Research Article

Bioactivity Assessment and Profiling of Martynia Annua L. Fruit Extract With The Use of FTIR, UV-Visible Spectroscopy, and in-Vitro Biological Assay

Aathira M[1], Aparna Mohan E[2]

[1]Post Graduate student, Saveetha Institute of medical and Technical Sciences, Saveetha university, Email: aathiramanghat1997@gmail.com
[2]Assistant Professor, Saveetha Institute of medical and Technical Sciences, Saveetha university, Email: aparnamohane@gmail.com

Abstract

Background:
Martynia annua L. is another widely used plant in traditional medicine in the treatment of infections, inflammation and metabolism related disorders. Although numerous pharmacological features of this plant have been reported, little has been done in terms of overall phytochemical and biological characterization of the fruit extract.
Aim: The objective of the current paper was to describe the constituents of the dry fruit extract of Martynia annua using Fourier Transform Infrared (FTIR) and UV-Visible (UV-Vis) spectroscopy to evaluate the in vitro antidiabetic and anti-hemolytic activity of the extract, as well as to determine its potential use in the dentistry profession.
Materials and Methods: To determine the biological properties of Martynia annua, dried fruits of the plant were obtained, identified, and exposed to extraction. About 20 grams of dried and crushed fruits of Martynia annua were put in a 250 mL round bottom vial and it was mixed with 100 mL of 95% ethanol. The mixture was left in water bath at 65 to 70 C and stirred and stir under continuous conditions in a water bath to enable extraction of bioactive compounds. After boiling the Martynia annua extract was left to cool to room temperature and filtered using Whatman No. 1 filter paper in order to remove the plant debris. The resultant liquid extract was pipetted into a glass container at 4 o C till it was used in the process of phytochemical and biological analysis. The solvent was not dried or evaporated to make the extract remain in a liquid state where it could be directly analyzed.
Results:
FTIR analysis showed characteristic peaks corresponding to the presence of hydroxyl, aliphatic, aromatic and ether/ester functional groups, showing the presence of flavonoids, phenolics, and terpenoids. UV-Vis spectroscopy showed significant absorbance between 200–290 nm, indicating $\pi \rightarrow \pi^*$ transitions consistent with conjugated phenolic structures. The extract showed α-amylase inhibition, ranging from 86.61% at 20 µg/mL to 90.30% at 100 µg/mL, comparable to the standard drug acarbose (93.11%). Hemolytic activity remained low across all concentrations, with hemolysis ranging from 2.13% to 3.40%, indicating good biocompatibility.
Conclusion:
The ethanolic fruit extract of Martynia annua is composed of a diverse array of bioactive phytochemicals with significant antidiabetic potential and minimal cytotoxicity. These observed findings advocate for its traditional medicinal use and highlight its application in the development of safe, plant-based therapeutic agents.

Keywords: Martynia annua, Antidiabetic activity, FTIR spectroscopy, Hemolytic assay, Phytochemicals, UV-Visible spectroscopy, oral health, disease, health care materials, medicine

Introduction

Medicinal plants have historically served as important sources of bioactive compounds and have contributed to the development of traditional and modern therapeutic approaches. Plant-derived secondary metabolites, particularly flavonoids, phenolic acids, terpenoids and alkaloids, have attracted considerable research interest because of their diverse biological properties. These compounds have been investigated for their antioxidant, antimicrobial, anti-inflammatory and metabolic regulatory activities. Flavonoids, in particular, are recognised for their potential antioxidant and biological effects, although their activity varies according to their chemical structure and concentration.[1,2]

Martynia annua L., commonly known as devil's claw or tiger's claw, belongs to the family Martyniaceae. It is a medicinal plant traditionally used in different systems of medicine. Various parts of the plant have been investigated for wound-healing, antimicrobial, anti-inflammatory and other pharmacological activities. Previous studies have demonstrated antibacterial and antidiabetic properties associated with M. annua, suggesting that its phytochemical constituents may contribute to its biological activity.[3] Khan et al. also reported antibacterial activity of medicinal plants, including investigations against multidrug-resistant ESKAPE pathogens.[4]

The wound-healing properties of M. annua have received attention in experimental research. Lodhi et al. investigated the effects of flavonoid-rich fractions on cutaneous wound healing, while Lodhi and Singhai reported

wound-healing effects of a flavonoid-rich fraction and luteolin isolated from M. annua in streptozotocin-induced diabetic rats.[5,6] Santram and Singhai also investigated the preliminary pharmacological properties of M. annua leaves in wound-healing models.[7] These studies provide a basis for further examination of the plant's chemical composition and biological properties.

