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In Vitro Evaluation of Stem Extracts and Essential Oils from Sawdust of *Cedrus atlantica* (Endl.) G. Manetti ex Carrière for their Photoprotective and Antihyperglycemic Activities

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ABSTRACT

Cedrus atlantica commonly called Atlas cedar, is a prominent forest tree with numerous medicinal values. This study aimed to evaluate the photoprotective and *in vitro* antihyperglycemic activities of stem extracts and essential oils from sawdust of *Cedrus atlantica*. The extracts of *C. atlantica* (cyclohexane, ethyl acetate, ethanol, aqueous) and its essential oils (H0, H1, H2) were assessed for their ability to absorb ultraviolet (UV) rays (UVA and UVB) and to inhibit the enzymes α-amylase and α-glucosidase. Zinc oxide served as a positive control for UV absorption, while acarbose was used as the standard for enzyme inhibition assays. The results revealed strong photoprotective potential for *C. atlantica* extracts. F1 and F3 were the most effective for UVA absorption, with absorbance values of 1.968 ± 0.001 and 1.820 ± 0.017, respectively. For UVB absorption, F3 and F4 had the highest absorbance values (2.019 ± 0.010 and 2.120 ± 0.001, respectively). All extracts showed higher SPF values than zinc oxide (12.62 ± 0.02), with F1 (SPF = 20.48 ± 0.10) and F2 (SPF = 20.40 ± 0.07) showing the best results. Essential oils exhibited much lower photoprotective activity. In the antihyperglycemic assays, F2 showed the highest α-amylase inhibition (IC_{50} = 95.90 ± 0.02 µg/mL), while F1 exhibited the strongest α-glucosidase inhibition (IC_{50} = 27.50 ± 0.24 µg/mL). The essential oil fraction H1 was also active, outperforming acarbose in both assays. These findings suggest that *C. atlantica* has promising potential as natural sunscreen and antidiabetic therapies. Further research is needed to identify active compounds.

Keywords: Cedrus atlantica, Photoprotective activity, Antihyperglycemic activity, α-Amylase inhibition, α-Glucosidase inhibition, Essential oils.

Introduction

The search for natural remedies with sun protective effect, and for use in the management of chronic diseases, such as type 2 diabetes, has become an area of growing interest in modern medicine and cosmetology.[1] Type 2 diabetes is a chronic metabolic disorder characterized by insulin resistance and an inadequate compensatory insulin secretion, leading to sustained hyperglycemia. It is one of the most prevalent metabolic diseases globally, associated with complications such as hyperlipidemia, cardiovascular diseases, and increased mortality.[2,3] Ultraviolet (UV) radiation - emitted primarily by the sun, but also by artificial sources such as tanning beds and certain industrial equipment is a major factor contributing to premature skin aging, DNA damage, and the development of skin cancers.[4,5] UVA rays penetrate deeper into the skin and accelerate aging, while UVB rays primarily cause sunburn and direct DNA damage. Consequently, the development of therapeutic and preventive agents against UV radiation-induced damage that are both effective and safe has become a public health priority.[6]

Cedrus atlantica (Endl.) G. Manetti ex, commonly known as Atlas cedar, is a prominent forest tree native to North Africa. It belongs to the Pinaceae family, the Abieteae subfamily, and the *Cedrus* genus,[7] and is one of the most commercially and environmentally important plants in the Mediterranean highlands of Morocco. In traditional medicine, *Cedrus atlantica* (*C. atlantica*) is used to treat a variety of conditions. Different parts of the plant, including its essential oils and extracts, are used for the management of parasitic infections in animals, cancer, cellulite, stress, anxiety, and tension.[8] Studies have highlighted the anti-inflammatory properties of *C. atlantica* and its effectiveness in relieving symptoms of hay fever.[9] Furthermore, *C. atlantica* has been shown to have mucolytic properties and is utilized for conditions such as catarrh, chronic bronchitis, and cough. It also proves beneficial in the treatment of cystitis and urinary tract infections,[8,9] as well as for hair and skin care, particularly for oily skin, dandruff, seborrhoea of the scalp, and acne.[8,9] Phytochemical investigation has revealed that *C. atlantica* contains various bioactive compounds, including sesquiterpene hydrocarbons, monoterpene hydrocarbons, and oxygenated monoterpenes.[10–13] Numerous studies have examined the biological activities of extracts and essential oils from various parts of this plant, and results have demonstrated antibacterial,[13–15] anticancer,[13,16–18] analgesic,[19] antifungal,[20–22] antiparasitic,[23–26] and antioxidant properties.[8,13,27,28] However, the photoprotective and antihyperglycemic

