RESEARCH PAPER

ANTIOXIDANT AND HEPATOPROTECTIVE POTENTIAL OF TERMINALIA ARJUNA, CURCUMA LONGA, AND PHYLLANTHUS NIRURI: A COMPARATIVE STUDY OF HERBAL EXTRACTS

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ABSTRACT

This study aimed to evaluate the antioxidant and hepatoprotective effects of Terminalia arjuna bark, Curcuma longa rhizome, and Phyllanthus niruri leaves. The plants were extracted using ethanol and methanol, and their total phenolic content and antioxidant activity were assessed. The results revealed that ethanol and methanol extracts exhibited significantly higher levels of phenolic compounds and antioxidant activity compared to other solvents, with Phyllanthus niruri ethanol extract showing the highest phenolic content (48.35 mg/g) and Terminalia arjuna ethanol extract exhibiting the highest antioxidant activity (58.86 mMols/g). The findings suggest that polar solvents are more efficient in extracting bioactive polyphenols, which may contribute to the plants' therapeutic properties. These results support the potential of these plant extracts in developing natural antioxidants and hepatoprotective agents for medicinal applications.

Keywords: Antioxidant activity, hepatoprotective effects, Terminalia arjuna, Curcuma longa, Phyllanthus niruri,

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Introduction

Plants have long been a cornerstone of traditional medicine, with many species contributing valuable bioactive compounds that exhibit therapeutic properties. Among these, Terminalia arjuna (T. arjuna), Curcuma longa (C. longa), and Phyllanthus niruri (P. niruri) are highly regarded for their pharmacological potential. These plants have a longstanding history in traditional medicine systems, particularly Ayurveda, and are renowned for their antioxidant, hepatoprotective, and anti-inflammatory effects (Dixit et al., 2000; Lobo et al., 2010). The scientific exploration of their chemical composition and biological activity is crucial to validating their traditional uses and further investigating their therapeutic applications.

Terminalia arjuna, commonly known as Arjuna, is a tree native to the Indian subcontinent. The bark of this tree is rich in active compounds such as tannins, flavonoids, and phenolics, which have been linked to its cardiovascular, anti-inflammatory, and hepatoprotective properties (Vaidya et al., 2015). Its traditional use in treating heart-related conditions and liver disorders underscores its significance in modern pharmacology, particularly for its antioxidant and free radical scavenging activity (Tiwari et al., 2008).

Curcuma longa, or turmeric, is one of the most extensively studied medicinal plants, primarily due to its active constituent, curcumin. Curcumin has

demonstrated potent antioxidant, anti-inflammatory, and hepatoprotective properties, making it an attractive candidate for the treatment of chronic diseases, including liver disorders (Aggarwal et al., 2007). Curcuma longa has been widely used in both food and medicine, with its primary therapeutic benefits linked to its ability to combat oxidative stress and inflammation (Srinivasan, 2005).

Phyllanthus niruri, also known as the "stone breaker," is a small herb found in tropical and subtropical regions. This plant is well-known for its potential in treating liver disorders, jaundice, and kidney stones (Sharma et al., 2012). The plant contains flavonoids, alkaloids, and lignans, which are believed to possess

significant antioxidant and hepatoprotective activities. Studies have highlighted its ability to reduce oxidative stress and enhance liver function, thereby supporting its traditional use in liver health management (Saha et al., 2013).

Terminalia arjuna (Arjuna)

Terminalia arjuna, a deciduous tree native to the Indian subcontinent, has been extensively studied for its cardiovascular, anti-inflammatory, and hepatoprotective properties. The bark of T. arjuna is rich in bioactive compounds, including tannins, flavonoids, saponins, and glycosides, which are responsible for its therapeutic effects (Tiwari et al., 2008). According to Patil et al. (2011), T. arjuna has been shown to possess significant antioxidant activity, which plays a crucial role in preventing oxidative damage, a major contributor to liver toxicity and cardiovascular diseases. In a study conducted by Vaidya et al. (2015), the bark extracts of T. arjuna demonstrated hepatoprotective effects in animal models, where it effectively reduced liver enzymes and promoted liver regeneration, highlighting its potential as a natural remedy for liver ailments.