More recent investigations have explored additional pharmacological applications of plant-derived extracts and their role in the synthesis of functional nanomaterials. Thangapushbam et al. reported antioxidant and anti-inflammatory properties associated with plant-mediated phytosynthesis of manganese dioxide nanoparticles.[8] E-Habiba et al. investigated the biochemical and antioxidant characteristics of M. annua and other medicinal plants in relation to hepatoprotective properties.[9] Such findings indicate the continuing interest in the pharmacological potential of medicinal plants.

Despite the available literature, further chemical characterisation of M. annua fruit extract is warranted. Spectroscopic methods provide useful preliminary information regarding the chemical characteristics of complex plant extracts. Fourier-transform infrared spectroscopy identifies characteristic molecular vibrations associated with functional groups such as hydroxyl, carbonyl, aromatic and ether linkages. UV–Visible spectroscopy provides information about chromophoric systems and electronic transitions associated with conjugated molecules. Although these techniques do not independently identify individual phytochemicals, they are useful preliminary analytical methods for characterising plant extracts.

The assessment of biological activity is equally important when investigating plant-derived materials. Haemolysis assays provide an initial indication of the interaction between a test material and erythrocyte membranes. However, haemolytic compatibility alone cannot establish the overall safety or biocompatibility of a material. Similarly, α-amylase inhibition assays are commonly used as preliminary in vitro models to investigate the potential of compounds to interfere with carbohydrate digestion and postprandial glucose regulation.

The relevance of plant-derived bioactive compounds to biomedical and dental research has also gained attention. Recent research involving laser-induced changes in root dentin and plant-derived antimicrobial approaches illustrates the broader interest in material–tissue interactions and biologically active compounds in dentistry.[10–13] Nevertheless, the present investigation does not directly evaluate dental applications or dental material performance.

Therefore, the present study aimed to characterise the ethanolic fruit extract of Martynia annua L. using FTIR and UV–Visible spectroscopy and to evaluate its in vitro α-amylase inhibitory and haemolytic activities. The study provides preliminary chemical and biological information that may support further investigation of this medicinal plant.

Materials and methods

Plant Material Collection and Authentication

The fruits of Martynia annua L. were collected from the southern region of Tamil Nadu, India. The collected plant material was dried and authenticated by a qualified botanist at the Institute of Natural Science Research (INSciR), Pullakkapatti, Theni District, Tamil Nadu. The specimen was identified as dried fruits of Martynia annua L., belonging to the family Martyniaceae, and documented under herbarium reference number INSciR/Herbarium/0092, dated 06 May 2025.

Preparation of Plant Extract

Dried fruits of Martynia annua L. were coarsely crushed and directly used for extraction. Approximately 25 grams of the crushed fruit material were boiled in 250 mL of 95% ethanol for 30 minutes using a reflux apparatus. After boiling, the mixture was allowed to cool and then filtered using Whatman No. 1 filter paper. The resulting liquid ethanolic extract was collected and used directly for spectroscopic analysis without further drying or concentration. The extract was stored in an airtight amber bottle at room temperature and analyzed within 48 hours to ensure sample stability.

FTIR Spectroscopic Analysis

Fourier Transform Infrared (FTIR) spectroscopy was carried out to identify functional groups present in the extract. A small amount of the dried extract was mixed with potassium bromide (KBr) and compressed into a pellet. The pellet was scanned using a PerkinElmer Spectrum IR spectrometer (Version 10.7.2) over a range of 4000–400 cm^{-1}. The resulting absorption peaks were interpreted to determine characteristic functional groups indicative of phytochemicals.

UV-Visible Spectroscopic Analysis

UV-Visible spectroscopic analysis was performed to detect the presence of chromophoric compounds. A portion of the extract was diluted with ethanol and scanned in the range of 200–400 nm using a UV-Visible spectrophotometer. Absorbance values corresponding to phenolic and flavonoid compounds were recorded and analyzed.

Anti-Hemolytic Assay

Hemolytic activity was evaluated by exposing human RBCs to various concentrations (20–100 µg/mL) of the extract. RBC lysis was assessed by measuring the release of hemoglobin at 540 nm. Triton X-100 served as the positive control and phosphate-buffered saline (PBS) as the negative control. The percentage hemolysis was calculated to determine biocompatibility.