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properties of *C. atlantica* extract remain largely unexplored, despite the therapeutic potential of this plant.
The objective of this study is to evaluate the photoprotective and *in vitro* antihyperglycemic activity of stem extracts and essential oils from sawdust of *C. atlantica*, specifically their ability to absorb UV radiation and inhibit key digestive enzymes (α-amylase and α-glucosidase), with the goal of exploring their potential as natural alternatives for sun protection and type 2 diabetes management.

Materials and Methods

Plant materials
The stems and wood sawdust of *C. atlantica* were collected from the Atlas Mountains, specifically in the Ifrane region of Morocco (geographical coordinates: 33° 29' 54.2" N, 5° 08' 06.2" W), in October 2021. The plant material was authenticated at the Scientific Center of Rabat, where a specimen was deposited at the institute's herbarium under the reference specimen number RAB114017.
The stems were dried in the shade under stable ambient temperature to ensure uniform dehydration. The dried plant materials were then ground into fine powder (<25 µm) to optimize extraction and analysis.

Preparation of extracts
The powdered stems of *C. atlantica* (50 g) were placed in a cotton cellulose cartridge and subjected to sequential extraction with 400 mL of various solvents (cyclohexane F1, ethyl acetate F2, and ethanol F3, in that order) using a Soxhlet apparatus. The extraction process lasted 6 hours for cyclohexane and 8 hours for both ethyl acetate and ethanol. The appearance of colorless solvents in the siphon tube marked the end of the extraction for each solvent.
Subsequently, the residual plant materials were subjected to maceration (F4) in 1 L of distilled water at room temperature for 8 hours in the dark to preserve compounds sensitive to light and heat. The crude extracts were filtered using Whatman filter paper to remove solid impurities.[29]
The filtrates were then concentrated using a rotary evaporator (GREATWALL R-1001 Rotavapor WB-2000, China) at reduced pressure. The water bath temperature was maintained between 35 and 40°C to prevent thermal degradation of volatile compounds, while the rotation speed was set at 120 rpm to ensure efficient solvent evaporation. The concentrated aqueous extract was frozen at -60°C and then lyophilized to obtain a powdered extract. The concentrated extracts were stored at 4°C until further use.

Extraction of essential oil
The essential oil (H0) was extracted via hydrodistillation of wood sawdust of *C. atlantica* using a Clevenger-type apparatus (MEYER-WARNOD, 1984). For each trial, 150 g of raw material were mixed with 750 mL of distilled water in a 1-liter flask equipped with a 60 cm cooling column. The mixture was boiled at 100ºC and maintained at this temperature for 6 hours. The essential oil (H0) obtained was stored at 4°C for subsequent experiments.

Fractionation of essential oil
The essential oil (H0) was fractionated using a B-585 glass bead oven, separating the volatile components into distinct fractions. This process yielded two fractions, H1 and H2. The fractionation process involved placing all the glass beads into the oven, then 15 mL of the essential oil was introduced into the glass beads and subjected to boiling at 180°C (H1) and 200°C (H2) for 5 minutes each. The procedure was repeated three times. The crude essential oil and the recovered fractions were stored at 4°C until further use.[30]

Evaluation of photoprotective activity
Ultraviolet absorption test
The ultraviolet (UVA and UVB) absorption test of *C. atlantica* extracts (F1, F2, F3, and F4) and essential oils (H0, H1, and H2) was performed following the method described by Lee *et al*. (2011).[31] The ethanol and aqueous extracts at a concentration of 10 mg/mL were solubilized in distilled water, while the cyclohexane and ethyl acetate extracts (10 mg/mL) were solubilized in dimethyl sulfoxide (99%). Essential oils were dissolved in acetone. For each extract and essential oil, absorbance was measured using a UV-Vis spectrophotometer (UV-6300PC) at 300 nm (UVB) and 365 nm (UVA) and compared to zinc oxide (ZnO) at 5% and methyl salicylate (SAM) at 100 µg/mL, used as reference standards. The test was conducted in triplicate.