The antioxidant activity of T. arjuna was also confirmed by Garg et al. (2011), who reported that the ethanolic extract of the plant exhibited significant free radical scavenging activity, suggesting its utility in managing diseases associated with oxidative stress. In addition to its antioxidant effects, T. arjuna has been widely researched for its role in cardiac health. Chatterjee et al. (2003) observed that T. arjuna significantly improved lipid profiles and reduced oxidative stress in patients with heart disease, providing evidence of its cardio-protective potential.

Curcuma longa (Turmeric)

Curcuma longa, commonly known as turmeric, is one of the most studied plants for its therapeutic benefits, primarily due to the active compound curcumin. Curcumin exhibits potent antioxidant, anti-inflammatory, and hepatoprotective activities, making C. longa a valuable plant for liver health and oxidative stress-related conditions (Aggarwal et al., 2007). According to Srinivasan (2005), curcumin has been shown to reduce the levels of reactive oxygen species (ROS) and modulate various antioxidant enzymes, thereby mitigating the effects of oxidative stress.

Several studies have also demonstrated the hepatoprotective effects of C. longa. Kucharska et al. (2015) found that curcumin reduced liver enzyme levels and increased the antioxidant defense mechanisms in animal models of liver damage induced by alcohol and toxic chemicals. Furthermore, Prasad et al. (2014) highlighted curcumin's ability to protect the liver from fibrosis and cirrhosis, suggesting its potential as a treatment for chronic liver diseases.

The antioxidant properties of C. longa are attributed not only to curcumin but also to other polyphenolic compounds present in the rhizome. Chattopadhyay et al. (2004) demonstrated that both curcumin and its metabolites could inhibit lipid peroxidation and protein oxidation, further supporting the plant's role in oxidative stress management.

Phyllanthus niruri (Stonebreaker)

Phyllanthus niruri, also known as the stonebreaker, is another plant widely used in traditional medicine for its hepatoprotective, antiviral, and kidney-stone-dissolving properties. The plant contains various bioactive compounds, including flavonoids, lignans, alkaloids, and tannins, which have been shown to possess antioxidant and hepatoprotective activities (Saha et al., 2013). Mishra et al. (2010) reviewed the pharmacological properties of P. niruri, noting its significant ability to reduce liver damage induced by various toxins, including alcohol and carbon tetrachloride. The hepatoprotective effects are attributed to the antioxidant activity of the plant, which reduces oxidative stress and enhances liver function (Saha et al., 2012).

Phyllanthus niruri has also been shown to modulate liver enzyme levels, reduce the accumulation of lipids in liver tissues, and restore normal liver function in experimental models of liver toxicity (Sharma et al., 2012). According to Patel et al. (2015), the plant's ability to protect liver cells from oxidative damage is likely due to its potent free radical scavenging properties, which are enhanced by its flavonoid and lignan content.

In addition to its hepatoprotective effects, P. niruri has demonstrated antiviral activity against hepatitis B virus (HBV), with Sahu et al. (2013) finding that its extracts inhibited HBV replication in vitro. This antiviral property further elevates its importance in

managing liver diseases, particularly those caused by viral infections.

Antioxidant and Hepatoprotective Activity

The antioxidant properties of these plants are often attributed to their high content of phenolic compounds, which have been shown to exhibit significant free radical scavenging activity. Nayak et al. (2006) conducted a comparative study on the antioxidant activity of T. arjuna, C. longa, and P. niruri, and reported that all three plants exhibited significant antioxidant effects, with T. arjuna demonstrating the highest activity in scavenging free radicals. Similarly, Srinivasan et al. (2012) observed that the methanol extract of P. niruri showed a high degree of antioxidant activity, which contributed to its hepatoprotective potential.

