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Research Article

Comparative Study of the Antioxidant Power of Polyphenols of Leaves, Fruits, and Bark of *Pistacia atlantica* Desf. from Morocco

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Pistacia atlantica Desf. is a widely used plant species in the traditional medicine for its various pharmacological properties. The aim of this study is the valorisation of polyphenols and the antioxidant power of three organs from *Pistacia atlantica* Desf. (leaves, fruits, and bark). Phytochemical screening of secondary metabolites was performed using precipitation and coloring reactions. Total phenols, flavonoids, and condensed tannins were quantified, respectively, by the Folin-Ciocalteu method, the aluminum trichloride method, and the vanillin method. Evaluation of the antioxidant activity was made using two methods: DPPH∗ (2,2′-diphenyl-1-picryl hydrazyl) and FRAP (ferric reducing antioxidant power). The obtained results showed that the three organs of *Pistacia atlantica* are rich in total phenols, flavonoids, and condensed tannins. The highest contents of total phenols and flavonoids are recorded by the crude fruit extract, 723 mg EGA/gE and 34.57 mg EQ/gE, respectively, while the highest content of condensed tannins is recorded in the butanolic extract of the leaves (997.58 mg ECat/gE). The antioxidant activity of the three organs extracts from *Pistacia atlantica* Desf. confirmed their strong antiradical power, much higher than that of ascorbic acid and BHA (butylated hydroxyanisole). Indeed, the concentration of the crude extract of *P. atlantica* leaves reducing 50% of the DPPH∗ free radicals (IC_{50}) is 27.22 μg/ml. This concentration is much lower than those of ascorbic acid (31.44 μg/ml) and BHA (46.25 μg/ml). The antioxidant power using the FRAP method has also shown that the leaves extract of this species has a much higher reducing capacity of iron than those of the reference standards. A positive correlation between antioxidant capacities and flavonoids contents of leaves and fruits extracts was observed. The two methods (DPPH∗ and FRAP) proved that the three organ extracts of *Pistacia atlantica* possess very remarkable antioxydant activity. These extracts could be exploited as natural antioxidants against the oxidation phenomenons and the oxidative stress in several fields (food, cosmetic, pharmaceutic, and others).

1. Introduction

Aromatic and medicinal plants are a reservoir of natural molecules with various biological properties. These properties depend on the presence of various bioactive agents belonging to different chemical classes [1]. The genus *Pistacia* comprises 14 species that are divided into two monophyletic sections: *Pistacia* section and *Lentiscus* section [2]. Three endemic species of *Pistacia* colonize the Moroccan territory (*Pistacia lentiscus*, *Pistacia therebintus*, and *Pistacia atlantica*) [3].

Pistacia atlantica is a 15-20 m tall forest tree with a large crown. Its trunk is short and can reach 1 m in diameter, and its bark is chapped [4]. The deciduous alternate and imparipinnate leaves are composed by 7 to 9 oval and lanceolate leaflets. The flowers are arranged in clusters and devoid of corolla [5]. The fruit is a globose red drupe that becomes black of barely 5 to 6 mm. The Atlas pistachio or *Pistacia atlantica*, under the name Lbtam in Arabic and Ijj in Tamazight, is very well known to the Moroccan population because of its therapeutic virtues. It is found in semiarid or steppe areas, solitary or in association with *Ziziphus lotus* and Pinus halepensis [6].

Indeed, many studies mention the therapeutic use of this tree by the Moroccan local population. For example, the

floristic and ethnobotanical study of the medicinal flora, carried out in Khenifra city by Hachi et al. [7], has shown that Pistacia atlantica leaves decoction is indicated for the treatment of gastrointestinal pain and diabetes. Another ethnobotanical study on aromatic and medicinal plants (PAM), conducted by our research team in the same region (Kenifra-Middle Atlas) [8], showed that this tree is ranked fifth by the local population as a species of a therapeutic use. The fruit's kernel is edible and used, in powder, against the stomach diseases [9].

Another study by El Hassani et al. indicated that this species is externally used against eczema, and the gum of this plant is used in decoction against cough and asthma [10]. Another study mentioned that the gum infusion is used in washing for disinfection and cleaning of cutaneous leishmaniasis, and that the oil, extracted from the fruits, is used as cicatrizing [11].

The present work concerns the phytochemical study and the antioxidant activity evaluation of three organs from *Pistacia atlantica* Desf. from Khenifra region, Middle Atlas. The objective of this study is to characterize secondary metabolites and to quantify the polyphenol, flavonoid, and condensed tannin contents of the leaves, the fruits, and the bark of *Pistacia atlantica* Desf. Furthermore, their antioxidant capacity by the DPPH∗ and the FRAP methods was evaluated. The resin of this tree will be the subject of the next publication.

2. Experimental

2.1. Plant Material. The leaves, fruits, and bark of *Pistacia atlantica* Desf. were harvested in the rural commune of El Hammam (Khenifra, MiddleAtlas, Morocco) at their flowering period during May 2017, then they were dried at shade for ten days. The botanical identification of the species was carried out at the Floristic Laboratory of the Scientific Institute in Rabat.

2.2. Phytochemical Screening of the Three Organs of Pistacia atlantica Desf. The phytochemical screening is a qualitative study based on coloring and precipitation reactions using specific chemical reagents. It was performed on the extracts of three organs from *Pistacia atlantica* Desf. (leaves, fruits, and bark). These characterization tests of different chemical groups were performed according to the protocol of (Dohou et al., 2003; Judith, 2005; Bruneton, 2009 and N'Guessanetal., 2009) [12–15]. The various extracts were obtained using the following solvents: petroleum ether, methanol, ethanol, chloroform, and distilled water.

The search for alkaloids was carried out using Dragendorff and Mayer reagents. Characterization of the catechic tannins was carried out by isoamyl alcohol and hydrochloric acid and gallic tannins by Stiasny's reagent, sodium acetate, and ferric chloride. To detect sterols and triterpenes, acetic anhydride and concentrated sulfuric acid were used. Diluted hydrochloric alcohol, magnesium turnings, and isoamyl alcohol were used to search for flavonoids. Chloroform, diluted ammonia, and hydrochloric acid allowed the detection of quinone substances.