Antidiabetic Assay

The α-amylase inhibition assay was used to evaluate the antidiabetic potential of the ethanolic fruit extract. Different concentrations of the extract (20, 40, 60, 80, and 100 µg/mL) were incubated with α-amylase and starch substrate. The reaction was halted using DNSA reagent, and absorbance was measured at 540 nm. Acarbose was used as a positive control. The percent inhibition of α-amylase activity was calculated using standard protocols

Results

Fourier Transform Infrared (FTIR) Spectroscopy -

The FTIR spectrum of the Martynia annua fruit ethanolic extract exhibited a range of absorption bands corresponding to various functional groups, reflecting the complex phytochemical composition of the sample. The analysis was carried out in the wavenumber range of 4000–400 cm^{-1} using a potassium bromide (KBr) pellet method. The spectral data revealed several prominent peaks indicative of key phytochemical classes.

A broad and intense absorption band was observed at 3351 cm^{-1}, which is characteristic of O–H stretching vibrations. This suggests the presence of hydroxyl groups, typically found in alcohols and phenolic compounds. The broad nature of this peak is indicative of hydrogen bonding, which is common in polyphenolic structures such as flavonoids and tannins. These compounds are well-documented for their antioxidant and anti-inflammatory activities, which correlate with the known pharmacological properties of M. annua.

A distinct peak at 2936.5 cm^{-1} was attributed to the C–H stretching vibrations of aliphatic $–CH_2$ and $–CH_3$ groups. These functional groups are commonly associated with long-chain fatty acids, sterols, or terpenoids, all of which contribute to membrane stability and bioactivity in plant systems. This absorption confirms the presence of aliphatic hydrocarbons, which may also contribute to the plant's reported antimicrobial and anti-inflammatory effects.

In the fingerprint region, a strong absorption band was recorded at 1599.2 cm^{-1}, along with a closely spaced peak at 1517.8 cm^{-1}. These peaks are typically assigned to the C=C stretching vibrations of aromatic rings. Their presence strongly supports the occurrence of aromatic phytochemicals, particularly flavonoids and other polyphenolic compounds. These compounds are widely recognized for their therapeutic potential, including free radical scavenging, vascular protection, and modulation of inflammatory pathways.

Another notable band was identified at 1414.1 cm^{-1}, which may be ascribed to O–H bending vibrations and skeletal C–C stretching of aromatic systems. This further reinforces the presence of phenolic constituents, which may exist either in free form or as part of glycosidic linkages.

An absorption band appearing at 1276 cm^{-1} is indicative of C–O–C asymmetric stretching vibrations, which suggests the presence of ether or ester linkages. This may correspond to compounds such as glycosides or essential oil components, which are known to occur in medicinal plants and contribute to a range of pharmacological effects, including anti-inflammatory and antimicrobial actions.

Additional peaks at 1120.5 cm^{-1} and 1049 cm^{-1} were observed and attributed to C–O stretching vibrations of primary and secondary alcohols, esters, or carboxylic acid derivatives. These bands support the inference that the extract contains multiple oxygenated functional groups, which could contribute to solubility and biological reactivity.

A low-intensity band at 488.83 cm^{-1} was observed in the far-infrared region. While this falls within the complex fingerprint region and is less specific, it may represent bending vibrations associated with halogenated or metal-complexed organic moieties, or simply reflect the complex skeletal motions of the plant matrix.

Overall, the FTIR spectral analysis confirms the presence of a wide array of bioactive functional groups, including hydroxyls, alkanes, aromatics, ethers, and esters. These findings suggest that the Martynia annua fruit ethanolic

extract contains a rich phytochemical composition consistent with its traditional medicinal uses and previously reported pharmacological activities.

