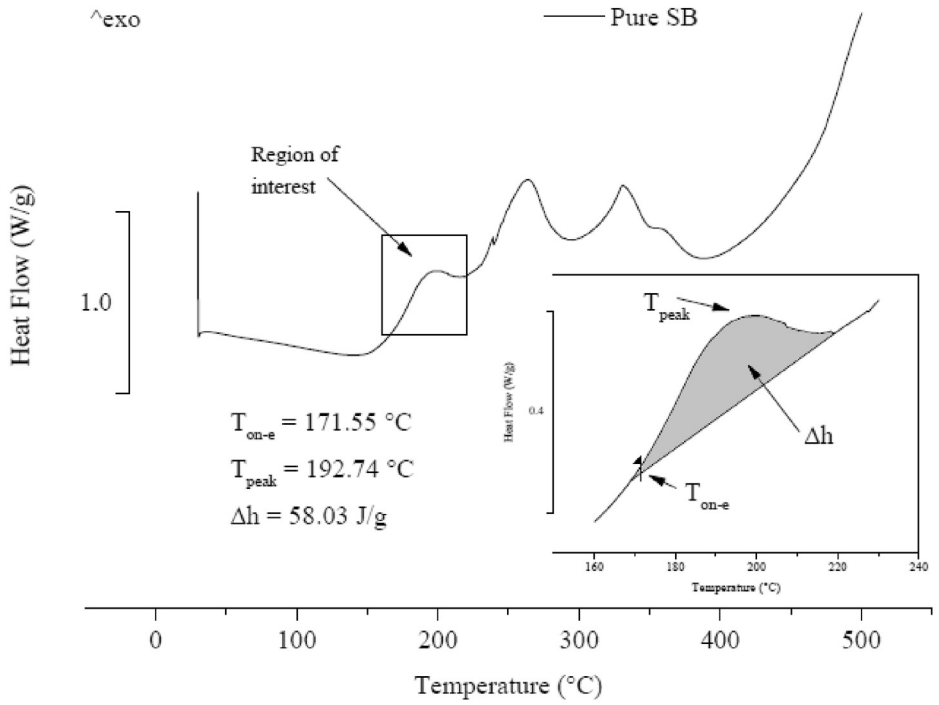


Fig. 6. DSC curve of the Pure SB, including the region of interest and oxidative stability parameters (Ton-e, Tpeak, and Δ*h*), according to ASTM E537.

Table 3
Enthalpy variation (Δ*h*), and peak temperature (Tpeak) for the SB and its formulations.

Sample	Δ*h* (J/g)	T_{peak} (K)
SB	58.01	192.74
SB PF-$CHCl_3$ 1000 mg/kg	82.07	198.08
SB PF-EtOH 1000 mg/kg	34.37	196.42
SB PF-$CHCl_3$ 5000 mg/kg	59.29	205.64
SB PF-EtOH 5000 mg/kg	51.39	204.98

Table 4
Kinetic parameters for SB and its formulations.

Samples	Ea (kJ/mol)	n	ln[Z]	R^2	k (383 K)
SB	137.27 ± 2.57	1	30.22	0.993	2.57E-06
SB PF-$CHCl_3$ 1000 mg/kg	154.17 ± 1.99	1.5	34.14	0.997	6.45E-07
SB PF-$CHCl_3$ 5000 mg/kg	188.12 ± 1.92	1	42.35	0.998	5.54E-08
SB PF-EtOH 1000 mg/kg	163.23 ± 1.17	1	36.83	0.997	5.50E-07
SB PF-EtOH 5000 mg/kg	170.65 ± 1.78	1	37.87	0.998	1.52E-07