2.3. Extraction and Fractionation of Polyphenols from Pistacia atlantica Desf.

2.3.1. Extraction of the Total Phenolic Compounds by Soxhlet. 30 g of thepowdered plant material from each organ of *Pistacia atlantica* Desf. is placed in a cartridge inside the Soxhlet extraction chamber. The plant material is extracted with 300 ml of methanol/water (70/30) mixture. A total of ten cycles are required for the depletion of the plant material. After filtration, the solvent is removed by vacuum evaporation. The obtained residue constitutes the crude extract of polyphenols (crude E.).

2.3.2. Fractionation of the Total Phenolic Compounds of Pistacia atlantica Desf. Fractionation of the crude polyphenolextracts from *Pistacia atlantica* Desf. was performed according to the Bruneton 2009 protocol with minor modifications [14]. It is based on the sharing of polyphenols, according to their solubility degree, between solvents with increasing polarity. Fractionation of the extracts is carried out using ethyl acetate and n-butanol. In addition to the hydromethanolic crude extract (crude E.), three other fractions are obtained: the ethyl acetate fraction (EthAcE.), the butanolic fraction (butanolic E.), and the remaining residual phase (residual Ph.) (Figure 1). The extracts are kept cold until used.

2.4. Determination of the Total Phenols of Pistacia atlantica Desf. The total phenol content of *Pistacia atlantica* Desf. extracts was determined by the Folin-Ciocalteumethod [16].In a volumetric flask of 100 ml, a quantity of each extract (allowing to obtain a blue color) is mixed with 1.5 ml of Folin-Ciocalteu reagent (10%) and 1.5 ml of sodium carbonate (Na_2CO_3) at 7.5% (m/v). Then, the flask is completed with distilled water. The whole is left for two hours at room temperature, and the reading is performed against a blank using a spectrophotometer (UV mini-1240) at 765 nm. The calibration curve is carried out under the same operating conditions using gallic acid as a positive control. The results are expressed in milligram equivalent of gallic acid per gram of extract (mg EGA/gE).

2.5. Determination of the Total Flavonoids of Pistacia atlantica Desf. The quantification of flavonoids was performed by the colorimetric method adapted by Djeridane et al. [17]. In a 50 ml volumetric flask, 100 μl of each extract is mixed with 20 ml of distilled water, after 5 min, 100 μl of aluminum trichloride ($AlCl_3$) at 10% (m/v) is added. The solutions were adjusted to 50 ml with pure methanol, shaken immediately, kept in the dark for 30 min at room temperature, and then read against a blank using a spectrophotometer (UV mini-1240) at 433 nm. The calibration curve is carried out under the same operating conditions using quercetin as a positive control. The results are expressed in milligram equivalent of quercetin per gram of extract (mg EQ/gE).

2.6. Determination of Condensed tannins of Pistacia atlantica Desf. The amount of condensed tannins is estimated by the vanillin method in an acid medium [18].

To plot the calibration curve, a volume of 3 ml of a vanillin/methanol solution (4% v/v) is added to different

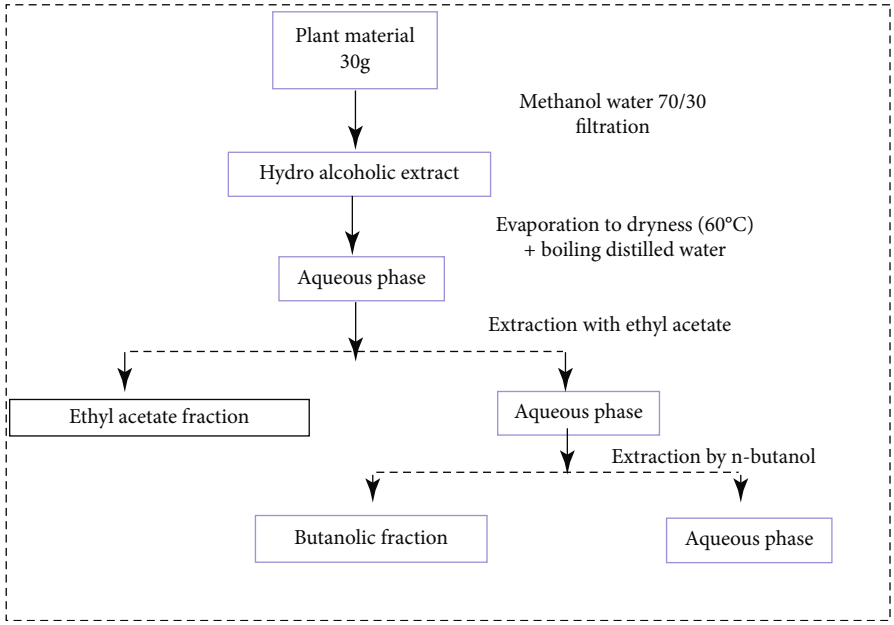


Figure 1: Stages of extraction and fractionation of phenolic compounds.

concentrations of the catechin solution (2 mg/ml). Everything is mixed manually, then 1.5 ml of concentrated hydrochloric acid is added to each concentration. The obtained mixtures are left to react at ambient temperature for 20 minutes. The absorbance is measured at 499 nm against a blank using a spectrophotometer. The amount of condensed tannins in the extracts was performed using the same procedure by replacing catechin with the samples. The concentration of tannins is estimated in milligram equivalent of catechin per gram of extract (mg EC/gE).

2.7. Antioxidant activity of *Pistacia atlantica* Desf. extracts

2.7.1. DPPH∗ Free Radical Scavenging Test. The antiradical activity of the three organs extracts of *Pistacia atlantica* is established by the DPPH∗ method (1,1-diphenyl-2-picryl-hydrazyl) as a relatively stable radical.

