Journal of Ethnopharmacology and Toxicology
Research Article

Antioxidant and insecticidal properties of *Asphodelus tenuifolius*: phytochemical characterization and polysaccharide analysis

Hafsia Bouzenna[1,2*], Hmed ben Nasr[3], Raouda Abbessi[1], Sabah Dhibi[1], Noura Samout[1], Khaled Athmouni[4], Fatma Guiesmi[5], Samira Jbehi[2], Najla Hfaiedh[1]

[1]Laboratory of Biotechnology and Biomonitoring of the Environment and Oasis Ecosystems (LBBEEO), Faculty of Sciences of Gafsa, University of Gafsa, Zarroug, Gafsa 2112, Tunisia.
[2]Energy and Matter Research Laboratory, Centre National des Sciences et TechnologiesNucléaires (CNSTN), Pole technologique, 2020, Sidi Thabet-Tunisia.
[3]Department of Life Sciences, Faculty of Sciences of Gafsa, University of Gafsa – Tunisia.
[4]Department of Life Sciences, Laboratory of Biodiversity and Aquatic Ecosystems, Ecology and Planktonology, University of Sfax, Tunisia. Faculty of Sciences, Unit UR 11 ES 72/Street of Soukra Km 3,5, B.P. 1171, CP 3000 Sfax, Tunisia.
[5]Laboratory of Risks Related to Environmental Stresses: Fight and Prevention, Unit UR03ES06, Faculty of Sciences of Bizerte, University of Carthage, Tunisia.

[*]**Correspondence**
Hafsia Bouzenna
hafsiahmed2024@gmail.com

Volume: 3, Issue: 1, Pages: 52-64
DOI: https://doi.org/10.37446/jet/rsa/3.1.2025.52-64
Received: 28 February 2025 / Accepted: 7 May 2025 / Published: 30 June 2025

This study investigates the phytochemical composition of aqueous and ethanolic extracts of *Asphodelus tenuifolius*, along with the antioxidant potential and characterization of its polysaccharide, including its antioxidant and insecticidal effects. Phytochemical analysis showed that the ethanolic extract had higher contents in polyphenol (251.53 ± 0.88 µg EAG/mg), flavonoid (160.60 ± 5.24 µg EQ/mg), and tannin (30.41 ± 0.72 µg EAT/mg) compared to the aqueous extract. Both extracts exhibited strong antioxidant activity against DPPH radical and reducing power. The polysaccharide yield reached 8.2%, contains sugars and minimal protein as confirmed by the Fourier Transform Infrared Spectroscopy analysis. It also exhibits considerable DPPH scavenging potential and reducing power. The polysaccharides' fraction also showed significant insecticidal activity against *Tribolium confusum*, achieving the highest mortality rate at 8 µg/ml. These findings suggest that polyphenols and flavonoids contained in the extract of *A. tenuifolius* may be responsible for antioxidant activity. Furthermore, the strong antioxidant and insecticidal properties of the polysaccharide of *Asphodelus tenuifolius* highlight its potential for further *in vivo* studies on oxidative stress, supporting its promising biological applications.

Keywords: *Asphodelus tenuifolius, antioxidant activity, insecticidal activity, polysaccharide, phytochemistry, Tribolium confusum*

Introduction

Plants have always been an essential part of human civilization, providing food, shelter, and medicine. Natural compounds derived from plants have attracted growing interest in both traditional and modern medicine due to their pharmacological properties (Newman & Cragg, 2020). These biologically active compounds exhibit diverse effects, such as antimicrobial, anti-inflammatory, anticancer, and antioxidant properties (Sun et al., 2023). Throughout the literature, several studies were devoted for the identification and recognition of these bioactive molecules, which form a basic step for their medicinal use. Recently, data banks have gathered numerous known active molecules including tannins, flavonoids, carbohydrates, vitamins, anthocyanins, coumarins, saponins, alkaloids, glycosides, proteins, lipids, and essential oils (Kumar et al., 2021). Among natural active molecules, polysaccharides polymers that consist of

monosaccharides linked by glycosidic bonds, have received significant attention due to their various biological functions, including antitumor, immunomodulatory, anti-inflammatory, antioxidant, anticoagulant, antidiabetic, and hepatoprotective activities (Govindarajan et al., 2021). Tunisia, like many Mediterranean countries, has a long-standing tradition of using herbal medicine to treat various ailments. The diverse climatic conditions in the region contribute to a rich biodiversity of medicinal plants among which many remain to be fully explored for their usefulness (Salem et al., 2023). *Asphodelus tenuifolius*, commonly known as "Tasia," belongs to the Liliaceae (Asphodelaceae) family. All parts of this plant are widely used in traditional medicine to treat diarrhea, epilepsy, diabetes, skin diseases, constipation, cough, fever, and hypertension (Almoshari et al., 2022). Because of its wide - traditional usage for several reasons, scientific studies on its phytochemical profile, biological effects and pharmacological properties are required. In particular, there is a growing interest to find new and safe antioxidant molecules that are essential for neutralizing free radicals and help protecting against chronic diseases such as cancer, cardiovascular issues, and neurodegenerative disorders (Muscolo et al., 2024). In this context, this study aims to assess the antioxidant and antibacterial properties of extracts derived from the aerial parts of *A. tenuifolius*. Specifically, it is intended a) To identify the phytochemical profile of *A. tenuifolius*; b) To assess the antioxidant and antibacterial properties of both aqueous and ethanolic extracts. c) To extract and analyze its polysaccharides. d)To assess the antioxidant and insecticidal properties of the extracted polysaccharides. By addressing these objectives, this study aims to add to the expanding body of knowledge on medicinal plants, providing scientific validation for the traditional uses of *A. tenuifolius* and exploring its potential applications in pharmaceutical and nutraceutical industries.