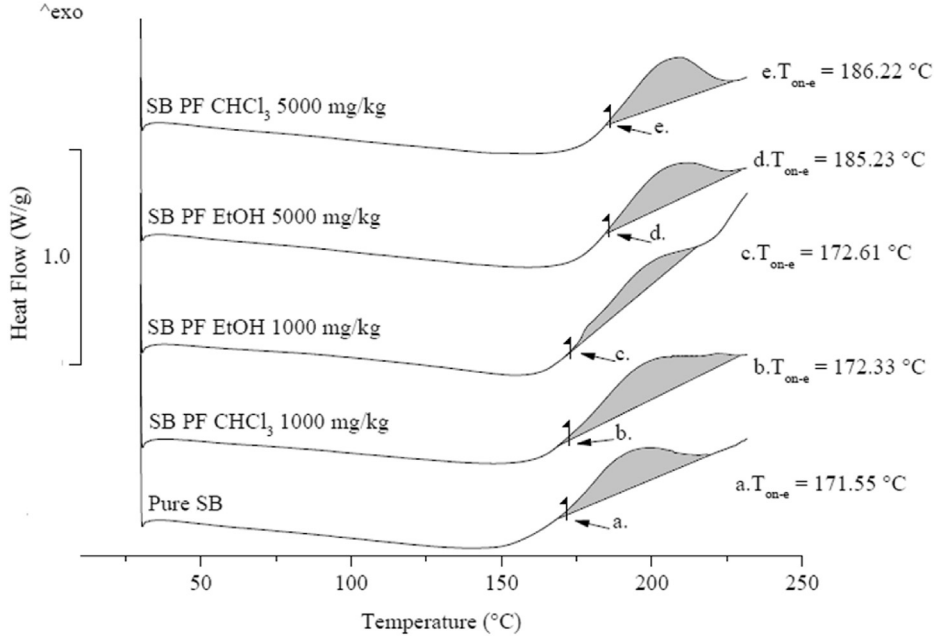


Fig. 7. DSC curves of the Pure SB and its formulations, highlighting each Ton-e. a. Pure SB; b. SB PF-$CHCl_3$ 1000 mg/kg; c. SB PF-EtOH 1000 mg/kg; d. SB PF-EtOH 5000 mg/kg; and e. SB PF-$CHCl_3$ 5000 mg/kg.

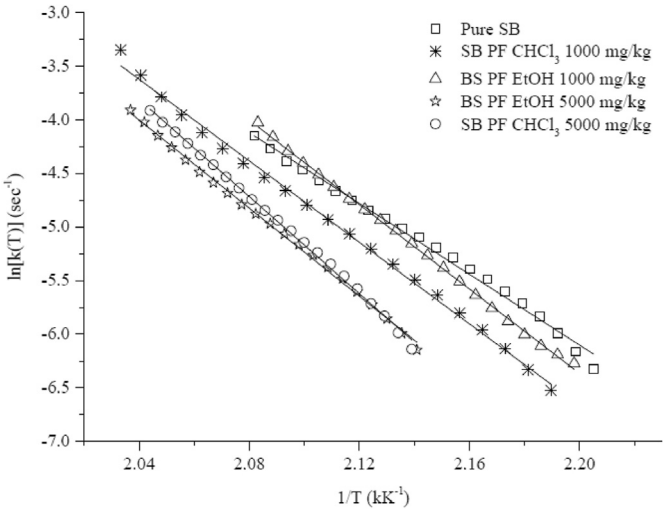


Fig. 8. Plot of 1/T *versus* ln[k(T)] of Pure SB and its formulations at 1000 and 5000 mg/kg.

results for the oxidative induction period, 17.58 ± 0.14 and 18.09 ± 0.07, were found to SB PF–CHCl3 and SB PF–EtOH respectively, at a concentration of 10000 mg/kg for both extracts, being more than 288% and 299% higher than the result found to the control sample (soybean biodiesel). When evaluated by the kinetic parameters, the addition of the *P. floribundum* extracts was shown to be efficient in the protection of biodiesel. The values obtained for the reaction rates were lower, and the activation energies higher in all formulations when compared to the soybean biodiesel without extract. The samples with ethanolic and chloroform extracts at concentrations of 5000 mg/kg and 10000 mg/kg had the highest induction periods and values greater than 12.00 h, the minimum limit recommended by the RANP 798/2019. The extracts showed good thermo-oxidative stability (DSC) corroborating with the results of oxidative stability of the formulations evaluated by Rancimat. Because the results of the oxidative induction period are following the established by ANP, the *P. floribundum* extracts can be used as potential antioxidant sources for biodiesel, begetting economic and environmental advantages. The innovative application of these extracts in biodiesel production is environmentally promising and can be an alternative to the synthetic as well as non-renewable antioxidants.

CRediT authorship contribution statement

Tiago Rocha Nogueira: Writing - original draft, Investigation. **Igor de Mesquita Figueredo:** Methodology, Formal analysis, Software. **Francisco Murilo Tavares Luna:** Methodology, Formal analysis. **Célio Loureiro Cavalcante:** Funding acquisition, Formal analysis. **João Evangelista de Ávila dos Santos:** Writing - original draft, Software. **Mary Anne Sousa Lima:** Resources, Visualization. **Thiala Soares Josino da Silva:** Methodology, Software. **Luzia Kalyne Almeida Moreira Leal:** Methodology, Formal analysis. **Fátima Miranda Nunes:** Visualization, Writing - review & editing. **Maria Alexsandra de Sousa Rios:** Data curation, Conceptualization, Writing - review & editing. **Antônia Torres Ávila Pimenta:** Project administration, Supervision, Data curation, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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