The hepatoprotective effects of T. arjuna, C. longa, and P. niruri are primarily attributed to their antioxidant properties, which help mitigate oxidative stress and prevent liver cell damage. Khan et al. (2011) highlighted that oxidative stress plays a central role in the pathogenesis of liver diseases, including alcoholic liver disease, non-alcoholic fatty liver disease, and hepatitis. Therefore, plants with potent antioxidant activity, such as T. arjuna, C. longa, and P. niruri, represent promising candidates for the treatment and prevention of liver diseases.Bottom of Form

Methods

Collection of all the plant materials

Terminalia arjuna (bark), Curcuma longa (rhizome), and Phyllanthus niruri (leaves) were collected from authenticated sources. T. arjuna and C. longa were obtained from a certified Ayurvedic supplier, while P. niruri was wild-harvested locally in season. All plant parts were shade-dried (10–15 days), ground into coarse powder, and stored in airtight containers for further use.

Physicochemical Evaluation

Physicochemical evaluation assesses the physical and chemical properties of a substance, aiding in its characterization across scientific disciplines:

Loss on drying

Loss on drying (LOD) quantifies moisture or volatile content in a sample by measuring weight loss after drying. Commonly used in pharmaceuticals, food, and materials science, the process involves weighing a prepared sample, drying it at ~105°C for 2–4 hours, cooling in a desiccator, and reweighing. The LOD is calculated as the percentage weight loss. Accurate weighing, consistent drying conditions, and proper equipment calibration are essential for reliable results.

Determination of Ash Value .

Total ash value

To determine the total ash value, a representative powdered sample (2–3 g) is accurately weighed and placed in a pre-ignited crucible. The sample is incinerated in a muffle furnace at 550°C–600°C until complete combustion occurs, leaving only inorganic ash. The crucible is then cooled in a desiccator to prevent moisture absorption and reweighed. The total ash content is calculated as a percentage of the original sample weight, providing a measure of the sample's total mineral content. Proper pre-ignition, combustion, and weighing techniques are essential for accurate results.

Total ash value = (z-x/y) × 100

Where,

X = weight of the silica crucible

Y = weight of the drug powder (g)

Z = weight of the silica cruicible with powder ash

Acid-insoluble ash

Acid-insoluble ash determination assesses the amount of inorganic matter in a sample that does not dissolve in dilute hydrochloric acid, indicating impurities like silica or sand. A finely powdered, accurately weighed sample is first incinerated at around 500°C to obtain total ash. This ash is then boiled with dilute HCl, and the insoluble portion is filtered, washed, dried, and weighed. The acid-insoluble ash is calculated as a percentage of the original sample weight, providing a more specific measure of sample purity, especially important in evaluating the quality of herbal materials.

Acid insoluble ash value % = (A/Y) × 100

where,

A = weight of the remaining residue

Y = weight of crude powder taken (g)

Water-soluble ash

Water-soluble ash determination measures the portion of total ash that dissolves in water, helping assess the purity of herbal materials. A finely powdered, accurately weighed sample is incinerated at around 500°C to obtain total ash. The ash is then boiled with distilled water, and the solution is filtered. The insoluble residue is collected, dried, and weighed. The difference between total ash and this residue gives the water-soluble ash content, expressed as a percentage of the original sample weight. This test is vital in pharmaceuticals for detecting excess soluble salts or impurities in herbal drugs.

Determination of swelling index

The swelling index measures the expansion of a material when exposed to a liquid, commonly used in pharmaceuticals and materials science. A representative sample is weighed and immersed in a liquid (often water) for a specified period. After swelling, the sample is blotted to remove excess liquid, and its final weight is recorded. The swelling

index is calculated as a percentage of the material's swelling capacity. This method helps assess materials like excipients and polymers, providing critical data for drug formulation and controlled-release systems.