Determination of Sun Protection Factor (SPF)
The *in vitro* photoprotective effect of *C. atlantica* extracts was evaluated according to the method described by Goudjil *et al*. (2021).[32] The absorbance of the extracts at a concentration of 2 mg/mL was measured across wavelength range of 290 to 320 nm, with 5 nm intervals. Zinc oxide (2 mg/mL) was used as a reference standard to compare the photoprotective effects of the extracts. The Sun Protection Factor (SPF) was calculated using the Mansur equation (1). The EE(λ) × I(λ) values (Table 1) determined by Goudjil *et al*. (2021)[32]were incorporated into Equation (1). Each sample was tested in triplicate.

$$SPF = FC \times \sum_{290}^{320} EE(\lambda) \times I(\lambda) \times Abs(\lambda) \quad \text{..... (1)}$$

Where;
EE(λ) = Erythemal effect spectrum,
I(λ) = Solar intensity spectrum,
Abs(λ) = Absorbance at wavelength λ
FC = Correction factor (10).

Table 1: Standardized product function used in the calculation of Sun Protection Factor (SPF)

Wavelength (nm)	EE x I (normalized)
290	0.015
295	0.0817
300	0.2874
305	0.3278
310	0.1864
315	0.0839
320	0.018

Evaluation of in vitro antihyperglycemic activity
α-Amylase inhibitory activity
The α-amylase inhibitory activity of different concentrations of the extracts and essential oils was determined using the starch-iodine method described by Chakrabarti *et al*. (2014),[33] with slight modifications. Briefly, 250 µL of the sample (extracts/essential oils) or acarbose was mixed with 100 µL of phosphate buffer (20 mM, pH 6.9) containing the α-amylase enzyme. The mixture was incubated at 37°C for 10 minutes, followed by the addition of 600 µL of starch substrate (1%). The reaction mixture was re-incubated at 37°C for another 10 minutes. At the end of the reaction, 250 µL of hydrochloric acid (HCl) solution and 100 µL of iodine solution were added. Absorbance was measured using a spectrophotometer at 630 nm. The results were calculated as a percentage using the formula:

$$\%\ Inhibition = 1 - \frac{A\ sample}{A\ control} \times 100 \quad (2)$$

α-Glucosidase Inhibitory activity
The α-glucosidase inhibitory activity of different concentrations of extracts and essential oils was determined using the substrate p-nitrophenyl-α-D-glucopyranoside (pNPG), which is hydrolyzed by α-glucosidase to release p-nitrophenol (a coloured compound that can be measured at 405 nm). The inhibition of α-glucosidase was assessed according to the method described by Kee *et al*. (2013).[34] Briefly, a mixture of 150 µL of the sample (extracts/essential oils) or acarbose and 100 µL of 0.1 M sodium phosphate buffer (pH 6.7) containing the α-glucosidase enzyme (0.1 U/mL) was incubated at 37°C for 10 minutes. After preincubation, 200 µL of 1 mM pNPG solution in 0.1 M sodium phosphate buffer was added. The reaction mixtures were incubated at 37°C for 30 minutes. After incubation, 1 mL of 0.1 M Na_2CO_3 was added, and absorbance was measured at 405 nm using a

spectrophotometer. The percentage inhibition was calculated using the following formula:

$$\% \ Inhibition = \frac{(AC - ACb) - (AS - ASb)}{(AC - ACb)} \times 100 \ (3)$$

Where;
A_C = Absorbance of the control (enzyme and buffer)
A_{Cb} = Absorbance of the control blank (buffer without enzyme)
A_S = Absorbance of the sample (enzyme and inhibitor)
A_{Sb} = Absorbance of the sample blank (inhibitor without enzyme)

Statistical analysis
Statistical analysis was performed using GraphPad Prism v8 software. The data were presented as the mean ± standard deviation of three replicates. The data were subjected to one-way analysis of variance (ANOVA). Differences between mean values were compared using Tukey's post hoc test at a significance level of $p < 0.05$.