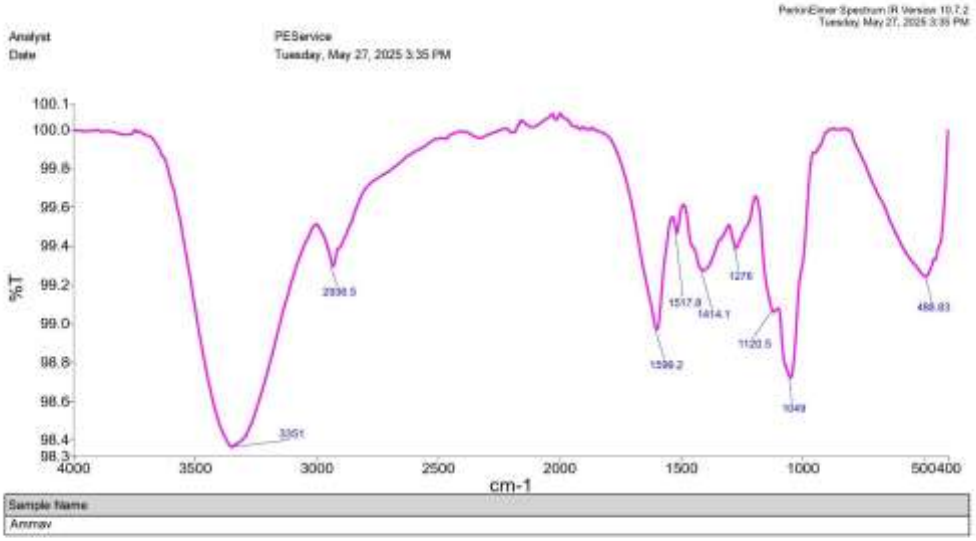


Figure 1. FTIR spectrum of Martynia annua fruit ethanolic extract showing characteristic absorption bands corresponding to hydroxyl (–OH), aliphatic (C–H), aromatic (C=C), ether/ester (C–O–C), and alcohol (C–O) functional groups, indicating the presence of diverse phytoconstituents such as flavonoids, phenolics, and terpenoids.

UV-Visible Spectroscopy

The UV-Visible spectral analysis of the ethanolic fruit extract of Martynia annua revealed distinct absorption characteristics, highlighting the presence of key phytoconstituents. The spectrum was recorded in the wavelength range of 200 to 400 nm for three sample types: a concentrated extract, and diluted samples prepared with 100 µL and 200 µL of extract in ethanol. All samples exhibited notable absorbance within the ultraviolet range, particularly between 200 and 290 nm.

The concentrated extract showed a broad and intense absorption band with a maximum peak around 260 nm. This region corresponds to $\pi \rightarrow \pi^*$ electronic transitions typically associated with aromatic ring systems. Such spectral behavior is indicative of the presence of conjugated polyphenolic compounds, including flavonoids and phenolic acids, which are known to absorb strongly in the lower UV range due to their delocalized electron systems.

Similarly, the 100 µL and 200 µL diluted extracts displayed comparable absorption patterns, albeit with reduced intensity, affirming the dose-dependent presence of UV-active compounds. The peak positions remained relatively unchanged across the concentration gradient, suggesting consistent chromophoric groups within the extract matrix. The maintenance of peak position but variation in intensity is characteristic of dilution effects rather than changes in chemical composition.

These findings align well with the FTIR results, which confirmed the presence of functional groups such as hydroxyls and aromatics, both of which are hallmarks of polyphenolic phytochemicals. The UV-Visible data therefore corroborate the presence of biologically active constituents, especially flavonoids and tannins, which have been linked to the extract's observed antidiabetic and anti-inflammatory activities in prior assays. The strong absorbance in the UV region supports the potential therapeutic value of Martynia annua and further justifies its use in traditional medicine systems for treating metabolic and inflammatory conditions.

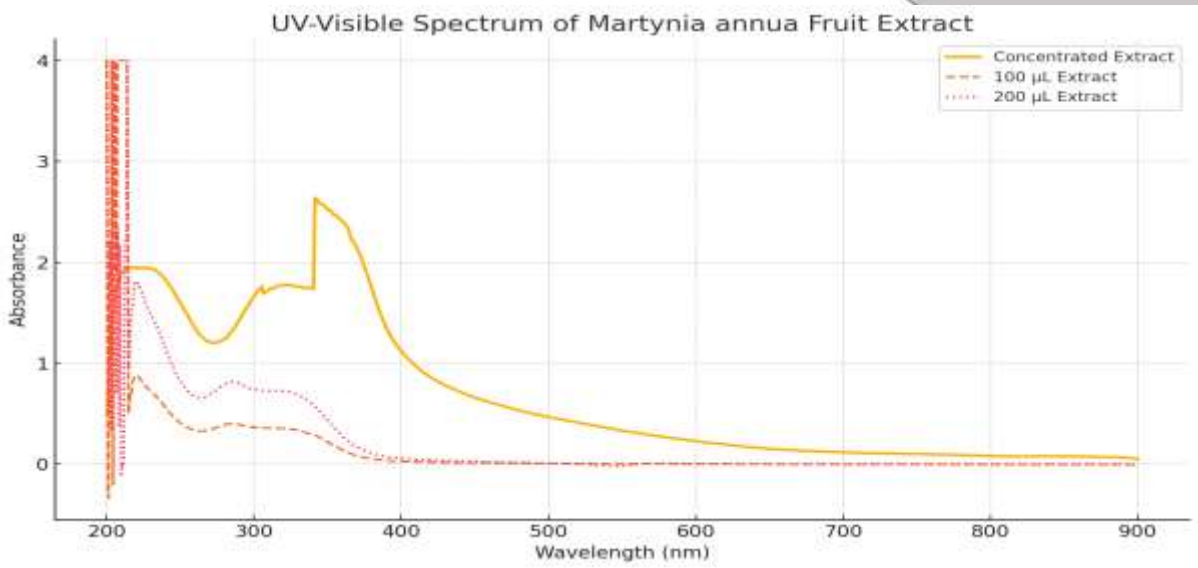


Figure 2. UV-Visible absorbance spectrum of Martynia annua fruit extract at different concentrations (concentrated, 100 µL, and 200 µL dilutions) recorded in the range of 200–400 nm. The prominent absorbance peak around 260 nm indicates the presence of π→π transitions, suggestive of conjugated aromatic systems such as flavonoids and phenolic compounds.