The DPPH∗ solution is prepared by solubilizing 2.4 mg of DPPH∗ in 100 ml of ethanol. The extracts are dissolved in ethanol at a rate of 0.475 mg/ml. This mother solution was then diluted to have the following concentrations: (11,81; 23,625; 47,25; 94,5; 141,75; 189; 236,25; 283,5; 330,75; 378; and 475,25 μg/ml). The test is carried out by mixing 200 μl of the testing compound and 2.8 ml of the DPPH∗ solution. The same concentrations were prepared with ascorbic acid (vitamin C) and butylated hydroxyanisole (BHA) to serve as positive controls. Also, a blank was made with only ethanol. The samples are then left in the dark for 30 minutes, and the discoloration is compared to the negative control at 517 nm. The results are expressed as the reduction percentage of DPPH∗ (AA%):

$$\mathrm{AA\%} = \frac{A_{\mathrm{control}} - A_{\mathrm{sample}}}{A_{\mathrm{control}}} \times 100, \quad (1)$$

AA%: Percentage of antiradical activity,

A_{control}: Absorbance of the DPPH∗ solution,

A_{sample}: Absorbance of the sample solutions.

The IC_{50} which is the concentration of the antioxidant that is needed to trap 50% of DPPH in the test solution was determinated from the graph of the absorbance variation on function of the extract concentrations.

The effective concentration (EC_{50}) was expressed in terms of the concentration of sample extract used for the test (mg/ml) and the amount of extract relative to the initial amount of DPPH (mg/mg DPPH).

$$\mathrm{EC}_{50}\left(\frac{\mathrm{mg}}{\mathrm{ml}}\right) = \left[\frac{\mathrm{IC}_{50}(\mathrm{mg/ml})}{\mathrm{Concentration\ of\ DPPH\ (mg/ml)}}\right] \times 100. \quad (2)$$

For rational reasons of clarity, the antiradical power (PAR) was determined to be the reciprocal value of the effective concentration EC_{50} [19].

$$\mathrm{PAR} = \left[\frac{100}{\mathrm{EC}_{50}(\mathrm{mg/ml})}\right]. \quad (3)$$

The correlation between the levels of phenolic compounds and the methods of antifree radical activity was determined by Pearson's coefficient using EXCEL (2013).

2.7.2. Iron Reduction Test: FRAP (Ferric Reducing Antioxidant Power). The ability of phenolic extracts to reduce ferric iron (Fe^{3+}), present in the ferricyanide potassium complex, to ferrous iron (Fe^{2+}) is determined by the method described by Zovko Koncicen et al. [20].In test tubes, 0.5 ml of the aqueous extract at different concentrations (11.81; 23.625; 47.25; 94.5; 141.75; 189; 236.25; 283.5; 330.75; 378; and 425.25 μg/ml) is mixed with 2.5 ml of a

Table 1: Phytochemical screening of the three organs from *Pistacia atlantica*.

Families			*Pistacia atlantica*		
			Bark	Leaves	Fruits
Alkaloids		Mayer	+	++	_
		Dragendorff	+	++	_
Polyphenols	Tannins	Gallic tannins	+	+++	+++
		Cathechic tannins	+++	+++	+++
	Flavonoids	Anthocyanins	_	_	++
		Cyanidine reaction	+++	+++	+++
		Leucoanthocyanins	+++(catechols)	+++	++(catechols)
Free anthracene derivatives			_	_	_
Combined anthracene derivatives		O-heterosides	++	++	++
		C-heterosides	_	+	+++
Sterols and triterpenes			+++	+++	+++
Mucilages			+++	_	+++
Saponosides			_	_	_
Cardiotonic heterosides			_	++	_
Carotenoids			_	_	-/+
Oses and holosides			+++	+++	+++
Quinones			_	_	_

0.2 M phosphate buffer solution (pH = 6.6) and 2.5 ml of a 1% $K_3Fe(CN)_6$ potassium ferricyanide solution.

The whole is incubated in a water bath at 50°C for 20 min. Then, 2.5 ml of 10% trichloroacetic acid is added to stop the reaction. The whole is centrifuged at 3000 rpm for 10 min. 2.5 ml of the supernatant of each concentration is then mixed with 2.5 ml of distilled water and 0.5 ml of the 0.1% aqueous $FeCl_3$ solution. The absorbance is read at 700 nm against a similarly prepared blank, by replacing the aqueous extract with distilled water, which makes it possible to calibrate the apparatus (UV-VIS spectrophotometer). The positive control is represented by standard solutions (ascorbic acid, BHA, and BHT), of which absorbance has been measured under the same conditions as the samples. An increase in absorbance corresponds to an increase in the reducing power of the tested extracts.

3. Results and Discussions

3.1. Phytochemical Screening. In this study, phytochemical tests were performed on the three organs extracts from *Pistacia atlantica*, in order to highlight the different classes of secondary metabolites constituting this medicinal tree.

These tests are based on solubility tests, coloring, and precipitation reactions, as well as examinations in ultraviolet.

The results of the analyzed chemical groups are shown in Table 1.

The results of the phytochemical characterization tests made it possible to highlight the presence of flavonoids, tannins, sterols, triterpenes, oses, and holosides. Also, these tests showed the absence of anthocyanins, free anthracene derivatives, quinones, saponosides, and carotenoids. Alkaloids and mucilage are absent in the fruits and the leaves, respectively.

The presence of chemical compounds, such as polyphenols, flavonoids, tannins, sterols, and polyterpenes in the organs of *P. atlantica*, suppose that these organs have very important biological activities. Indeed, food polyphenols are of considerable interest because of their antioxidant and anticarcinogenic properties [21]. Flavonoids exert a very broad spectrum of biological and pharmacological activities including antitumor, antioxidant, vasculoprotective, anti-inflammatory, antihepatotoxic, antiallergic, and antiulcerous activities [22], while tannins are endowed with antimicrobial [23, 24, 25] and antioxidant activities [26].

The polyphenolic compounds being the most represented in the organs of *Pistacia atlantica*, and probably the most important in the traditional remedies, this research was progressed by determining the contents of these polyphenolic compounds in the three organs of *P. atlantica*.

3.2. Determination of Total Phenols. The total phenol contents of leaves, fruits, and bark extracts of *P. atlantica* are grouped in Figure 2. The values are expressed in mg equivalent of gallic acid per g of extract (mg EGA/g E).

The results of Figure 2 show that the different extracts, obtained from the leaves, the fruits, and the bark, are rich in total phenols. Polyphenol contents of these organs vary between 723 and 203.78 mg EGA/gE.

The fruits are the richest in total phenols, followed by the bark and then the leaves. The raw extracts record the highest contents.