Results and Discussion

Photoprotective activity
Ultraviolet absorption
The evaluation of the dermoprotective activity of *C. atlantica* extracts (F1, F2, F3, and F4) and essential oils (H0, H1, and H2) was performed through UVA and UVB absorption tests. The results are summarized in Table 2.

Table 2: Absorbance values of C. atlantica extracts and essential oils, methyl salicylate and zinc oxide

	Absorbance	
Extract and Standard	**UVA**	**UVB**
F1	1.968 ± 0.001^{a}	1.968 ± 0.001^{a}
F2	1.806 ± 0.008^{b}	1.981 ± 0.002^{a}
F3	1.820 ± 0.017^{b}	2.019 ± 0.010^{b}
F4	1.792 ± 0.016^{b}	2.120 ± 0.001^{c}
H0	0.274 ± 0.001^{c}	0.030 ± 0.006^{d}
H1	0.263 ± 0.001^{dc}	0.020 ± 0.001^{d}
H2	0.307 ± 0.006^{ec}	0.026 ± 0.001^{d}
SAM	0.030 ± 0.010^{f}	2.230 ± 0.020^{e}
OXZ	2.330 ± 0.040^{j}	3.250 ± 0.020^{f}

Different letters in the same column indicate a significant difference ($p < 0.05$). The values were compared with the standard using a one-way ANOVA followed by a multiple comparison test. F1: Cyclohexane extract; F2: Ethyl acetate extract; F3: Ethanolic extract; F4: Aqueous extract; H0: Pure essential oil; H1: Fraction 1 of the essential oil; H2: Fraction 2 of the essential oil; SAM: methyl salicylate; OXZ: zinc oxide.

The UVA absorption results for the different extracts and essential oils showed significant variation in dermoprotective activity ($p < 0.05$). The cyclohexane extract (F1) displayed the highest absorbance value of 1.968 ± 0.001, followed closely by the ethyl acetate extract (F2), the ethanol extract (F3), and the aqueous extract (F4) with absorbance of 1.806 ± 0.008, 1.820 ± 0.017, and 1.792 ± 0.016, respectively. In contrast, the pure essential oil (H0) and its fractions (H1 and H2) exhibited much lower absorbance values of 0.274 ± 0.001, 0.263 ± 0.001, and 0.307 ± 0.006, respectively. Zinc oxide (absorbance = 2.330 ± 0.040) demonstrated superior UVA absorption compared to all the extracts ($p < 0.05$), whereas methyl salicylate exhibited the lowest absorption capacity of 0.030 ± 0.010.
Regarding UVB absorption, notable differences were also observed among the extracts. The aqueous extract (F4) displayed the highest absorbance of 2.120 ± 0.001, followed by the ethanolic extract (F3), the ethyl acetate extract (F2), and the cyclohexane extract (F1) with absorbance values of 2.019 ± 0.010, 1.981 ± 0.002, and 1.968 ± 0.001, respectively. Conversely, the pure essential oil (H0) and its fractions (H1 and H2) showed significantly lower absorbance values of 0.030 ± 0.006, 0.020 ± 0.001, and 0.026 ± 0.001, respectively ($p < 0.05$). The standards, methyl salicylate (SAM) and zinc oxide (ZnO) exhibited absorbance values of 2.230 ± 0.020 and 3.250 ± 0.020, respectively.
In the light of these findings, which revealed the significant ability of *C. atlantica* extracts to absorb UV rays within the wavelength ranges corresponding to UVA and UVB, further investigation was deemed necessary through complementary analysis. While UV absorption serves as a critical preliminary indicator for assessing the photoprotective capacity of a compound, it does not provide an exhaustive quantification of the solar protection offered. Therefore, to ensure a more comprehensive and rigorous evaluation of the photoprotective effect of the extracts, a second experimental phase was conducted, focusing on the determination of the Sun Protection Factor (SPF). This does not only measure the ability of the extracts to prevent UV-induced erythema but also quantifies their effectiveness as protective agents based on internationally recognized and standardized criteria.