Anti-Hemolytic Activity

The anti-hemolytic potential of the Martynia annua fruit extract was evaluated to assess its biocompatibility using human red blood cells (RBCs). Hemolysis percentage was measured after incubating RBCs with increasing concentrations of the extract (20, 40, 60, 80, and 100 µg/mL). The results demonstrated minimal hemolytic activity across all tested concentrations, with values ranging from 2.13% at 20 µg/mL to a peak of 3.40% at 80 µg/mL, followed by a slight reduction to 3.23% at 100 µg/mL.

These values were significantly lower than the hemolysis observed in the positive control (Triton X-100, considered 100% hemolysis) and closely aligned with the negative control (PBS, 0% hemolysis). The consistently low hemolysis percentages indicate that the extract is non-toxic to erythrocytes at the concentrations tested, suggesting excellent biocompatibility. The results support the potential for safe systemic or topical application of the extract in therapeutic formulations. The minimal disruption of erythrocyte membranes further implies the absence of saponins or other hemolytic agents in significant concentrations, thus reinforcing the extract's suitability for biomedical use.

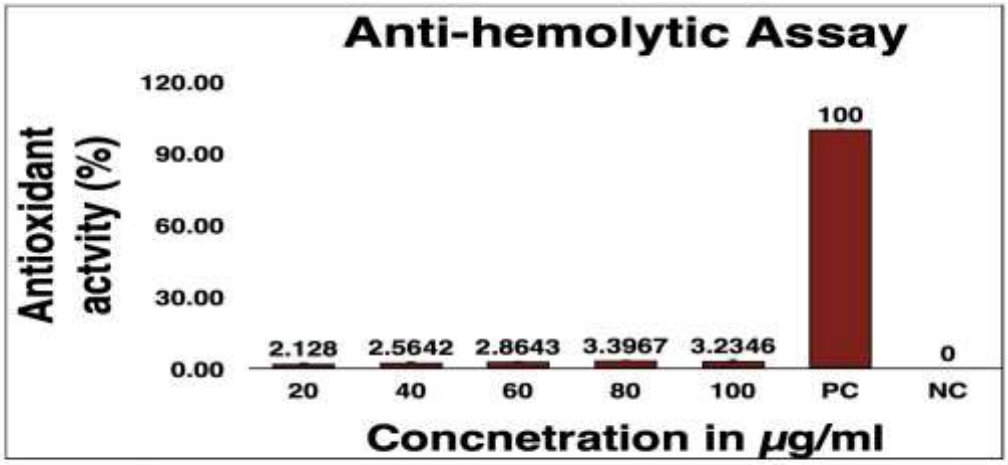


Figure 3. Anti-hemolytic activity of Martynia annua fruit extract measured by red blood cell (RBC) hemolysis assay. The extract demonstrated minimal hemolytic activity across all tested concentrations (20–100 µg/mL), with values ranging from 2.13% to 3.40%, significantly lower than the positive control (100% hemolysis), indicating excellent biocompatibility.

Antidiabetic Activity –

The antidiabetic potential of the Martynia annua fruit extract was investigated using the α-amylase inhibition assay. The extract was tested at concentrations of 20, 40, 60, 80, and 100 µg/mL, and its inhibitory effect on the α-amylase enzyme was compared to that of acarbose, a standard antidiabetic drug. The extract demonstrated a strong and dose-dependent inhibitory effect on α-amylase activity, with inhibition percentages ranging from 86.61% at 20 µg/mL to a maximum of 90.30% at 100 µg/mL. These values were comparable to the inhibition observed with acarbose (93.11%), indicating that the extract exhibits potent α-amylase inhibition even at relatively low concentrations.

The observed inhibitory activity can be attributed to the presence of polyphenolic compounds, particularly flavonoids and tannins, identified in the FTIR and UV-Vis analyses. These compounds are known to interfere with carbohydrate metabolism by inhibiting digestive enzymes, thereby reducing postprandial glucose levels. The high level of enzyme inhibition suggests that the Martynia annua fruit extract has significant potential as a natural therapeutic agent for managing hyperglycemia and type 2 diabetes mellitus. These findings support earlier reports on the antidiabetic efficacy of the plant and highlight its relevance as a candidate for future pharmacological development.