Materials and Methods

Materials

Asphodelus tenuifolius leaves were gathered from the Sidi Aich area in the Gafsa governorate. The plant was identified by Dr. Issam Saidi, a botanist at the Faculty of Sciences, University of Gafsa. The leaves were carefully rinsed with water to remove impurities (salts, sand, shells, etc.), then dried under sunlight and at room temperature. Once dried, they were finely ground to obtain a homogeneous powder.

Extraction

The extracts were prepared using the maceration technique. One gram of powdered plant material was mixed with 10 mL of either water or ethanol and allowed to macerate for 24 hours with constant stirring. The mixture was then centrifuged at 3000 rpm for 10 minutes, and the supernatants were filtered. The filtered extracts were left to dry in the open air before being collected for subsequent analysis.

Total phenolic content determination

The total phenolic content was measured using the Folin-Ciocalteu method (Singleton & Rossi, 1965). A 200 µL aliquot of plant extract was mixed with 1 mL of Folin-Ciocalteu reagent. After 8 minutes, 500 µL of a 7.5 g/L sodium carbonate (Na_2CO_3) solution was added. The reaction mixture was incubated in the dark at room temperature for 30 minutes. Absorbance was recorded at 760 nm. The concentration of total phenolic compounds was determined using the regression equation derived from a gallic acid calibration curve (50–200 µg/mL). Results were expressed as micrograms of gallic acid equivalents per milligram of extract (µg EAG/mg extract).

Total flavonoid content determination

The total flavonoid content was quantified using an aluminum chloride and sodium hydroxide-based method (Dewanto et al., 2002). A 500 µL portion of plant extract was mixed with 75 µL of 7% sodium nitrite solution and 1500 µL of distilled water. The mixture was incubated at room temperature for 5 minutes, after which 75 µL of 10% aluminum chloride solution and 500 µL of 1M sodium hydroxide were added. The final volume was adjusted to 2500 µL with distilled water, and the mixture was vortexed. Absorbance of the resulting pink color was measured at 510 nm. A calibration curve was created using quercetin solutions (100, 250, 500, and 750 µg/mL) as a standard. Results were expressed as micrograms of quercetin equivalents per milligram of extract (µg EQ/mg extract).

Total tannin content determination

The total tannin content was assessed using the vanillin assay in an acidic environment. A 200 µL aliquot of the sample or standard was mixed with 3 mL of a 4% vanillin solution in methanol and 1.5 mL of hydrochloric acid. A calibration

curve was generated using tannic acid concentrations ranging from 0 to 300 µg/mL. Results were expressed as micrograms of tannic acid equivalents per milligram of extract (µg EAT/mg extract).
Antioxidant Evaluation

DPPH radical scavenging activity

The scavenging activity of free radicals was determined using the DPPH method as outlined by Blois (1958). A 50 µL portion of extract, prepared at various concentrations (25–500 µg/mL), was combined with 950 µL of a 0.5 mM methanolic DPPH solution. The blank was made by mixing 25 µL of methanol with 950 µL of DPPH solution. Ascorbic acid was used as a positive control. All readings were taken in triplicate."

The DPPH inhibition percentage (I%) was calculated using the following formula:

$$I\% = \left(\frac{DOA - DOB}{DOA}\right) x100$$

where:
• DOA: Absorbance of the blank (negative control)
• DOB: Absorbance of the sample extract"

The results were used to plot the percentage inhibition (I%) as a function of extract concentration (µg/mL), allowing for the determination of the IC_{50} value (the concentration required to inhibit 50% of DPPH radicals).

Reducing power assay

The reducing power of both aqueous and ethanolic extracts of *Asphodelus tenuifolius* was assessed using the method described by Oyaizu (1986). To 1 mL of extract at varying concentrations (100–500 µg/mL), 2.5 mL of 0.1 M potassium phosphate buffer (pH 6.6) and 2.5 mL of 1% (w/v) potassium ferricyanide were added. The reaction mixture was incubated at 50°C for 20 minutes, followed by the addition of 2.5 mL of 10% (w/v) trichloroacetic acid. After centrifugation, 2.5 mL of the supernatant was mixed with 2.5 mL of distilled water and 0.5 mL of 0.1% (w/v) ferric chloride ($FeCl_3$). The mixture was incubated at 28°C for 30 minutes to allow for color formation. The absorbance was measured at 700 nm and compared with a standard curve using BHT as a reference.

Extraction and chemical analyses of polysaccharides

Extraction

The dried leaves of *Asphodelus tenuifolius* were ground and subjected to a pretreatment with hexane under magnetic stirring for 30 minutes. Afterward, the mixture was filtered through Whatman paper to separate hexane-soluble components, such as polyphenols, simple sugars, and amino acids. The remaining residue from the leaves was dried in a dark environment and then macerated in two volumes of distilled water at 90°C for 4 hours. This was followed by a second boiling step with ten volumes of distilled water at the same temperature and duration. The resulting mixture was filtered, and the supernatant (S2) was collected. The S1 fraction was then combined with S2, and polysaccharides in the mixture were precipitated by adding ethanol and leaving it overnight at 4°C. After centrifugation at 4500 × g for 15 minutes, the pellet was dissolved in distilled water. To remove proteins, 5% trichloroacetic acid (TCA) was introduced, followed by centrifugation at 4000 × g for 5 minutes. Finally, the polysaccharides present in the supernatant were subjected to dialysis with distilled water for a period of 3 days, then dried.