Sun Protection Factor (SPF)
One method for evaluating sunscreen activity is by measuring the Sun Protection Factor (SPF). The SPF is defined as the amount of UV energy required to produce a Minimal Erythema Dose (MED) on skin protected by sunscreen products or active sunscreen substances, divided by the amount of UV energy required to produce a MED on unprotected skin.[35]
The SPF values for *C. atlantica* extracts and zinc oxide were determined using a UV-Vis spectrophotometer, within the UV-B wavelength range (290-320 nm). According to the FDA (Food and Drug Administration), sunscreen effectiveness is classified into five categories (Table 3): minimal, moderate, extra, maximum, and ultra.[36]
The absorbance values for *C. atlantica* extracts are shown in Table 4, while the SPF values calculated using the Mansur equation are presented in Table 5.

Table 3: FDA Classification of Sunscreen Effectiveness

Capacity	**SPF Value**
Minimal	2-4
Medium	4-6
Extra	6-8
Maximal	8-15
Ultra	< 15

Table 4: Absorbance of C. atlantica extracts

Wavelength (nm)	F1	F2	F3	F4	ZnO
290	1.8833 ± 0.007	1.8843 ± 0.008	1.948 ± 0.008	2.2877 ± 0.032	1.7003 ± 0.001
295	2.4123 ± 0.038	2.3397 ± 0.018	2.388 ± 0.034	2.363 ± 0.003	1.484 ± 0.004
300	2.176 ± 0.007	2.141 ± 0.013	2.1573 ± 0.004	2.0533 ± 0.006	1.394 ± 0.005
305	2.0277 ± 0.005	2.049 ± 0.008	2.0037 ± 0.004	1.872 ± 0.007	1.204 ± 0.004
310	1.8767 ± 0.006	1.873 ± 0.004	1.8683 ± 0.006	1.7583 ± 0.006	1.1107 ± 0.001
315	1.8087 ± 0.022	1.836 ± 0.005	1.82 ± 0.013	1.6407 ± 0.004	1.1143 ± 0.001
320	1.6743 ± 0.016	1.659 ± 0.010	1.6273 ± 0.004	1.4317 ± 0.004	1.1113 ± 0.001

F1 : Cyclohexane extract ; F2 : Ethyl acetate extract ; F3 : Ethanolic extract ; F4 : Aqueous extract ; ZnO : Zinc oxide.

Table 5: Sun Protection Factor (SPF) of C. atlantica extracts

Extract	SPF Value
F1	20.48 ± 0.10^{a}
F2	20.40 ± 0.07^{ab}
F3	20.31 ± 0.07^{b}
F4	19.22 ± 0.06^{c}
ZnO	12.62 ± 0.02^{d}

Different letters within the same column indicate a significant difference ($p < 0.05$). The values were compared with the standard using a one-way ANOVA followed by a multiple comparison test. F1: Cyclohexane extract; F2: Ethyl acetate extract; F3: Ethanolic extract; F4: Aqueous extract; ZnO: Zinc oxide.

The results showed that all *C. atlantica* extracts exhibited comparable SPF values which significantly surpassed that of zinc oxide (ZnO), a conventional photoprotective agent. This consistent performance suggests that each extract contains compounds effective against UV radiation, indicating promising potential as natural photoprotective agents. The fact that these extracts outperformed a known photoprotective agent such as ZnO highlights the opportunity to explore plant extracts for the development of alternative sunscreen formulations. This paves the way for further research on the active compounds responsible for this effectiveness, with possible implications for safer and more environmentally friendly sunscreen products.

Numerous substances with antioxidant activity are naturally present in human skin. However, under oxidative stress, particularly induced by ultraviolet (UV) rays from the sun, these antioxidant compounds are significantly reduced, contributing to skin aging. This observation underscores the importance of applying topical antioxidant substances or other compounds with antioxidant activity.[37,38] Furthermore, direct or indirect exposure to UV rays leads to a decrease in skin immune responses. A strong link has been established between immunosuppression and the promotion of skin cancers, a phenomenon widely observed in animals.[39,40] Several plant-derived phytocompounds have shown protective activity against UV-induced damage, particularly UVA rays. For example, lucidone, extracted from the fruits of *Lindera erythrocarpa*, has proven effective in protecting human keratinocytes against UVA-induced oxidative stress. This protection is explained by the activation of cellular antioxidant systems via the regulation of Nrf2, a key factor in the response to oxidative damage. Lucidone stabilizes Nrf2, thus enhancing the production of antioxidant enzymes such as heme oxygenase-1 (HO-1) and NAD(P)H quinone dehydrogenase 1 (NQO-1), which are crucial for preventing UV-induced skin damage. These findings highlight the effectiveness of plant extracts rich in antioxidants, such as lucidone, as natural alternatives for protection against harmful UV effects, especially in the context of photoaging and skin cancer. Additionally, other phytocompounds, such as quercetin, have shown a similar capacity to alleviate UV-induced oxidative stress by stimulating the Nrf2 pathway.[41]