The evaluated polyphenol content in the leaves crude extract is 560 mg EGA/gE, and for the fruit, this value is

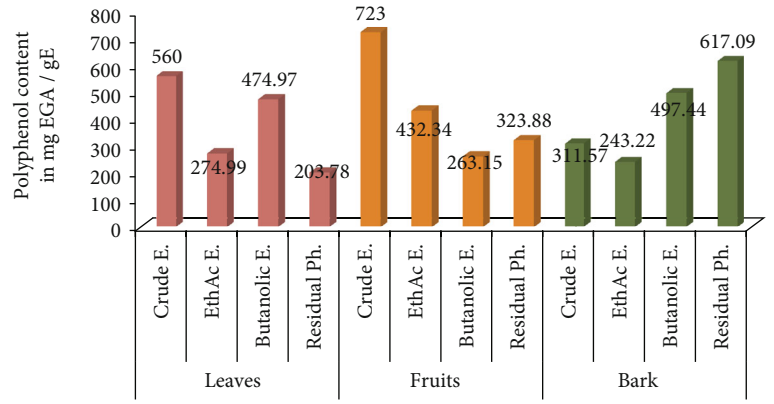


Figure 2: Polyphenol content in mg EGA/gE of *Pistacia atlantica* Desf. extracts.

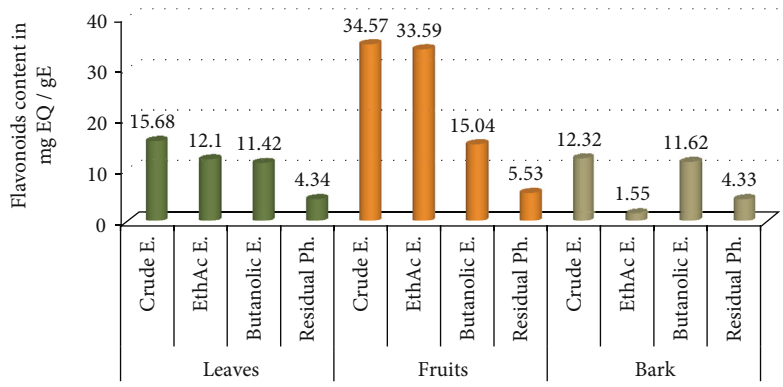


Figure 3: Flavonoids content of three organs from *Pistacia atlantica* Desf. in mg equivalent quercetin per gram of extract.

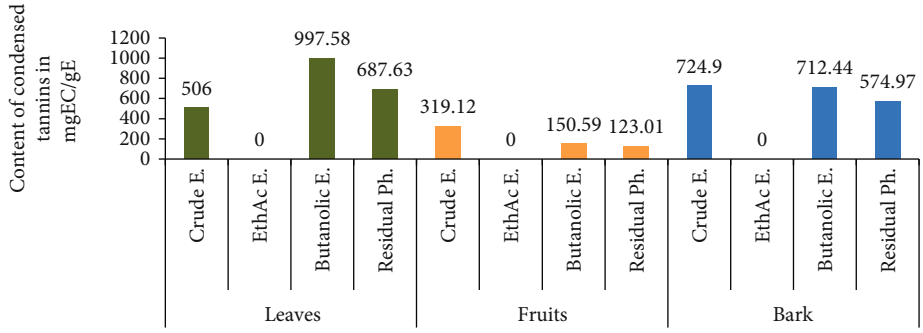


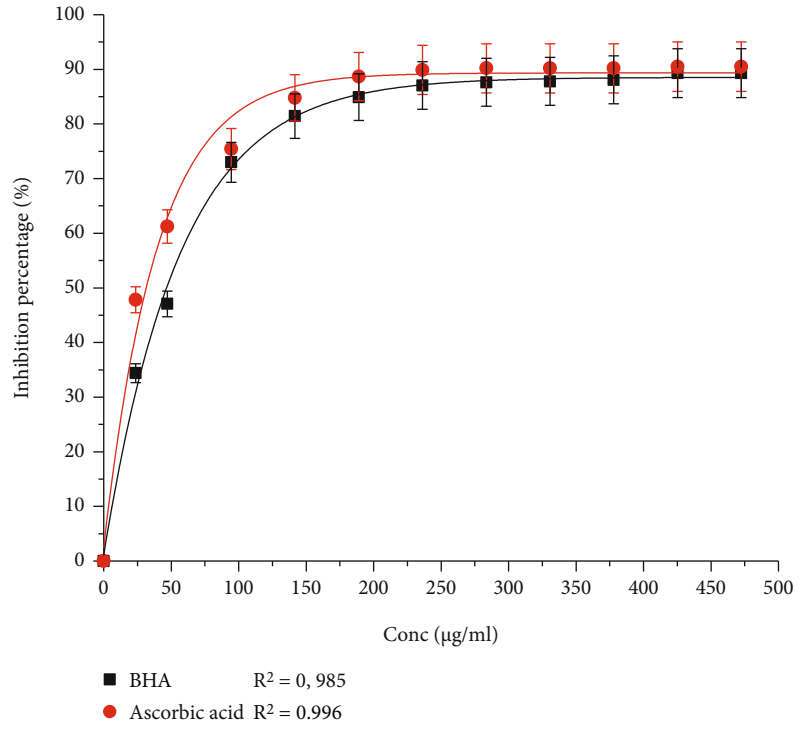
Figure 4: Content of condensed tannins in mgEC/gE.

723 mg EGA/gE. For the bark, the highest polyphenols are recorded in the residual aqueous phase (617.09 mg EGA/gE).