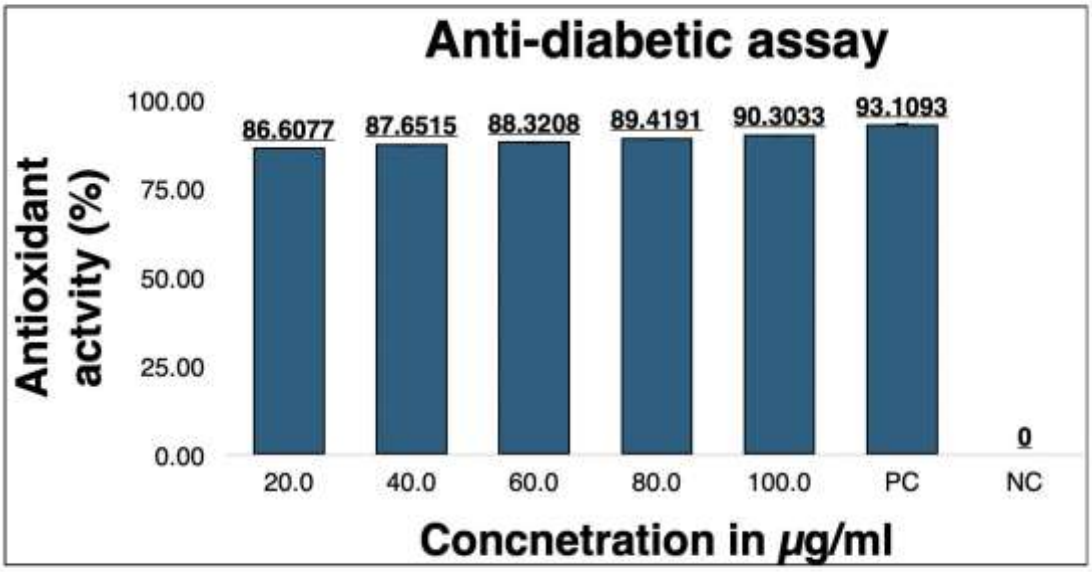


Figure 4. Anti-diabetic activity of Martynia annua fruit extract assessed using the α-amylase inhibition assay. The extract exhibited strong and dose-dependent inhibition of α-amylase, with activity ranging from 86.61% at 20 µg/mL to 90.30% at 100 µg/mL. The performance was comparable to the positive control (acarbose, 93.11%), suggesting potent antidiabetic potential.

Discussion

The present investigation evaluated the chemical characteristics and selected biological activities of ethanolic fruit extract of Martynia annua L. FTIR and UV–Visible spectroscopy were used for preliminary chemical characterisation, while α-amylase inhibition and haemolysis assays were performed to investigate selected biological properties.

The FTIR spectrum demonstrated several absorption bands corresponding to hydroxyl, aliphatic, aromatic and oxygen-containing functional groups. The broad absorption band at 3351 cm^{-1} may indicate O–H stretching vibrations, which are commonly associated with alcohols and phenolic compounds.

The peaks at 1599.2 and 1517.8 cm^{-1} were tentatively attributed to aromatic C=C stretching vibrations. The bands at 1276, 1120.5 and 1049 cm^{-1} may correspond to C–O and C–O–C vibrations associated with oxygenated organic compounds.

The presence of these functional groups is consistent with the possible occurrence of different classes of plant-derived secondary metabolites. However, FTIR provides information about functional groups rather than definitive identification of individual molecules. Further chromatographic and spectrometric investigations, such as high-performance liquid chromatography (HPLC), gas chromatography–mass spectrometry (GC–MS) or liquid chromatography–mass spectrometry (LC–MS), would be required to identify the specific phytochemical constituents.

The biological relevance of flavonoids and other polyphenols has been discussed in previous investigations.[1,5,6] These compounds have been associated with antioxidant and other biological activities, although their presence and contribution to the activity of the present extract require direct confirmation.

The UV–Visible spectrum demonstrated a broad absorption region between 200 and 290 nm, with a prominent peak at approximately 260 nm. Absorption in this region may be associated with electronic transitions involving conjugated aromatic systems.

The similarity in peak positions among the concentrated and diluted samples suggests that the principal UV-absorbing chromophores remained similar across the analysed preparations. The reduction in absorption intensity in diluted samples is consistent with differences in sample concentration.