The protective effect against UV rays can be attributed to the flavonoids present in *C. atlantica* extracts, which possess activity against ultraviolet radiation.[42] Several studies have shown that flavonoids can inhibit UVB-induced hydrogen peroxide (H_2O_2) formation in keratinocytes and reduce malondialdehyde levels after sun exposure (UVB).[43] In comparison with other studies, it has been shown that the essential oil of *C. atlantica* (CAEO) significantly inhibits the enzyme tyrosinase, a key player in the melanogenesis process.[44] Inhibition of this enzyme can contribute to dermatoprotective effects, such as the prevention of uneven skin pigmentation. The study measured the IC_{50} (median inhibitory concentration) of CAEO at 141.103 ± 0.06 µg/mL, slightly higher than the standard compound, quercetin, which had an IC_{50} of 93.27 ± 0.021 µg/mL. This suggests a notable efficacy of the essential oil against tyrosinase activity. It is important to note that Heinrich *et al* (2021)[45] reported in their review that the essential oil of *Cedrus deodara* is primarily used for treating dermatological complications in India, Nepal, and Pakistan.[45] Due to the complexity of essential oil compositions, tyrosinase activity inhibition is mainly attributed to a synergistic interaction of their components with the enzyme.[46] Additionally, several studies have revealed that certain plants from the Pinaceae family, such as *Morus alba*, *Pinus thunbergii*, *Pinus sylvestris*, *Cedrus deodara*, and *Larix kaempferi*, possess significant dermatoprotective properties (anti-melanogenic, anti-tyrosinase, anti-elastase, hyaluronidase, and anti-tanning activities).[47–50]

In vitro antihyperglycemic activity

Inhibitory activity of α-amylase and α-glucosidase

The extracts of *C. atlantica* as well as its essential oils were tested for their inhibitory effect on digestive enzymes, namely α-amylase and α-glucosidase. The results obtained are detailed in Table 6.

The extracts and essential oils of *C. atlantica* demonstrated significant inhibitory effects on α-amylase and α-glucosidase when compared to the standard acarbose. For α-amylase inhibition, the ethyl acetate extract (F2) exhibited notable activity (IC_{50} = 95.9 ± 0.02 µg/mL), showing a potency approximately four times higher than that of acarbose (IC_{50} = 396.42 ± 0.03 µg/mL). Among the essential oils, fraction 1 (H1) displayed the strongest inhibition (IC_{50} = 13.9 ± 0.01 µg/mL), with a considerably higher efficacy than acarbose.

Regarding α-glucosidase inhibition, the cyclohexane extract (F1) was the most effective (IC_{50} = 27.5 ± 0.24 µg/mL), demonstrating approximately seven times greater inhibitory activity compared to acarbose (IC_{50} = 199.0 ± 0.01 µg/mL). Fraction 1 of the essential oil (H1) also exhibited significant activity (IC_{50} = 68.25 ± 0.43 µg/mL), outperforming acarbose by a substantial margin.

Hyperglycemia is a condition characterized by an abnormal elevation in blood glucose levels, constituting one of the primary causes of type 2 diabetes (T2D), a metabolic disease caused by insulin resistance. This resistance impairs the ability of cells to properly respond to insulin, leading to excessive glucose accumulation in the blood. To address this anomaly, drugs such as acarbose and orlistat are used as therapies aimed at reducing hyperglycemia and, consequently, managing metabolic complications associated with T2D, such as hyperlipidemia.[51] Acarbose acts by inhibiting key digestive enzymes, including pancreatic α-amylase and intestinal α-glucosidase, which play a crucial role in the catabolism of polysaccharides into glucose molecules that are easily absorbed by the small intestine. By limiting this glucose absorption, acarbose helps control postprandial blood sugar levels. However, long-term use of these pharmacological agents is often associated with side effects, such as gastrointestinal disorders, nutrient malabsorption, and other metabolic complications.[51] These side effects limit the effectiveness of these treatments in some patients, highlighting the need to develop safer and more effective therapeutic approaches for managing diabetes and its associated complications. In this context, the exploration of natural compounds from plants, such as extracts and essential oils, is gaining increasing interest. These may offer a promising alternative to conventional drugs by reducing hyperglycemia while presenting fewer undesirable side effects.[52]