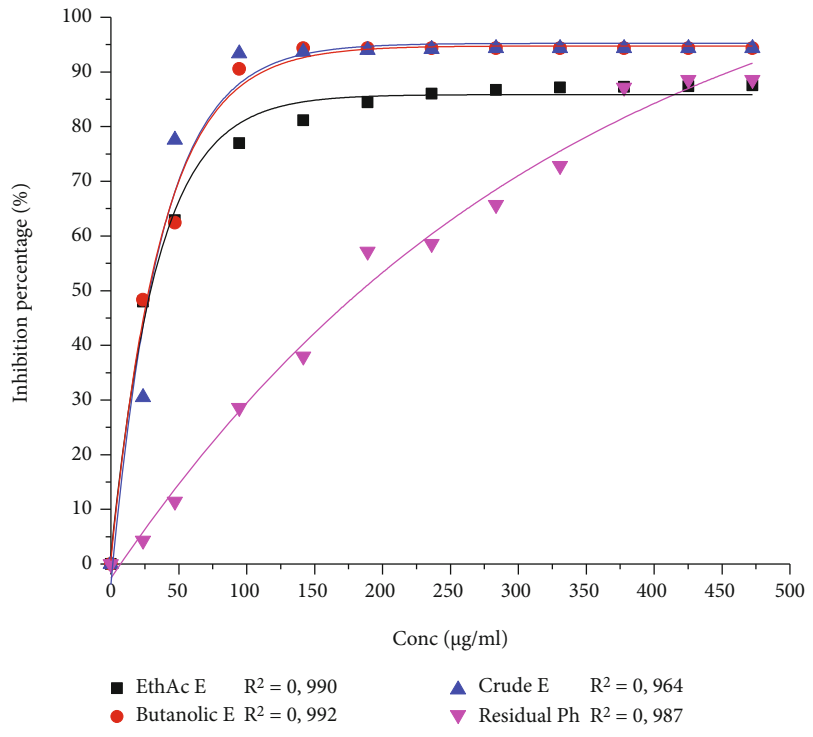
For fractioned extracts obtained from different parts of P. atlantica using the liquid-liquid extraction of crude extracts, the highest total phenols were detected in the butanolic extract of the leaves and the bark, 474.97 mg EGA/gE and 497.44 mg EGA/gE, respectively, while in the fruit, it is the ethyl acetate fraction that registered the highest amount of polyphenols (432.34 mg EGA/gE).

These results confirmed that the fruits are still very rich in total phenols. Indeed, the fruits represent one of the main sources of polyphenols. Also, their concentration is influenced by the degree of maturity of the fruit [27]. Another study of ten medicinal plants from Algeria reported that the fruits of *Pistacia atlantica* are rich in total phenols. In that study, the recorded level (285,956 mg EAG/g DM) was the highest compared to the other studied plant extracts [28]. The richness of *Pistacia atlantica* in polyphenols could help to justify its use in traditional medicine.

3.3. Determination of Flavonoids. The flavonoid assay results are shown in the histogram of Figure 3, and the flavonoid



(a)



(b)

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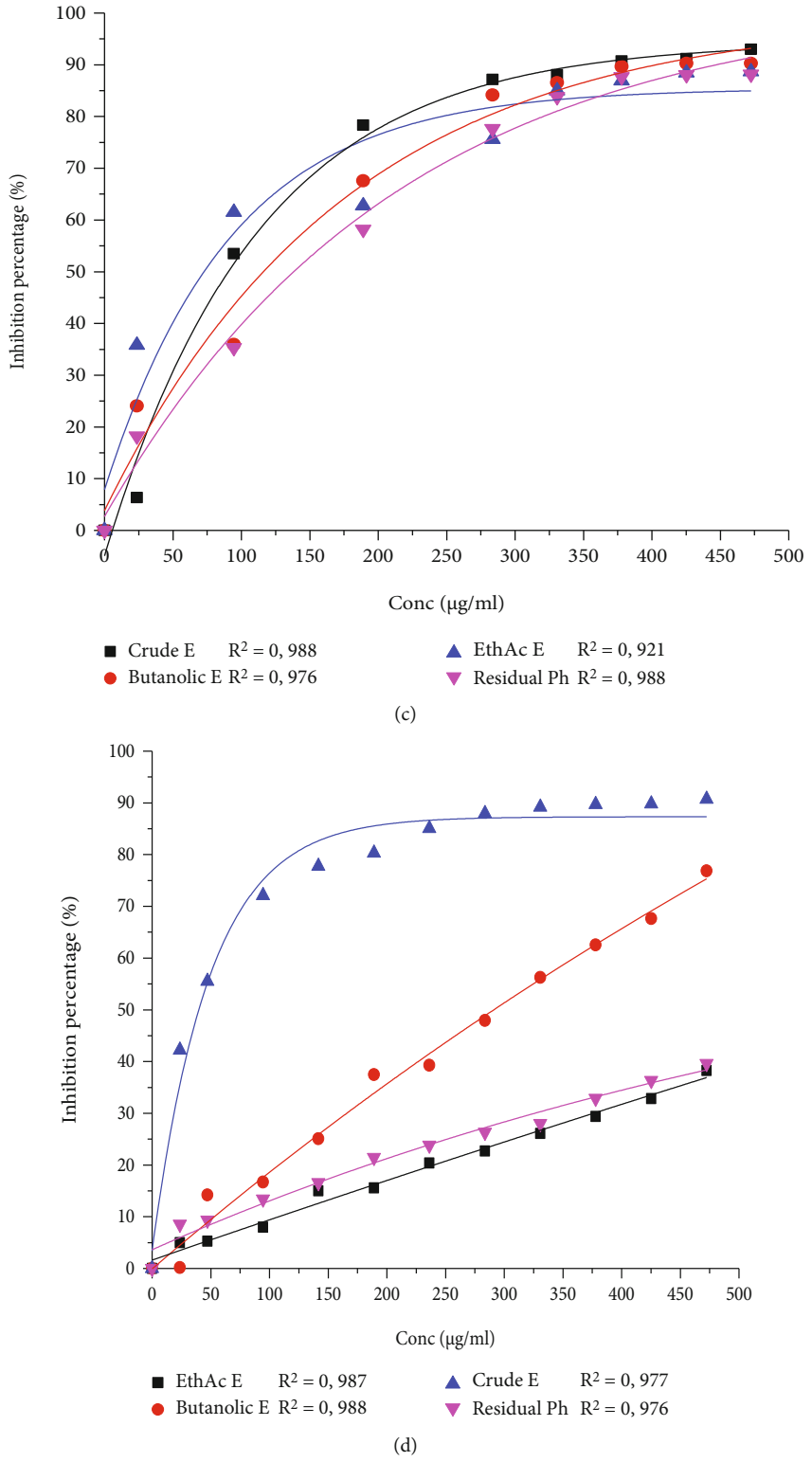


Figure 5: Inhibition Percentage of *Pistacia atlantica* extracts: reference standards (a), leaves (b), fruits (c), and bark (d).

content is expressed in milligrams equivalent of quercetin per gram of extract (mg EQ/gE).