Determination of yield, sugar, and protein content

The polysaccharide yield was calculated using the following equation:

$$y(\%) = \frac{W1}{W0} \times 100$$

where:
- W_1 = weight of crude polysaccharide (g)
- W_0 = weight of pretreated dry powder (g)

The sugar content of the crude polysaccharide was measured using the phenol–sulfuric acid method, with glucose serving as the reference standard (DuBois et al., 1956). The protein content was quantified by the Bradford method, with bovine serum albumin as the reference standard (Bradford, 1976).

Analysis using Fourier Transform Infrared Spectroscopy (FTIR)

The polysaccharides and extracts of *Asphodelus tenuifolius* were examined through Fourier Transform Infrared Spectroscopy (FTIR) at room temperature, following the procedure described by Alimi et al. (2013). To prepare translucent sample disks, two milligrams of dried polysaccharide powder were mixed with 100 mg of KBr. The spectral analysis was conducted using a Shimadzu FTIR-8400S infrared spectrometer, equipped with IR Solution 1.10 Shimadzu software. The recorded spectra spanned the infrared region from 4000 to 500 cm^{-1}.

Microscopic examination of polysaccharide surfaces using scanning electron microscopy

Scanning electron microscopy (SEM) was employed to examine the polysaccharides, providing high-resolution images of their surface through electron-matter interactions.

Antioxidant activity assays

The antioxidant activities of the polysaccharides extracted from *Asphodelus tenuifolius* were evaluated using two assays: DPPH Free Radical Scavenging Assay and Evaluation of Reducing Power. These assays were performed using the same methods as those applied to the plant extracts.

Insecticidal activity of the polysaccharide of the plant

Determination of residual effect

Different concentrations of plant-derived polysaccharides were prepared using distilled water. A 1 mL portion of each solution was applied to 20 g of grain and thoroughly mixed. After 10 minutes, air-dried insects were introduced into the petri dish (Arifuzzaman et al., 2014). Each concentration of the plant extract, along with a control, was tested in triplicate. The treated samples were maintained at an ambient laboratory temperature of 28 ± 0.5°C. Mortality rates were assessed at 1, 2, 7, 15, and 21 days post-treatment (DAT). The mortality percentage was determined using the following equation:

$$Mc = \frac{(\mathrm{M2} - \mathrm{M1})}{(100 - \mathrm{M1})} \times 100$$

M1: Corrected mortality percentage of control
M2: Mortality percentage of treated insects
MC%: Corrected mortality percentage

Detection of repellency effect

To begin, Whatman No. 1 filter papers were cut in half. Using a pipette, 1 mL of each plant extract solution was applied to one half, while the other half, serving as a control, was treated only with distilled water. Both halves were then allowed to air-dry.

Ten insects were introduced at the center of each petri dish, which was then covered. For each plant extract and dosage, three replications were conducted. The number of insects on each section was recorded at hourly intervals for up to six hours. The results were expressed as percentage repulsion (%PR) using the following formula:

$$\mathbf{\%PR = (NC - 50) \times 2}$$

Where:

- **%PR** = Percentage repulsion
- **NC** = Percentage of insects present in the control half

A positive (+) value indicated repellency, while a negative (-) value suggested attractancy. The average values were classified according to the scale established by McDonald et al. (1970).

Class	Repellency (%)	Class	Repellency (%)
0	> 0.01 to 0.1	III	40.1 to 60
I	0.1 to 20	IV	60.1 to 80
II	20.1 to 40	V	80.1 to 100

Statistical analyses

All biochemical and bioactivity experiments were conducted in triplicate, with three biological replicates for each experiment. Data are presented as the mean ± standard error (SE). A p-value of less than 0.05 was considered statistically significant.

Results

Determination of Total Polyphenols, Flavonoids, and Tannins

The contents of total polyphenols, flavonoids, and tannins were calculated based on standard curves and expressed in microgram equivalents of gallic acid (µg EAG/mg), quercetin (µg EQ/mg), and tannic acid (µg ETA/mg) per milligram of extract, respectively. The obtained results are presented in Table 1. Notably, the ethanol extract of *Asphodelus tenuifolius* exhibited the highest levels of these bioactive compounds compared to the aqueous extract.

Table 1. Total phenolic, flavonoid and tannins contents of leaves of extract of *Asphodelus tenuifolius*

	Total phenolic	flavonoid	Tannins
ATA	231.15±0.44	106.06±5.42	13±0.25
ATE	251.53±0.88	160.60±5.24	30.41±0.72

Analysis Using Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR analysis of the aqueous extract of *A. tenuifolius* revealed revealed characteristic absorption bands at 3451.08, 1604.57, 1256.92, 778.14, and 618.04 cm^{-1}, suggesting the presence of functional groups like alcohols and alkanes, carboxylic acids (O–H stretch), nitro compounds, esters, amines, and alkenes (Figure 1a, Table 2). Similarly, the ethanolic extract displayed peaks at 3411.43, 2932.65, 1615.24, 1386.53, 1037.35, and 618.04 cm^{-1}, which are attributed to alcohols, alkanes, carboxylic acids (O–H stretch), esters, amines, and alkenes (Figure 1, Table 2).