The analysis of the results from the present study revealed that the ethyl acetate extract (F2) stands out for its efficacy in inhibiting α-amylase, while the cyclohexane extract (F1) demonstrates exceptional performance in inhibiting α-glucosidase. Furthermore, fraction H1 of the essential oil is particularly notable for its superior efficacy in simultaneously inhibiting both α-amylase and α-glucosidase, significantly outperforming acarbose. Additionally, the ethyl acetate extract (F2) and ethanol extract (F3) also exhibited noteworthy inhibitory activities, particularly against α-glucosidase. The essential oils, especially H1, showed strong inhibition of both enzymes, further highlighting their potential for application in hyperglycemia management. The differences observed between the extracts and essential oil fractions suggest that the specific chemical composition of each extract plays a critical role in their inhibitory activity.

To the best of our knowledge, no published report on the α-amylase and α-glucosidase inhibitory activity of *C. atlantica* have been found in the scientific literature. Results from a study on a similar species, *Cedrus libani*, showed that the essential oil obtained by hydrodistillation of *C. libani* wood exhibited interesting activity with an IC_{50} of 0.14 mg/mL. In contrast, essential oils extracted from the cones showed an inhibition percentage of 31% at a concentration of 1 mg/mL (IC_{50} > 1 mg/mL), while no inhibition was observed with the oil from the leaves. The wood oil from *C. libani* contains mainly a sesquiterpenic alcohol, himachalol, which was not found in the essential oils from the leaves or cones.[53]

Table 6: Alpha-amylase and alpha-glucosidase inhibitory activity (IC_{50} values) of C. atlantica extracts and essential oils

	IC_{50} (µg/mL)	
	Alpha-amylase	**Alpha- glucosidase**
F1	229.00 ± 0.06^{a}	27.50 ± 0.24^{a}
F2	95.90 ± 0.02^{b}	70.50 ± 0.33^{b}
F3	335.00 ± 0.02^{c}	76.50 ± 0.01^{c}
F4	444.00 ± 0.02^{d}	151.00 ± 0.11^{d}
H0	321.00 ± 0.12^{e}	78.20 ± 0.03^{c}
H1	13.90 ± 0.01^{f}	68.25 ± 0.43^{e}
H2	72.25 ± 0.01^{j}	524.15 ± 0.14^{f}
Acarbose	396.42 ± 0.03^{h}	199.00 ± 0.01^{j}

The data represent the mean ± standard deviation (SD) of three independent experiments. Values within the same column with different superscript letters indicate significant differences (p-value < 0.05). F1: Cyclohexane extract; F2: Ethyl acetate extract; F3: Ethanolic extract; F4: Aqueous extract; H0: Pure essential oil; H1: Fraction 1 of the essential oil; H2: Fraction 2 of the essential oil.

Conclusion

The results obtained for the photoprotective activity and *in vitro* antihyperglycemic activity of *Cedrus atlantica* extracts and essential oils revealed promising potential in two areas of health. In terms of sun protection, the extracts of *Cedrus atlantica* demonstrated a remarkable ability to absorb UV rays, even surpassing the effectiveness of zinc oxide, making them interesting candidates for natural sunscreen formulations. On the other hand, the antihyperglycemic activity evaluation revealed that the extracts, particularly the ethyl acetate extract (F2) and the H1 fraction of the essential oil, effectively inhibited α-amylase and α-glucosidase enzymes, suggesting their potential for treating type 2 diabetes. These results highlight the importance of exploring plant extracts as alternatives to conventional treatments for safer and more effective remedies. However, further studies are needed to deepen the understanding of the mechanisms of action and the compounds responsible for these beneficial effects. In summary, *Cedrus atlantica* could be a valuable resource for the development of natural dermoprotective and antidiabetic products.

Conflict of interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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