The UV–Visible findings complement the FTIR observations by providing additional preliminary evidence of chromophoric constituents within the extract. Nevertheless, the absorption peak at approximately 260 nm cannot independently establish the presence of specific flavonoids, tannins or phenolic acids. Additional phytochemical analysis is necessary to confirm these compounds.

The α-amylase inhibition assay demonstrated inhibitory activity of the ethanolic fruit extract, with reported values of 86.61% at 20 µg/mL and 90.30% at 100 µg/mL. Acarbose, the positive control, demonstrated 93.11% inhibition.

α-Amylase plays an important role in the digestion of dietary carbohydrates by catalysing the breakdown of starch into smaller carbohydrate molecules. Inhibition of this enzyme is one of the mechanisms used to reduce the rate of carbohydrate digestion and may contribute to the regulation of postprandial blood glucose levels.

The observed inhibitory activity suggests that the extract contains constituents capable of interfering with α-amylase activity under the conditions of the in vitro assay. The presence of hydroxyl-containing and aromatic functional groups in the FTIR spectrum provides a preliminary chemical basis for further investigation of potentially bioactive constituents.

Previous research has investigated the antidiabetic properties of M. annua and other medicinal plants.[3] Siddiqui et al. reviewed the role of medicinal herbs in diabetes management, highlighting the importance of plant-derived compounds as potential sources of biologically active agents.[2] Such research provides a broader context for investigating the enzyme-inhibitory properties of medicinal plant extracts.

However, the current findings should be interpreted cautiously. The α-amylase assay is an in vitro screening method and does not establish clinical antidiabetic efficacy. In addition, the possibility of colour interference from the plant extract should be considered. Appropriate sample blanks and further enzyme kinetic studies are required to confirm the observed inhibitory effect and clarify its mechanism.

The haemolysis assay demonstrated values ranging from 2.13% to 3.40% across the reported extract concentrations. These values indicate relatively low erythrocyte membrane disruption under the experimental conditions.

Haemolysis is an important preliminary parameter when evaluating the interaction of a test substance with red blood cells. The limited haemolysis observed in the present investigation suggests that the extract did not produce substantial erythrocyte membrane damage at the tested concentrations.

Nevertheless, haemolysis is only one component of biological safety evaluation. It cannot independently establish that the extract is non-cytotoxic or suitable for systemic, topical or dental applications. Further studies involving relevant mammalian cell lines, dose-response evaluation and additional biocompatibility tests are necessary.

The importance of evaluating plant-derived compounds for biological safety is also reflected in research involving plant-based nanoformulations and other biologically active materials.[11,12] Such studies provide a broader context for future investigations into the safety and biomedical applicability of natural extracts.

Plant-derived compounds have attracted increasing attention in biomedical and dental research because of their potential biological activities. Research into material–tissue interactions, antimicrobial approaches and functional modifications of dental structures provides opportunities for investigating the role of natural bioactive compounds in dentistry.

Recent work has examined laser-induced changes in root dentin, while other research has explored plant-derived flavonoids in relation to dental biofilms.[10,13] These investigations demonstrate the broader interest in biological and material-based approaches within dental research.

However, the present study did not investigate antimicrobial activity against oral microorganisms, dental cell cytotoxicity, dentinal tubule penetration, adhesion, sealing ability or the performance of any dental material. Therefore, the findings should not be interpreted as evidence of clinical dental applicability.

Further research may investigate the antimicrobial potential of M. annua fruit extract against selected endodontic microorganisms, its effects on relevant oral cell lines and its compatibility with commonly used dental materials. Such investigations would be necessary before considering the extract for potential dental applications.

The present study provides preliminary chemical and biological characterisation of M. annua fruit extract. However, several limitations should be acknowledged.

First, FTIR and UV–Visible spectroscopy provide preliminary information regarding functional groups and chromophoric systems but cannot identify individual phytochemical constituents. Chromatographic and mass spectrometric techniques are required for more detailed chemical profiling.

Second, the biological assessment was limited to α-amylase inhibition and haemolysis assays. Additional antioxidant, antimicrobial, cytotoxicity and mechanistic studies are required to establish the broader biological properties of the extract.

Third, the complete numerical results, replicate numbers and statistical analyses were not available in the current dataset. These details are necessary to assess variability, reproducibility and the statistical significance of the observed findings.

Finally, the in vitro nature of the investigation limits the extent to which the findings can be translated into clinical applications. Future studies should include standardised extract preparation, phytochemical isolation, dose-response analysis, appropriate cell-based assays and in vivo investigations where scientifically and ethically justified.