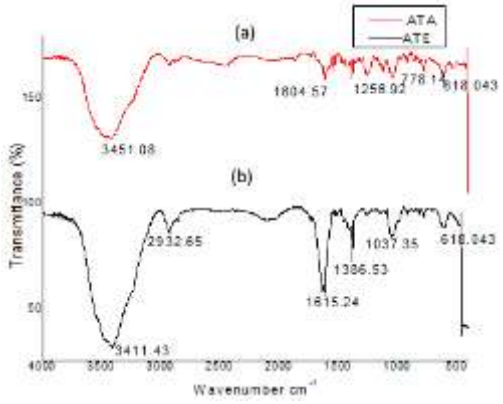


Figure 1. FTIR spectra analysis of aqueous and ethanol extract of *Asphodelus tenuifolius* leaves

Table 2. FTIR spectral wavenumber's values and functional groups obtained from the aerial parts extract and polysaccharides of *Asphodelus tenuifolius*

Wavenumbers			Functional groups
ATA	ATE	Polysaccharide	
3451.08	3411.43	3415.42	Alcool
_	2932.65	2925.64	Alcane
1604.57	1615.24	1765.51 and 1605.88	Carboxylic acid
1256.92	1386.53	1383.32 and 1425.27	Nitro,Uronic acid
778.14	_	847.64	Esters, amines, D-glucose
618.043	618.043	633.98	Esters, amines, alkyl halide, alkene;

Evaluation of antioxidant activity

Assessment of DPPH radical scavenging activity

The DPPH radical-scavenging activity of the extracts was evaluated in vitro and showed a dose-dependent response (Figure 2). As the concentration of the extract increased, the DPPH radical-scavenging activity also increased. The antioxidant capacity was assessed by determining the IC_{50} values, which indicate the concentration needed to neutralize 50% of the DPPH radicals. The aqueous extract of *A. tenuifolius* exhibited an IC_{50} of 320.71 ± 17.23 µg/mL. The ethanol extract demonstrated a significantly lower IC_{50} of 24.47 ± 1.58 µg/mL, indicating stronger antioxidant activity compared to the standard antioxidant BHT.

Fe^{3+} reduction activity assay

The reducing power test evaluates the capacity of antioxidants to convert Fe^{3+} into Fe^{2+}, leading to the formation of a green-colored complex. The reducing capacity of *A. tenuifolius* extracts and the BHT standard was illustrated in the figure 2. Results show a concentration-dependent increase in reducing power, reinforcing the antioxidant potential of the plant extracts.