Preparation of crude Extracts

Plant materials were cleaned, shadow dried, and then dried in a hot air oven at a temperature of no more than 50°C.

Soxhlet extraction

The dried, coarsely powdered plant materials of Terminalia arjuna (bark), Curcuma longa (rhizome), and Phyllanthus niruri (leaves) were extracted using Soxhlet extraction with 95% ethanol, chosen for its ability to extract a wide range of phytochemicals like phenolics, flavonoids, alkaloids, and tannins. Each plant material (100 g) was placed in a thimble and extracted for 6–8 hours, until the solvent in the siphon tube was clear. The extracts were filtered, concentrated under reduced pressure using a rotary evaporator, and dried in a desiccator. The final semi-solid extracts were stored in airtight containers at 4°C for further analysis.

Phytochemical screening of extracts

Test for Proteins: Biuret Test

- Principle: Detects peptide bonds in proteins.
- Procedure: Add 1% copper sulfate and sodium hydroxide to the extract. A violet color indicates proteins.
- Test for Carbohydrates: Benedict's Test
- Principle: Detects reducing sugars.
- Procedure: Mix extract with Benedict's reagent and heat. A red, orange, or yellow precipitate indicates reducing sugars.

Molisch's Test

- Principle: A general test for carbohydrates.
- Procedure: Add Molisch's reagent and concentrated sulfuric acid. A violet ring indicates carbohydrates.

Test for Lipids: Sudan III Test

- Principle: Detects lipids.
- Procedure: Add Sudan III solution to extract. A red color indicates lipids.

Test for Phenols: Ferric Chloride Test

- Principle: Detects phenolic compounds.
- Procedure: Add ferric chloride solution. A blue-green or black color indicates phenols.

Test for Terpenoids: Salkowski Test

- Principle: Detects terpenoids, particularly steroids.
- Procedure: Mix extract with chloroform and sulfuric acid. A reddish-brown color indicates terpenoids.

Test for Flavonoids: Shinoda Test

Principle: Detects flavonoids.

Procedure: Add magnesium and hydrochloric acid. Pink, red, or violet color indicates flavonoids.

Test for Terpenoids: Bornträger's Test

- Principle: Detects triterpenes.
- Procedure: Dissolve extract in chloroform, add sulfuric acid. Reddish-brown color indicates triterpenes.

Test for Alkaloids: Hager's Test

- Principle: Detects opium alkaloids like morphine.
- Procedure: Add Hager's reagent. Yellow or orange precipitate indicates alkaloids.

Test for Anthraquinones: Bornträger's Test (Modified)

- Principle: Detects anthraquinones.
- Procedure: Add ammonia solution to chloroform extract. Pink, red, or violet color indicates anthraquinones.

Test for Cardiac Glycosides: Keller-Kiliani Test

- Principle: Detects cardenolides (cardiac glycosides).
- Procedure: Add glacial acetic acid and ferric chloride. Bluish-green or violet color indicates cardenolides.

Test for Cyanogenic Glycosides: Guignard's Test

- Principle: Detects cyanogenic glycosides.
- Procedure: Treat extract with picric acid and sodium hydroxide. Red or orange color indicates cyanogenic glycosides.

In vitro antioxidant studies

Estimation of Total Phenolic Content

The Folin–Ciocalteu method (Malick and Singh, 1980) was employed to determine the total phenolic content of the plant extract. A 0.2 mL aliquot of the extract was mixed with 2.8 mL of distilled water and 0.5 mL of diluted Folin–Ciocalteu reagent (1:2 with distilled water). After incubating the mixture at room temperature for 3 minutes, 2.0 mL of a 20% sodium carbonate solution was added. The tubes were then placed in a boiling water bath for 1 minute, followed by cooling to room temperature. The absorbance of

the solution was measured at 650 nm using a UV–Visible Spectrophotometer (Shimadzu UV-1601). A standard curve was prepared using varying concentrations of catechol, and the phenolic content in the plant extract was calculated based on this curve, with results expressed as milligrams of catechol equivalent per gram of dry sample. Each sample was tested in triplicate to ensure accuracy and reliability of the results.