The results show that the content of total flavonoids differs from one extract to another and from one plant to another. The highest flavonoid contents were recorded in the crude extract and the ethyl acetate fraction from the fruits of *P. atlantica*.

Also, the obtained results prove that the fruits of *P. atlantica* still have the highest levels of total flavonoids compared to the two other organs.

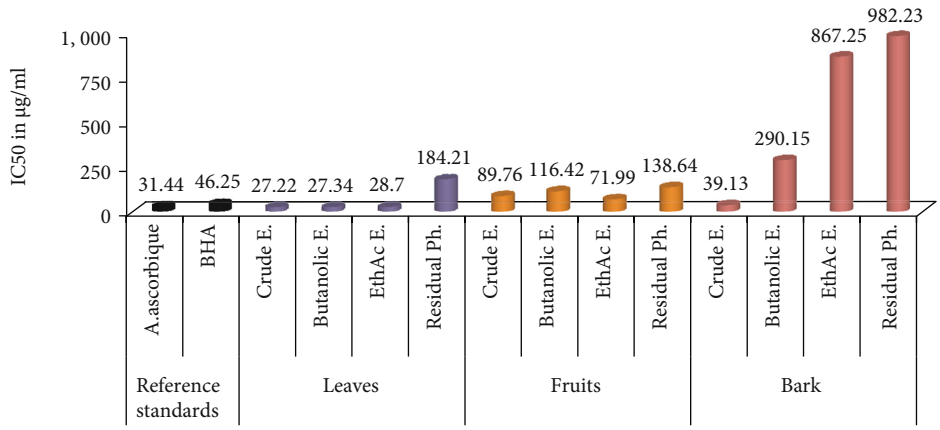


Figure 6: Inhibitory concentrations of 50% of free radicals DPPH (IC50 in μg/ml).

3.4. Determination of Condensed Tannins. The results for condensed tannins content are shown in Figure 4. These results are expressed in mg equivalent catechin per gram of extract (mg EC/gE). The analysis of this figure reveals that *P. atlantica* leaves are rich in condensed tannins. The butanolic extract has the highest content (997.58 mgEC/gE), followed by the residual phase (687.63 mg EC/gE), then the crude extract (506 mgEC/gE).

The bark of *P. atlantica* contains high levels of condensed tannins. The obtained values with the bark are particularly important for the crude extract (724.9 mg EC/gE) and the butanolic extract (712.44 mg EC/gE).

For *P. atlantica*'s fruits, the raw extract (crude E.) has the highest content (319.12 mgEC/gE), followed by the butanolic extract (150.59 mg EC/gE).

It can be deduced that ethyl acetate is not an adequate solvent for the extraction of condensed tannins. These results are comparable to those of Boutalbi who found that the condensed tannins are absent in the ethyl acetate extracts, in the trichloromethane extracts, and in the aqueous extract. On the other hand, they are present in the methanolic and butanolic extracts for *Arthrospira platensis* [29].

The obtained contents are different from one organ to another and from one extract to another. These variations could suggest a variability of the molecules affinity towards solvents.

3.5. Antioxidant Activity

3.5.1. Antiradical Activity by DPPH∗ (2,2′-Diphenyl-1-Picrylhydrazyl)

(1) Determination of the Inhibition Percentage. The results of antiradical activity of leaves, fruits, and bark extracts of P. atlantica are presented respectively in Figures 5(b), 5(c), and 5(d), as well as the reference standards Figure 5(a). It appears that the inhibition percentage of the free radical increases with increasing concentrations for either reference standards or extracts.

It is remarkable that the crude extract and the butanolic fraction of the leaves have very high inhibition percentages (94.31% and 94.31%, respectively) compared to those of the reference standards (ascorbic acid and BHA), followed by the residual phase (88.57%), and finally the ethyl acetate fraction which inhibits 87.53% of the DPPH∗.

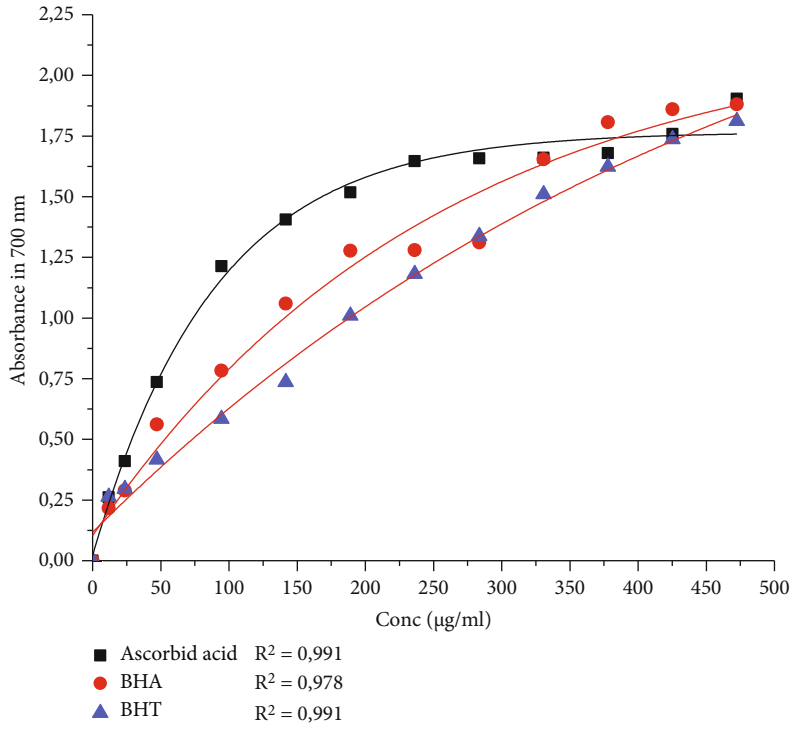
The fruit extracts have significant inhibition percentages when compared with those of the reference standards. Indeed, the crude extract has an inhibition percentage of 93.00%, followed by the butanolic extract (90.26%), then the ethyl acetate extract (88.70%), and finally the residual fraction (88.18%).