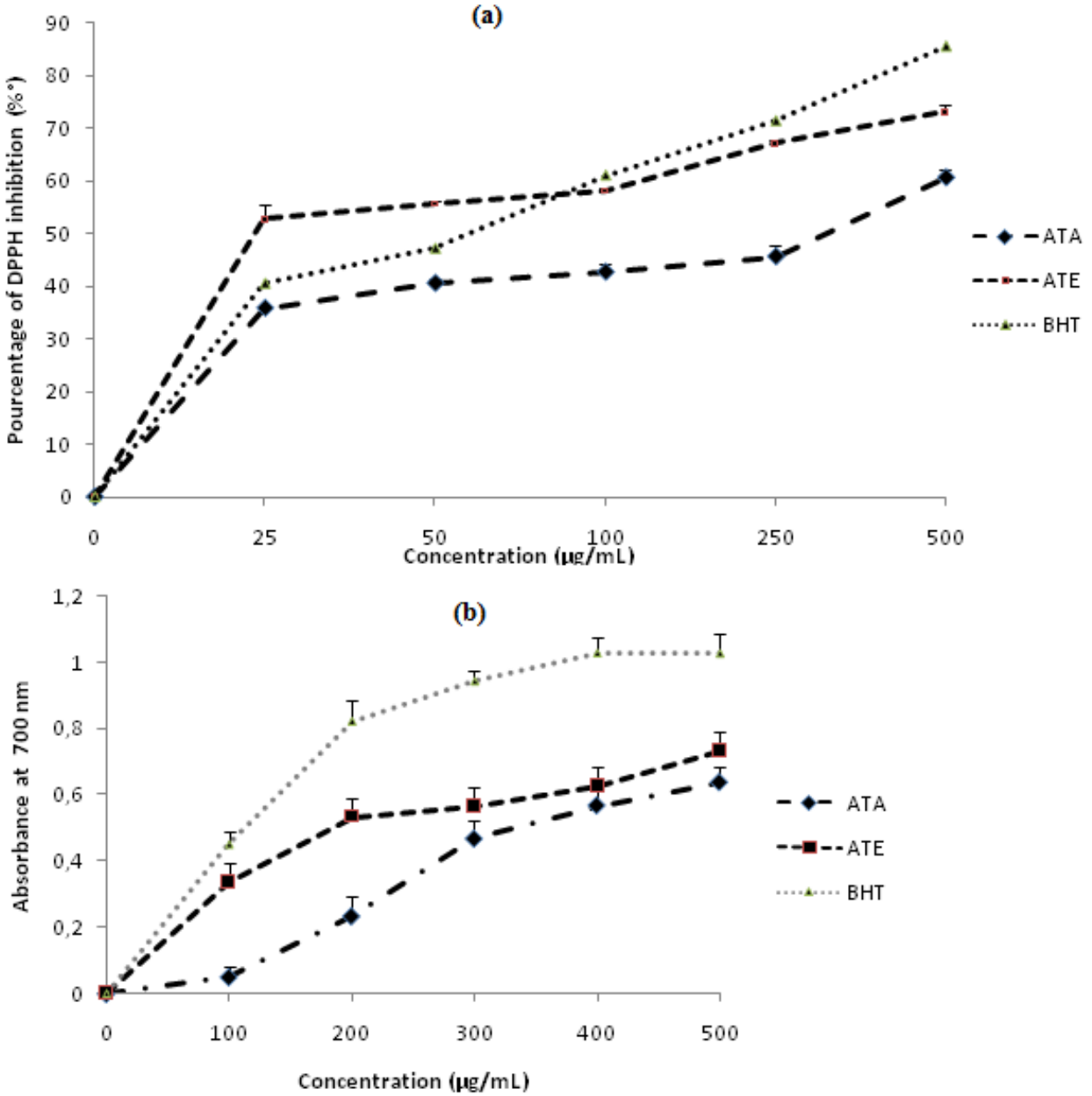


Figure 2. Inhibition % of DPPH free radical scavenging activity and reducing power of different extract of *Asphodelus tenuifolius*

Spectral study of the polysaccharide of *Asphodelus tenuifolius*

Determination of yield, total sugar, and protein content

Polysaccharide of *Asphodelus tenuifolius* was prepared from *Asphodelus tenuifolius* and obtained a yield with value 8.2%. The chemical analysis revealed that the neutral sugar and protein contents were 10.27% and 4.9%, respectively. (Table 3, Figure 3)

Table 3. Percentage of mortality of Tribolium confusum adults on 21 days after at different concentrations of polysaccharide of *Asphodelus tenuifolius*

	PAS	2 µg/ml	4 µg/ml	8 µg/ml
% Insect mortality (Date)	1 Date	0±0	0±0	3.3±5.7
	2 DATE	0±0	0±0	3.3±5.7
	7 DATE	3.33±5.7	10±10	33.33±15.27
	15 DATE	6.66±5.77	10.66±9.01	20±0
	21 DATE	66.66±15.72	80±17.32	86.66±5.77

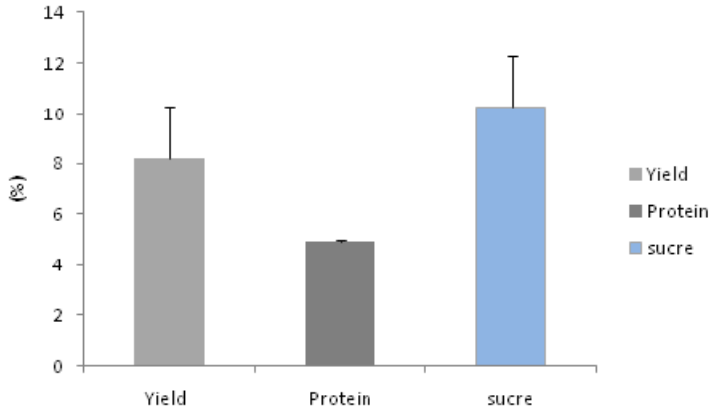


Figure 3. Determination of contents of yield, total sugars and protein of the polysaccharide of *Asphodelus tenuifolius.* The values are expressed by means ±SEM (n = 3)

FTIR Analysis of Polysaccharides

The FTIR spectrum of the polysaccharides extracted from *A.tenuifolius* leaves displayed characteristic absorption bands (Figure 4, Table 2). The analysis revealed the following bands: a broad stretching band at 3415 cm^{-1} for OH, a stretching band at 2925 cm^{-1} for CH, and another around 1765 cm^{-1} for C=O. A band near 1605 cm^{-1} corresponds to the COO^{-} group, while the one at 1425 cm^{-1} confirms the presence of uronic acid. The peak at 1020 cm^{-1} indicates pyranose structures, and the peak at 847 cm^{-1} is characteristic of D-glucose.

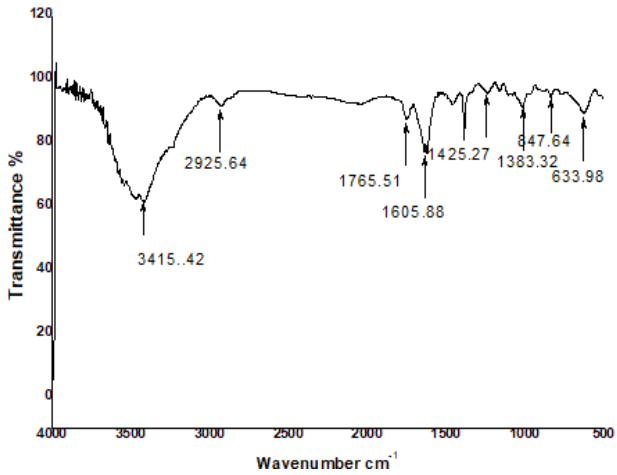


Figure 4. The FT-IR spectrum of polysaccharide of *Asphodelus tenuifolius*

Microscopic observation of polysaccharide surfaces of extracts by scanning electron microscope

To further characterize the polysaccharides extracted from the leaves of *Asphodelus tenuifolius*, a scanning electron microscopic (SEM) analysis was performed (Figure 5). The SEM images revealed that the polysaccharides exhibit irregular structures with rough, non-porous surfaces. This differs from polysaccharides reported in other studies, where a porous structure is often observed. The porosity of polysaccharides plays a crucial role in their water retention capacity, a property highly valued in the pharmaceutical cosmetic and food, industries. It is essential to recognize that the extraction and purification processes can significantly impact the shape and structure of polysaccharides.