Total antioxidant activity (FRAP assay)

The Ferric Reducing Antioxidant Power (FRAP) assay, as modified by Benzie and Strain (1996), was used to assess the antioxidant activity of the plant extract. For this assay, 20 µL of the plant extract was pipetted into a clean test tube, followed by the addition of 900 µL of freshly prepared FRAP working solution. The FRAP solution was prepared by mixing 25 mL of acetate buffer (pH 3.6), 2.5 mL of TPTZ solution, and 2.5 mL of ferric chloride solution. The reaction mixture was allowed to incubate for 4–6 minutes at room temperature or 37°C. After the incubation period, the absorbance was measured at 593 nm using a UV–Visible spectrophotometer. A standard curve was prepared using known concentrations of ferrous sulfate ($FeSO_4$) to calculate the antioxidant activity, which was expressed as mmol Fe^{2+} equivalents per gram of the sample. The results were obtained in triplicates to ensure reliability.

Results

Macroscopic studies:

The organoleptic characters of Terminalia arjuna (bark), Curcuma longa (rhizome), and Phyllanthus niruri (leaves) vary distinctly in terms of shape, size, odour, taste, and colour.

Table 1. Organoleptic characters of plants *Terminalia arjuna* (bark), *Curcuma longa* (rhizome), and *Phyllanthus niruri* (leaves)

S.No	Parameters	Observations of Terminalia arjuna (bark)	Observations of Curcuma longa (rhizome)	Observations of Phyllanthus niruri (leaves)
1.	Shape	Curved or flat strips	Irregularly oval or cylindrical	Lanceolate or elliptic
2.	Size	6–15 cm long, 1–3 cm wide	4–8 cm long, 2–4 cm thick	2–5 cm long, 1–2 cm wide
3.	Odour	Slight, characteristic	Strong, aromatic	Slight, herbaceous
4.	Taste	Astringent, slightly bitter	Pungent, slightly bitter	Bitter
5.	Colour	Outer surface grey to reddish-brown	Yellow to orange	Green
6.	Foreign organic matter	Absent or within permissible limits	Absent or within permissible limits	Absent or within permissible limits

Physicochemical Standardization of Terminalia arjuna (bark), Curcuma longa (rhizome), and Phyllanthus niruri (leaves)

The physicochemical standardization parameters of Terminalia arjuna bark reveal important quality indicators.

Table 2: Standardization parameters of Physicochemical Standardization of Terminalia arjuna (bark).

S.No	Parameters % (w/w)	Terminalia arjuna (bark) (%w/w)
1	Ash value	12.25
2	Foreign organic matter	1.25
3	Water soluble ash	5.4
4	Acid insoluble ash	1.6
5.	Moisture content	7.8

Fig 1: Graph of Standardization parameters of Physicochemical Standardization of Terminalia arjuna (bark).

Physicochemical Standardization of Curcuma longa (rhizome)

The physicochemical standardization of Curcuma longa rhizome provides key insights into its quality and purity.

Fig 2: Graph of Standardization parameters of Physicochemical Standardization of Curcuma longa (rhizome)

Physicochemical Standardization of Phyllanthus niruri (leaves)

The physicochemical standardization of Phyllanthus niruri leaves highlights important quality control parameters.