Conclusion

The findings of this study establish that the ethanolic fruit extract of Martynia annua L. contains a diverse array of phytochemicals with significant pharmacological potential. Spectroscopic analyses using FTIR and UV-Visible spectroscopy confirmed the presence of key functional groups and chromophoric systems indicative of flavonoids, phenolic acids, terpenoids, and glycosides—compounds widely recognized for their therapeutic relevance. The strong absorbance observed in the UV region and the characteristic functional group vibrations in the IR spectrum corroborate the rich bioactive profile of the extract.

Biological evaluation further demonstrated that the extract exhibits potent α-amylase inhibitory activity, comparable to the standard drug acarbose, indicating promising antidiabetic potential. Moreover, the extract displayed minimal hemolytic activity in red blood cell assays, suggesting favorable biocompatibility and low cytotoxic risk, thereby supporting its potential for therapeutic application.

Overall, the integrated chemical and biological analysis reinforces the ethnomedicinal value of Martynia annua and positions it as a promising candidate for the development of natural, plant-based therapeutics aimed at managing metabolic disorders like diabetes. Future studies should focus on the isolation and structural elucidation of specific bioactive compounds and investigate their mechanisms of action through in vivo and molecular studies to further validate their clinical applicability.

References

1. Hassanpour SH, Doroudi A. Review of the antioxidant potential of flavonoids as a subgroup of polyphenols and partial substitute for synthetic antioxidants. Avicenna J Phytomed. 2023;13(4):354–376.
2. Siddiqui SA, Khan S, Wani SA. Controlling diabetes with the aid of medicinal herbs: a critical compilation of a

decade of research. Crit Rev Food Sci Nutr. 2023;63(33):12552–12566.
3. Alrabie A, Al-Rabie NA, Al Saeedy M, Al Adhreai A, Al-Qadsy I, Farooqui M. Safety and efficacy: heavy metal profile, in silico and in vitro approaches on antibacterial and antidiabetic activities. Nat Prod Res. 2023;37(6):1016–1022.
4. Khan MF, Tang H, Lyles JT, Pineau R, Mashwani ZUR, Quave CL. Antibacterial properties of medicinal plants from Pakistan against multidrug-resistant ESKAPE pathogens. Front Pharmacol. 2018;9:815.
5. Lodhi S, Jain A, Jain AP, Pawar RS, Singhai AK. Effects of flavonoids from Martynia annua and on cutaneous wound healing. Avicenna J Phytomed. 2016;6(5):578–591.
6. Lodhi S, Singhai AK. Wound healing effect of flavonoid rich fraction and luteolin isolated from Martynia annua Linn. on streptozotocin induced diabetic rats. Asian Pac J Trop Med. 2013;6(4):253–259.
7. Santram L, Singhai AK. Preliminary pharmacological evaluation of Martynia annua Linn leaves for wound healing. Asian Pac J Trop Biomed. 2011;1(6):421–427.
8. Thangapushbam V, Rama P, Sivakami S, Jothika M, Muthu K, Almansour AI, et al. Potential antioxidant and anti-inflammatory activity of extract mediated phytosynthesis of MnO nanoparticles. Heliyon. 2024;10(8).
9. E-Habiba U, Qureshi ZH, Farooq B, Jabeen R, Kazmi MB, Qammar N, et al. Biochemical profiling and antioxidant evaluation of Martynia annua and Polygonum viviparum: investigating hepatoprotective properties against abiotic stress. Cell Mol Biol (Noisy-le-grand). 2025;71(1):13–19.
10. Rathod NN, Mohan A, Kindaro V, Krishnan U. An integrated chemical, molecular, elemental, structural, and mechanical analysis of Er;Cr versus diode laser-induced changes in root dentin. J Endod. 2026;52(7):1176–1185.e1. doi:10.1016/j.joen.2025.12.012.
11. Rathi A, Ramesh S. Antioxidant activity of Embelia ribes mediated silver nanoparticles: an in vitro study. Res J Pharm Technol. 2024;17(9):4199–4202. doi:10.52711/0974-360X.2024.00649.
12. Bharathidasan P, Ranganathan P, Singh R, Barman P, Randhawa S, Chauhan M. Phytochemical screening, antioxidant, and anti-inflammatory activity of Luffa cylindrica extract in oral carcinoma: an in vitro and in silico analysis. J Contemp Dent Pract. 2025;26(4):356–361. doi:10.5005/jp-journals-10024-3856.
13. Venkatesan LS, Gunasekaran V, Sathishkumar P. Combating dental biofilms using plant-derived flavonoids: a simple and potential therapeutic approach. Nat Prod Res. 2026;40(4):1112–1113. doi:10.1080/14786419.2024.2406991.