Table 4. Repellency activity of polysaccharide of *Asphodelus tenuifolius* against *Tribolium confusum*

Dose	Repellency rate (%) of PAS				
	1h	3H	6H	Average	Rappel class
2	60±20	86±11	80±20	75.33±30	IV
4	46.66±30	30.55±30	66.66±11	47.69±30.55	III
8	46.66±30	66.66±30	100	82.22±11.54	V
20	80	66	100	71.11±26.94	V

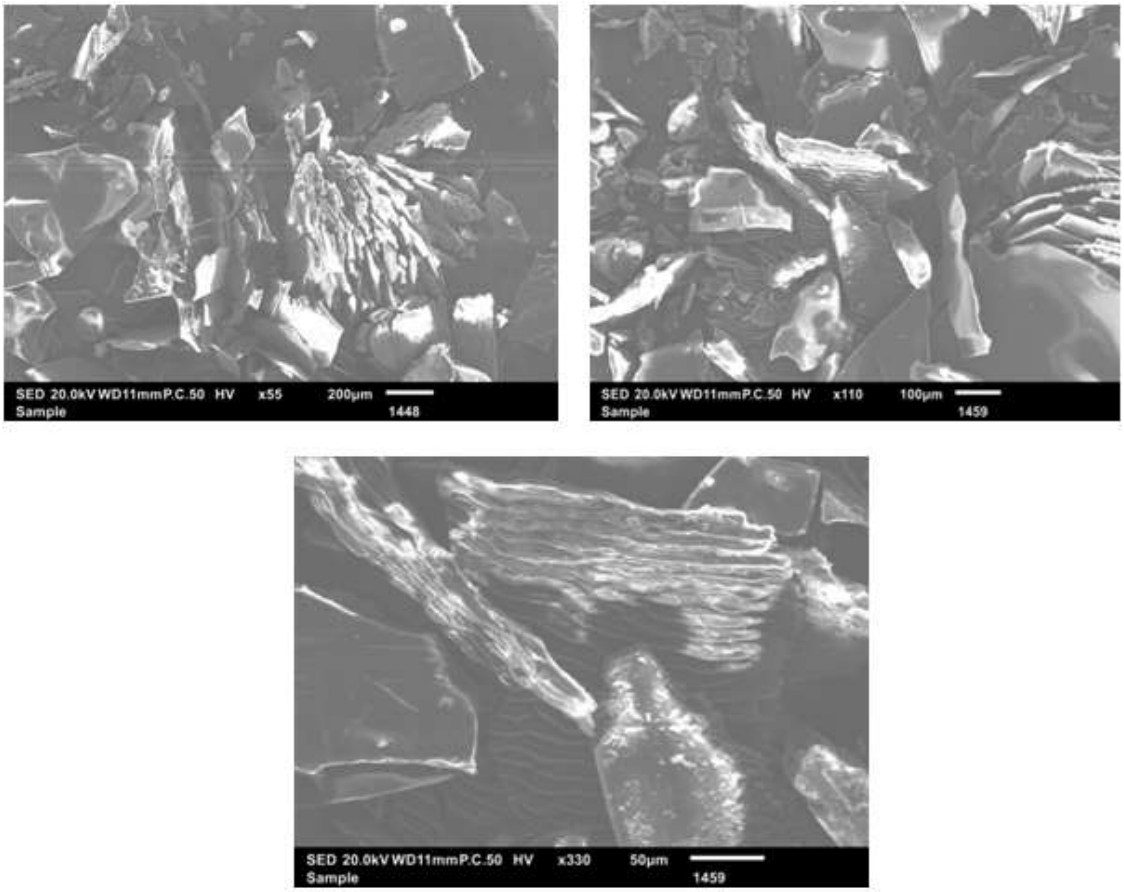


Figure 5. Scanning electron microscope (SEM) analysis of polysaccharide of the leaves of *Asphodelus tenuifolius*. Gr : X55, X 110, X 330

Determination of antioxidant activity

As shown in Figure 5, the DPPH free radical-scavenging activity of PAS exhibited a concentration-dependent increase. PAS exhibited its highest radical-scavenging activity, reaching 58.9% at a concentration of 500 µg/mL.

Reducing Power Assay

As illustrated in Figure 5, PAS demonstrated the ability to reduce Fe^{3+} to Fe^{2+}, confirming its electron-donating capacity. The reducing power of PAS and BHT increased progressively with concentration, reaching its maximum at 500 µg/mL

Scanning electron microscope (SEM) analysis

Further SEM analysis confirmed the irregular, rough, and non-porous surface morphology of PAS from *A. tenuifolius* (Figure 6). This structure contrasts with previous findings on polysaccharides, which often display porous surfaces that enhance water retention capacity - a critical feature in the cosmetic pharmaceutical, and industries food. The extraction and purification methods can significantly influence the final structure of polysaccharides.