Table 3. Physicochemical Standardization of Phyllanthus niruri (leaves)

S.No	Parameters % (w/w)	Curcuma longa (rhizome) (%w/w)
1	Ash value	6.26
2	Foreign organic matter	1.55
3	Water soluble ash	2.7
4	Acid insoluble ash	1.52
5.	Moisture content	9.05

Fig 3: Graph of Standardization parameters of Phyllanthus niruri (leaves)

Prelimnary Phytochemical Analysis

These results suggest that all three plants are rich in bioactive compounds like alkaloids, flavonoids, tannins, and triterpenoids, supporting their traditional use in herbal medicine

Table 4. Phytochemical Profile of Terminalia arjuna (bark)

S.No	Parameters % (w/w)	Phyllanthus niruri (leaves) (%w/w)
1	Ash value	11.25
2	Foreign organic matter	1.24
3	Water soluble ash	6.05
4	Acid insoluble ash	1.88
5.	Moisture content	8.75

Where + is Present and – is Absent

Table 5. Phytochemical Profile of Curcuma longa (rhizome)

S.no	Chemical Tests	Terminalia arjuna bark Extract
S.no	Chemical Tests	Ethanol
1.	Tests for Steroids and Triterpenoids:	
1.	• Liebermann's Burchard Test	+
1.	• Salkowski Test	+
2.	Test for Saponins:	
2.	• Foam Test	+
3.	Tests for Alkaloids:	
3.	• Hager's Test	+
3.	• Mayer's Test	+
4.	Tests for Glycosides:	
4.	• Borntrager's Test	-
4.	• Keller Killiani Test	-
5.	Tests for Tannins and Phenolic compounds:	
5.	• Gelatin Test	+
5.	• Ferric Chloride Test	+
6.	Tests for Flavonoids:	
6.	• Ferric chloride Test	+
6.	• Alkaline reagent Test	+
7.	Tests for Proteins:	
7.	• Biuret Test	-
7.	• Xanthoproteic Test	-
8.	Test for Polysaccarides:	
8.	• Molish Reaction	-

Where + is Present and – is Absent

Table 6. Phytochemical Profile of Phyllanthus niruri (leaves)

S.no	Chemical Tests	Curcuma longa (rhizome) Extract
S.no	Chemical Tests	Ethanol
1.	Tests for Steroids and Triterpenoids:	
1.	• Liebermann's Burchard Test	+
1.	• Salkowski Test	+
2.	Test for Saponins:	
2.	• Foam Test	+
3.	Tests for Alkaloids:	
3.	• Hager's Test	+
3.	• Mayer's Test	+
4.	Tests for Glycosides:	
4.	• Borntrager's Test	-
4.	• Keller Killiani Test	-
5.	Tests for Tannins and Phenolic compounds:	
5.	• Gelatin Test	+
5.	• Ferric Chloride Test	+
6.	Tests for Flavonoids:	
6.	• Ferric chloride Test	+
6.	• Alkaline reagent Test	+
7.	Tests for Proteins:	
7.	• Biuret Test	-
7.	• Xanthoproteic Test	-
8.	Test for Polysaccarides:	
8.	• Molish Reaction	-

Where + is Present and – is Absent

Biochemical Analysis

Total Phenolic Content

The total phenolic content in various extracts of Terminalia arjuna bark varies significantly depending on the solvent used, indicating the influence of solvent polarity on phenolic extraction efficiency.

Table: Total phenolics in various extracts of Terminalia arjuna (bark)

S.No	Extracts of Terminalia arjuna (bark)	Total phenolics (mg/g)
1.	Petroleum Ether Extract	5.2 ± 0.5
2.	Chloroform Extract	9.3 ± 0.8
3.	Ethyl Acetate Extract	13.2 ± 1.1
4.	Methanol Extract	27.4 ± 2.0
5.	Ethanol Extract	41.7 ± 1.5
6.	Aqueous Extract	29.9 ± 1.3

The data were expressed as mean ± SE (n=3).