The bark has a weaker antioxidant power than those of the leaves and the fruits. The same concentrations of the ethyl acetate extract and the residual phase cannot reach 50% of inhibition.

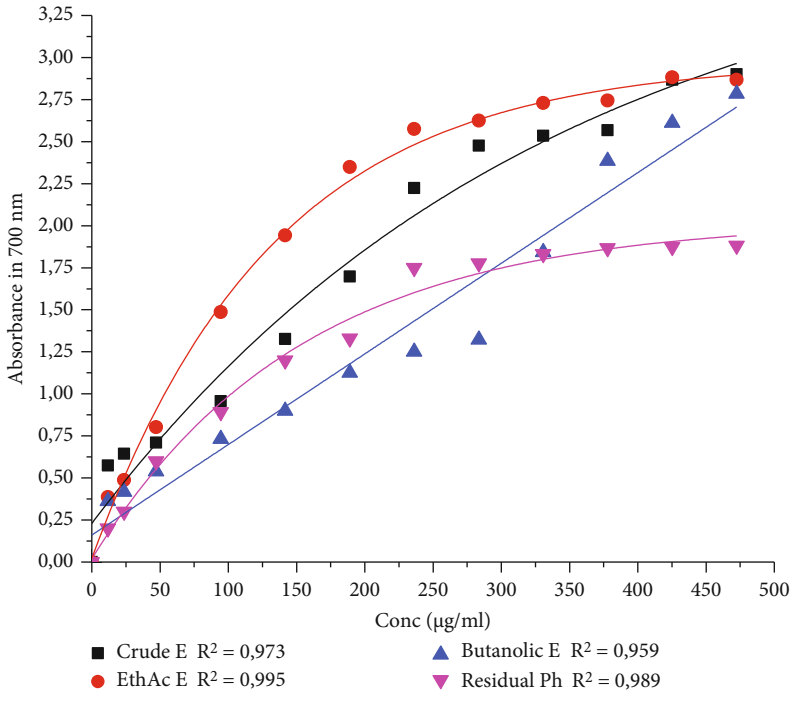
(2) Determination of the Inhibitory Concentration of 50% of Free Radicals IC_{50}. The inhibitory concentration of 50% of free radicals (IC_{50}) is inversely linked to the antiradical capacity of a compound. It expresses the antiradicals quantity required to decrease the free radical concentration by 50%. The lower the IC_{50} value is, the greater the antiradical activity of a compound.

The IC_{50} values of the standards and the extracts are presented in Figure 6. The leaf extracts showed very low inhibitory concentrations when compared to those of the reference standards (ascorbic acid 31.44 μg/ml and BHA 46.25 μg/ml). The crude extract gave an IC_{50} of 27.22 μg/ml, followed by butanolic extract (27.34 μg/ml) and the ethyl acetate extract (28.7 μg/ml). The highest IC_{50} is recorded by the residual phase (84.21 μg/ml). For fruits extracts have significant inhibitory concentrations. The ethyl acetate extract has an IC_{50} of 71.99 μg/ml, followed by the crude extract with an IC_{50} of 89.76 μg/ml, and finally the butanol extract and the residual phase with IC_{50} of 116.42 and 138.64 μg/ml, respectively. The crude extract of the bark has a very low IC_{50} about 39.13 μg/ml, while the other extracts recorded very high inhibitory concentrations compared to the standards and extracts of leaves and fruits.

It is remarkable that the leaves showed an antioxidant power highly superior to those of fruits and the bark. It is also found that the crude extracts of the leaves, fruits, and bark revealed the lowest IC_{50} compared to the other



(a)



(b)

Figure 7: Continued.