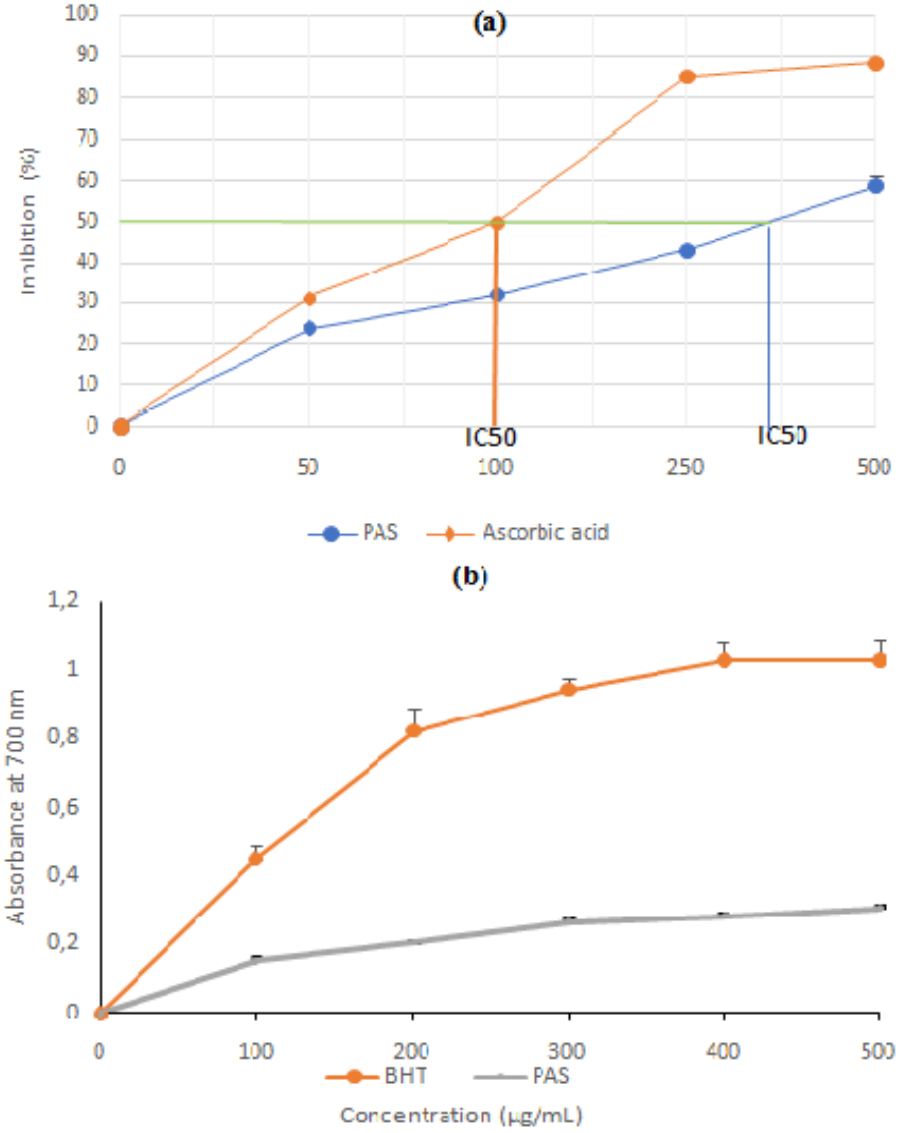


Figure 6. Antioxidant activities of PAS: (a) DPPH radical scavenging activities, (b) reducing power. PAS: *Asphodelus tenuifolius* polysaccharides

Insecticidal activity of polysaccharides

The results indicated the mortality of the insect *Tribolium confusum* was increased with increasing concentration of PAS. After 21 days of treatment, mortalities were increased to reach 66.66, 80.1 and 86 % (w/v) at 2, 4 and 8 respectively against *Tribolium confusum* (Figure 7 a, table 4). The results indicated very high repellence values recorded after 6h at different concentrations. The repellence increased with exposure time (Figure 7, Table 4).

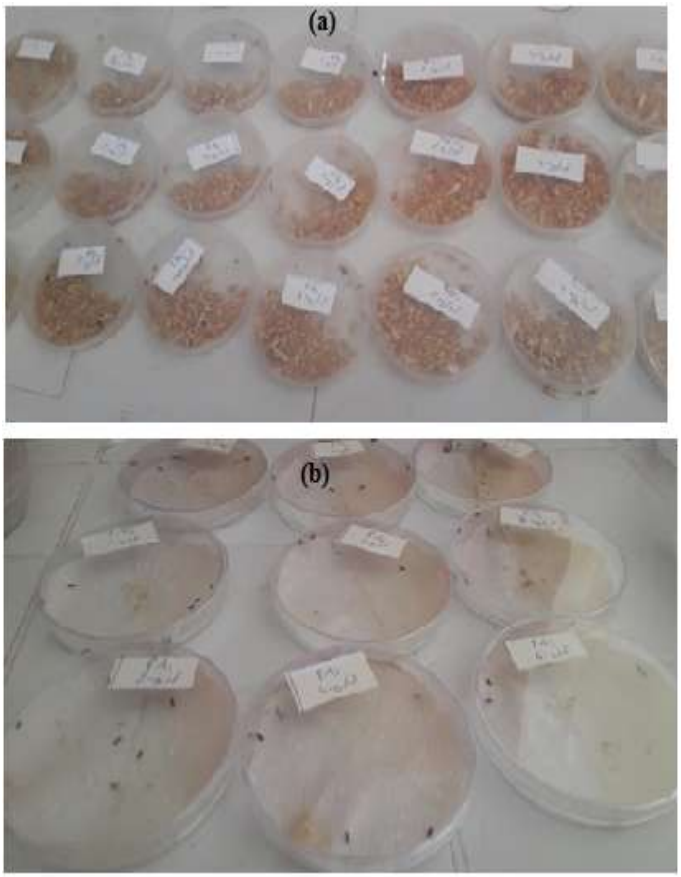


Figure 7. Insecticidal activity of polysaccharide of *Asphodelus tenuifolius* against *Tribolium confusum* with two methods: (a) Contact toxicity and (b) Repellency bioassay