Total Phenolic Content

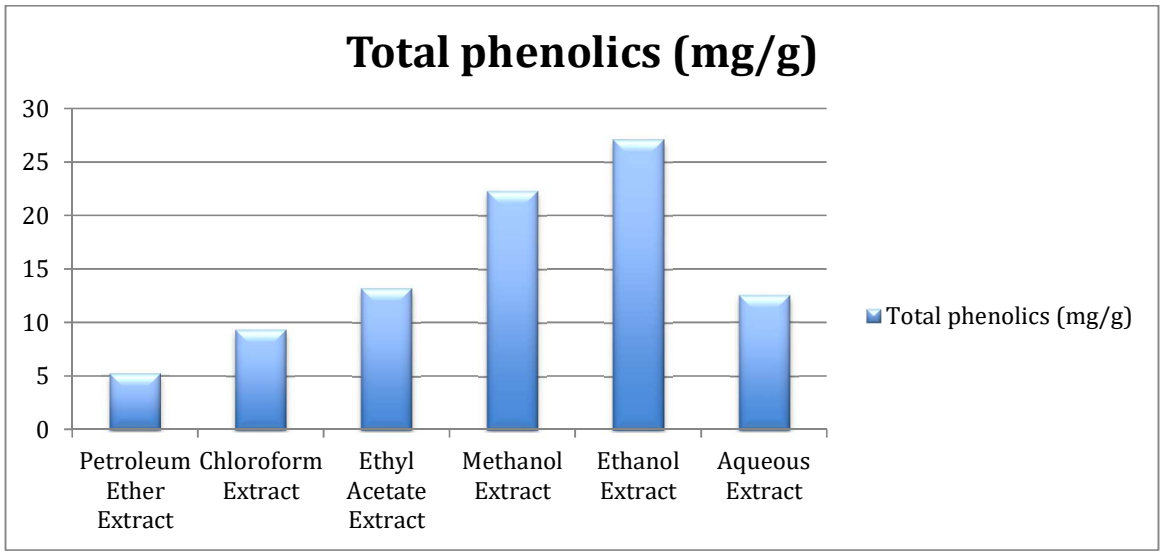
The total phenolic content in different extracts of Curcuma longa (rhizome) demonstrates notable variation based on the solvent used for extraction.

Table : Total phenolics in various extracts of Curcuma longa (rhizome)

Table : Total phenolics in various extracts of Curcuma longa (rhizome)

S.No	Extracts of Curcuma longa (rhizome)	Total phenolics (mg/g)
1.	Petroleum Ether Extract	5.2 ± 0.5
2.	Chloroform Extract	9.3 ± 0.8
3.	Ethyl Acetate Extract	13.2 ± 1.1
4.	Methanol Extract	22.3 ± 2.4
5.	Ethanol Extract	27.12 ± 0.52
6.	Aqueous Extract	12.5 ± 1.0

The data were expressed as mean ± SE (n=3).



Total Phenolic Content

The total phenolic content in various extracts of Phyllanthus niruri (leaves) shows a clear pattern of increasing values with solvent polarity.

Table: Total phenolics in various extracts of Phyllanthus niruri (leaves)

S.No	Extracts of Phyllanthus niruri (leaves)	Total phenolics (mg/g)

1.	Petroleum Ether Extract	10.25 ± 0.42
2.	Chloroform Extract	17.33± 0.57
3.	Ethyl Acetate Extract	15.34± 0.51
4.	Methanol Extract	44.25± 1.27
5.	Ethanol Extract	48.35± 1.38
6.	Aqueous Extract	25.61± 0.96

The data were expressed as mean ± SE (n=3).

Total antioxidant activity (FRAP assay)

The total antioxidant activity of Terminalia arjuna bark extracts was assessed using different solvents, and the results reveal significant variation in antioxidant potential based on the extraction solvent.

Table : Total antioxidant activity in various extracts of

The data were expressed as mean ± SE (n=3)

Total antioxidant activity (FRAP assay)

These results highlight ethanol as the most effective solvent for extracting antioxidants from Curcuma longa rhizome, suggesting its potential for therapeutic use in managing oxidative stress.