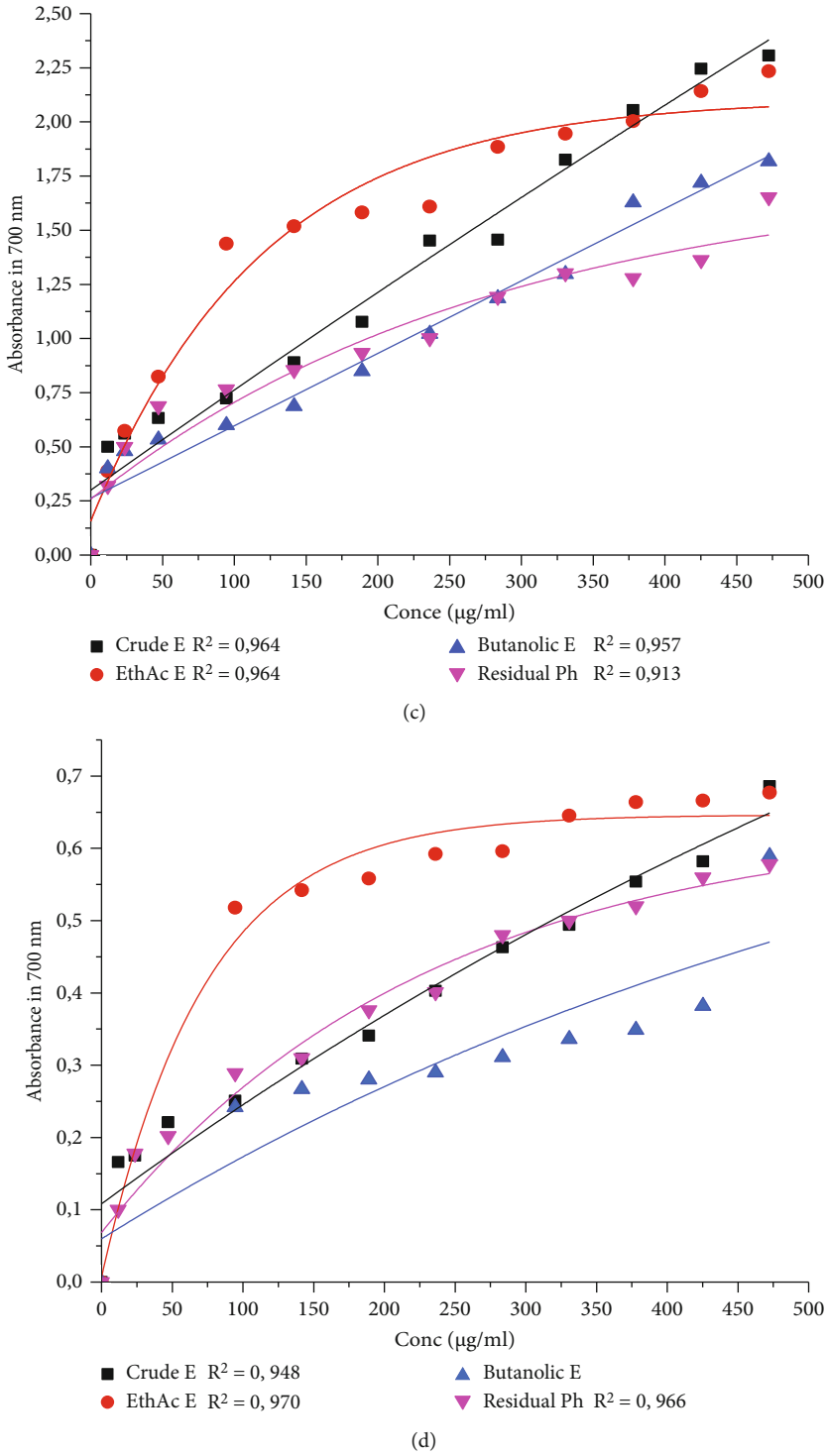


Figure 7: Iron reduction by *Pistacia atlantica* and reference standards: (a) standards, (b) leaves, (c) fruits, and (d) bark.

fractions of each organ. These results could be explained by the existence of a molecular synergy between the phenolic compounds in the crude extracts.

(3) Iron Reduction Test (Ferric Reducing/Antioxidant Power Assay). The results of antioxidant activity evaluated by the iron reduction "FRAP" method of leaves, fruits, and bark extracts of P. atlantica are indicated respectively in Figures 7(b), 7(c), and 7(d), as well as the reference standards Figure 7(a).

The crude extract (crude E), the butanolic extract (butanolic E), and the ethyl acetate extract (EthAc E) of the leaves showed a greater ability to reduce iron than those of ascorbic acid, BHA, and BHT. As for the bark and fruits extracts, there capacity for reducing iron is much lower than the one of ascorbic acid, BHA, and BHT.

Table 2: Linear correlation coefficients (R^2) between the content of phenolic compounds and the antioxidant activity of the extracts studied.

			TPT	TFT	ARP(DPPH)	$1/EC_{0,5}$(FRAP)
P. atlantica	Leaves	TPT	1	0,42	0,44	0,49
		TFT		1	0,92	0,6
		ARP(DPPH)			1	0,3
		$1/EC_{0,5}$(FRAP)				1
	Fruits	TPT	1	0,43	0,5	0,98
		TFT		1	0,82	0,57
		ARP(DPPH)			1	0,57
		$1/EC_{0,5}$(FRAP)				1
	Bark	TPT	1	-0,17	-0,6	-0,86
		TFT		1	0,71	-0,003
		ARP(DPPH)			1	0,36
		$1/EC_{0,5}$(FRAP)				1

The antioxidant activity by FRAP confirmed that the leaves and fruits of *Pistacia atlantica* have a very important antioxidant power than that of standard molecules (ascorbic acid, BHA, and BHT).

(4) Correlation between the Content of Phenolic Compounds and Activity Methods. All the results of the determination of phenolic compounds and antioxidant activities (DPPH and FRAP) indicate that the extracts have significant antioxidant potential while noting the highest contents of polyphenols and flavonoids. Therefore, there are proportional relationships between antioxidant activities and total polyphenols. To characterize better these possible relationships between the different variables, the correlation coefficients were calculated (Table 2).

The analysis of the results summarized in Table 2 and Figures 2–3 shows that the antioxidant power of the extracts depends on the quality of the phenolic compounds especially the flavonoids which are more endowed with antiradical power compared to other phenolic compounds.

In spite of the fact that the fruits had the highest content of flavonoids, the leaves showed a stronger antioxidant power, and we can thus conclude that the antioxidant power depends of the quality and quantity of the flavonoid molecules present in the extract studied.

Generally, the antioxidant activity of an extract depends mainly on the nature of the compounds it contains, their vulnerability to the treatment they undergo during the extraction process, and the selectivity of the solvent to extract certain groups of antioxidants. Typical phenolic compounds which possess antioxidant activity are mainly phenolic acids and flavonoids [30].

Moreover, the antioxidant power by the leaves of *P. atlantica* may be due to the richness of the phenolic compounds that are known by antioxidant properties. Furthermore, Khiya et al. [31] found that the leaves of *P. atlantica* harvested including the region of Khenifra (Morocco) characterized by the presence of ascorbic acid, gallic acid, 4-hydrobenzoic acid, and tannic and rutin in the methanolic and ethanolic extracts. In the ethyl acetate fraction, they identified gallic acid, protocatechic acid, 4-hydrobenzoic acid, chlorogenic acid, vanillic acid, ferric acid, tannic acid, rutin, rosmarinic acid, myrcetin, and luteolin. In addition, Yousefi et al. [32] found that the fruits and leaves of *P. atlantica*, collected in Algeria, contain the derivatives of benzoic acids, luteolin, and gallic acid, but the leaves are characterized by the amount of benzoic acid derivatives (92%) and fruits are characterized by flavonoids (95%). In addition, *P. atlantica* collected in Egypt contains kaempferol-3-glucoside, quercetin-3-glucoside, quercetin-3-galactoside, quercetin-3-rutinoside, and quercetin-3-glucoside-7-galactoside [33]. Several authors have reported that antioxidant molecules such as ascorbic acid, tocopherol, flavonoids, and tannins act as donors of hydrogen atoms or electrons [34, 35]. Luteolin is well known for its anti-inflammatory and antioxidant activity, and gallic acid has been introduced as antioxidant compounds [36].

4. Conclusion

The present study has highlighted the richness of the three organs (leaves, fruits, and bark) of *P. atlantica* in polyphenols, flavonoids, and condensed tannins. It has also shown that the antiradical activity is a function of the quality and quantity of flavonoids present in the extract. In the same way, this study confirmed that *P. atlantica* leaves have excellent antiradical properties and therefore justify their excessive use in the traditional herbal medicine to treat several diseases.

Data Availability

The authors confirm that all data underlying the findings of this study are fully available without.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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