Discussion

Medicinal plants serve a vital function in pharmacological research and drug development due to their diverse phytochemical composition. These bioactive compounds, particularly natural antioxidants, are known for their free radical-scavenging activities. This research focused on investigating the antioxidant, antibacterial, and free radical-scavenging activities of *Asphodelus tenuifolius*, as well as its polysaccharide extraction and characterization. The findings of Mahboub (2018), who reported hydroalcoholic extraction yields depending on the drying method. The efficiency of extraction depends on the polarity of the solvent, the chemical properties of the target molecules, and the method used for extraction (Idoudi et al., 2023). Quantitative analysis of polyphenols, flavonoids, and tannins confirmed the richness of *A. tenuifolius* in bioactive substances. The measured levels were higher than those reported in previous studies Sharma et al. (2025). This variation may result from both intrinsic (genetic) and extrinsic (environmental) factors, including climate, cultivation methods, harvest maturity, and storage conditions (Rayess et al., 2023). The significant presence of these compounds is consistent with the findings of Sharma et al. (2025), who also identified steroids, flavonoids, tannins, and polyphenols in the methanolic and ethanolic extracts of *A. tenuifolius.* The DPPH radical scavenging and the Ferric Reducing Antioxidant Power assays confirmed the strong antioxidant potential of both aqueous and ethanolic extracts. The richness of bioactive compounds, particularly phenolics, enhances the potential of these extracts to neutralize free radicals. These findings are consistent with previous research on *Satureja montana*, a polyphenol-rich species known for its antioxidant and antibacterial activities (Aćimović et al., 2022). Antioxidant molecules Including compounds like ascorbic acid, tocopherols, and flavonoids, and tannins Are recognized for their ability to donate hydrogen atoms, resulting in the reduction of DPPH radicals (Anbessa et al., 2024). FTIR spectroscopy verified the presence of functional groups, including alcohols, alkanes, and carboxylic acids (O–H stretch), nitro compounds, esters, amines, and alkenes, which are known to contribute to antioxidant activity. The alkene and carboxylate groups in polysaccharides can further stabilize free radicals, thereby enhancing antioxidant effects (Ozuna-Valencia et al., 2024). In the second part of this study, polysaccharides were isolated from A. tenuifolius using hot water extraction, yielding 8.2% (w/w). The extracted polysaccharides contained 10.27% neutral sugars and 4.9% proteins. These values differed from the results reported Boual et al. (2011), who reported a lower extraction yield (0.65% w/w) but higher protein (26.13%) and carbohydrate (28.96%) contents in *A. tenuifolius* from Algeria. The extracted polysaccharides demonstrated strong antioxidant capacities, likely due to variations in molecular weight,

monosaccharide composition, and structural conformation (Huang et al., 2024). The insecticidal potential of *A. tenuifolius* polysaccharides was evaluated against *Tribolium confusum*, revealing a dose-dependent increase in mortality, reaching 86.66 ± 5.77% at 8 µg/mL after 21 days of treatment. In addition, the polysaccharides exhibited repellent activity against *T. confusum*, with the highest average repellency of 82.22 ± 11.54% observed at 8 µg/mL. These findings support the potential use of *A. tenuifolius* polysaccharides as natural antioxidant and insecticidal agents.

Conclusion

This study demonstrated that the leaves of *Asphodelus tenuifolius* are rich in polyphenols, flavonoids, tannins, and polysaccharides, contributing to its antioxidant, and insecticidal activities. The strong antioxidant capacity is attributed to the high concentration of Bioactive compounds that possess free radical-scavenging properties. These results emphasize the pharmacological potential of *A. tenuifolius* in natural medicine, cosmetics, and pest management. Additional research is required to investigate its mechanistic pathways and explore potential applications in drug development.

Acknowledgment

The authors acknowledge, Tunisian Ministry of Higher Education and Scientific Research through the laboratory of Biotechnology and Biomonitoring of the Environment and Oasis Ecosystems (LBBEEO).

Author contributions

H. Bouzenna: methodology, investigation and write the first draft ; H ben Nasr, R. Abbessi, S. dhibi, K. Athmouni , F. Guiesmi, S. Jbehi: conceptualization, formal analysis, draft reviewing, supervision ; N. Hfaiedh: original draft writing, software.

Funding

This research was funded by the Tunisian Ministry of Higher Education and Scientific Research through laboratory of Biotechnology and Biomonitoring of the Environment and Oasis Ecosystems (LBBEEO).

Ethics approval

Not applicable.

Competing interests

The authors declare no conflict of interest. The manuscript has not been submitted for publication in another journal.

AI tool declaration

The authors declare that no AI or related tools were used in the creation of the scientific content of this manuscript.

Availability of material and data

The datasets generated and/or analyzed during the current study available from the corresponding author on reasonable request.

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