Table : Total antioxidant activity in various extracts of Curcuma longa (rhizome)

The data were expressed as mean ± SE (n=3).

Total antioxidant activity (FRAP assay)

These results suggest that ethanol is the most effective solvent for extracting antioxidants from Phyllanthus niruri leaves, supporting its potential use for antioxidant-based therapies.

Table : Total antioxidant activity in various extracts of Phyllanthus niruri (leaves)

The data were expressed as mean ± SE (n=3).

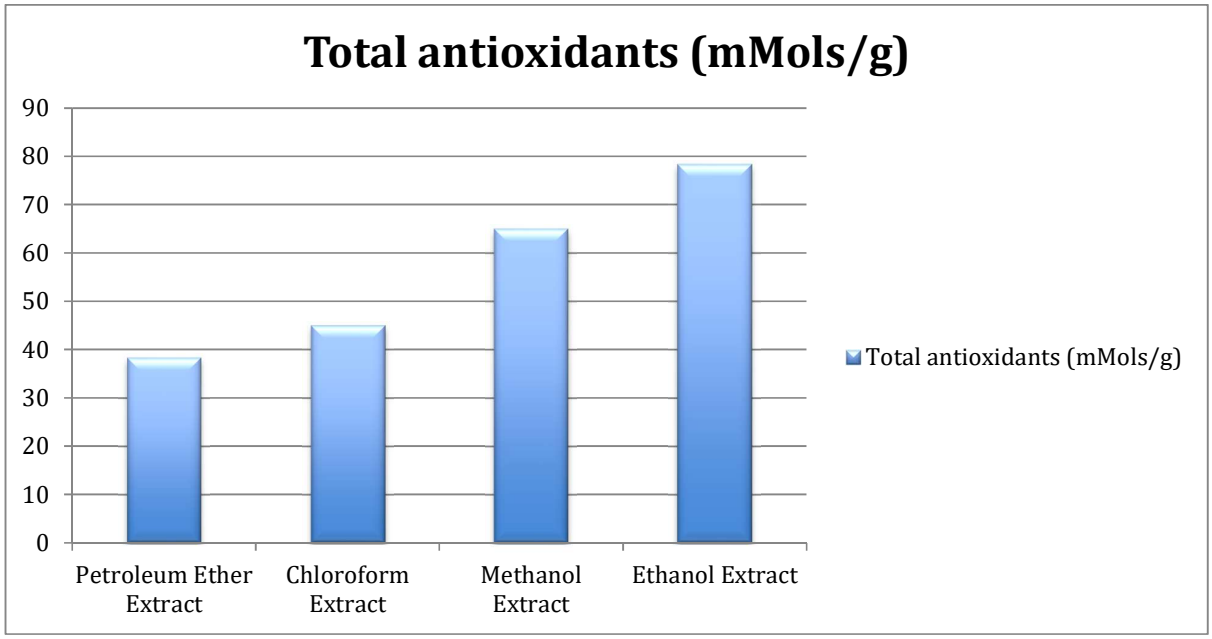


Fig :Total antioxidant activity in various extracts of Phyllanthus niruri (leaves)

Conclusion

In conclusion, the study highlights the potent antioxidant and hepatoprotective potential of Terminalia arjuna bark, Curcuma longa rhizome, and Phyllanthus niruri leaves, particularly when extracted using polar solvents like ethanol and methanol. The findings suggest that ethanol extracts, especially from Phyllanthus niruri, exhibit the highest phenolic

content, while Terminalia arjuna ethanol extract demonstrates superior antioxidant activity. These results indicate the promising therapeutic potential of these plant extracts, especially for applications targeting oxidative stress-related conditions and liver protection. Further pharmacological investigations are warranted to validate these effects and explore their mechanisms of action.

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Conflict of Interest

The authors declare that there are no conflicts of interest related to this study.

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