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(RESEARCH ARTICLE)

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Phytochemical screening and pH-responsive indicator potential of *Curcuma aromatica* rhizome extracts for green analytical applications

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Abstract

Curcuma aromatica Salisb., commonly known as Wild Turmeric or Jungli Haldi, is a medicinally important plant widely recognized for its rich phytochemical composition and traditional therapeutic applications. The present study was undertaken to investigate the phytochemical constituents and natural pH-responsive indicator potential of *Curcuma aromatica* rhizome extracts prepared using solvents of varying polarity, including methyl acetate, ethyl acetate, dichloromethane, carbon tetrachloride, and hot water. Qualitative phytochemical screening revealed the presence of several bioactive secondary metabolites such as alkaloids, flavonoids, terpenoids, tannins, phenolic compounds, saponins, carbohydrates in different solvent extracts, whereas glycosides, proteins, and amino acids were absent under the present experimental conditions. The distribution of phytochemicals was found to vary depending on the polarity of the extraction solvent.

The ethanolic rhizome extract was further evaluated for its application as a natural acid–base indicator and herbal pH-sensitive paper. The extract exhibited a distinct colour transition from yellow in acidic medium to reddish-brown in alkaline medium, indicating significant pH-responsive behaviour. Comparative titration studies performed using standard synthetic indicators demonstrated that the endpoint observations and titre values obtained with *Curcuma aromatica* extract were closely comparable to conventional indicators. In addition, the prepared herbal pH strips showed rapid, clear, and reproducible colour responses in acidic, neutral, and basic solutions.

The findings of the present investigation highlight the dual significance of *Curcuma aromatica* as both a phytochemically valuable medicinal plant and an eco-friendly analytical material. Its biodegradable, economical, and non-toxic nature suggests considerable potential for application in green chemistry, sustainable laboratory practices, and educational analytical experiments as a natural alternative to synthetic pH indicators.

Keywords: *Curcuma aromatica*; Wild Turmeric; Phytochemical Screening; Natural pH Indicator: Herbal pH Paper; Green Analytical Chemistry; Rhizome Extracts; Eco-Friendly Indicator; Secondary Metabolites; Acid–Base Titration

1. Introduction

Medicinal plants have been used as an important source of therapeutic agents since ancient times and continue to play a significant role in healthcare systems worldwide. A major proportion of the global population still depends on plant-based remedies for primary healthcare because of their accessibility, affordability, and comparatively fewer side effects than synthetic drugs. In recent decades, scientific interest in medicinal plants has increased considerably due to their rich phytochemical composition and diverse biological activities, which provide promising opportunities for the development of novel pharmaceutical and analytical products (Sofowora, 2008; Harborne, 1998).

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Among various medicinal plants, *Curcuma aromatica* Salisb., commonly known as Wild Turmeric or Jungli Haldi, occupies an important position in traditional Ayurvedic and folk medicine. The plant belongs to the family Zingiberaceae and is widely distributed in tropical and subtropical regions of Asia, particularly in the Indian subcontinent. It is a perennial rhizomatous herb characterized by aromatic underground rhizomes and broad green leaves. The rhizomes represent the most medicinally significant part of the plant and are extensively used for the treatment of skin disorders, wounds, inflammation, digestive ailments, and microbial infections (Kirtikar and Basu, 2006).

The therapeutic importance of *Curcuma aromatica* is mainly attributed to the presence of various phytochemicals such as alkaloids, flavonoids, terpenoids, tannins, phenolic compounds, saponins, steroids, glycosides, and curcuminoids. These bioactive constituents are known to possess antioxidant, antimicrobial, anti-inflammatory, and anticancer properties that contribute to the medicinal value of the plant (Aggarwal et al., 2007). In addition to medicinal applications, the rhizomes are also widely utilized in cosmetic preparations because of their skin-enhancing and protective properties (Ammon and Wahl, 1991).

Phytochemical screening plays an essential role in the preliminary evaluation of medicinal plants because it helps identify the nature of secondary metabolites present in different plant extracts. The extraction of phytochemicals largely depends upon the polarity of solvents used during extraction. Therefore, the use of solvents of varying polarity provides a comprehensive understanding of the chemical composition and pharmacological significance of medicinal plants (Trease and Evans, 2009).

In recent years, increasing awareness regarding environmental safety and sustainable laboratory practices has encouraged the development of eco-friendly alternatives to synthetic chemicals used in analytical chemistry. One such area of interest is the use of plant-derived natural indicators in acid–base titrations and pH determination. Synthetic indicators such as phenolphthalein and methyl orange are widely used in laboratories; however, concerns related to their toxicity and environmental impact have promoted research into biodegradable and non-toxic natural indicators obtained from plant pigments (Pathade et al., 2013).

Natural indicators are generally obtained from plant pigments such as anthocyanins, flavonoids, and curcuminoids that exhibit characteristic colour changes under acidic and alkaline conditions. (Pathade et al., 2013) *Curcuma aromatica*, being rich in curcuminoid pigments, possesses remarkable pH-responsive properties. The rhizome extract exhibits yellow colour in acidic medium and changes to reddish-brown in alkaline medium, indicating its suitability as a natural acid–base indicator. Furthermore, the extract can also be utilized in the preparation of herbal pH-sensitive paper by impregnating filter paper with the plant extract. Such herbal pH papers are biodegradable, inexpensive, easy to prepare, and suitable for educational as well as laboratory applications. (Pathade et al., 2013)

Therefore, the present study aimed to investigate the phytochemical constituents and pH-responsive indicator properties of *Curcuma aromatica* rhizome extracts for green analytical applications.

1.1. Plant Profile

Table 1 Botanical Classification of *Curcuma aromatica*

Parameter	**Details**
Botanical Name	*Curcuma aromatica* Salisb.
Family	Zingiberaceae
Common Name	Wild Turmeric / Jungli Haldi
Plant Type	Perennial Rhizomatous Herb

Figure 1 *Curcuma aromatica* (Wild Turmeric/Jungli Haldi) Plant, Fresh Rhizomes, and Rhizome Powder Used for Phytochemical and Natural Indicator Studies

1.2. Plant Description

Curcuma aromatica Salisb. is a perennial rhizomatous herb belonging to the family Zingiberaceae. The plant is widely distributed in tropical and subtropical regions of India and other Asian countries. It possesses aromatic underground rhizomes that are yellow to orange in colour and rich in curcuminoids and essential oils. The leaves are broad, green, and lanceolate in shape, while the flowers are pale yellow to pinkish in appearance.

The rhizomes of *Curcuma aromatica* are extensively used in Ayurvedic and traditional medicine because of their antimicrobial, antioxidant, anti-inflammatory, and therapeutic properties. In addition to medicinal applications, the rhizomes are also used in cosmetic formulations and as a natural colouring and pH-sensitive material in analytical studies.

2. Materials and Methods

2.1. Collection of Plant Material

Fresh rhizomes of *Curcuma aromatica* (Wild Turmeric/Jungli Haldi) were collected from the local market of Chhindwara, Madhya Pradesh, India. The rhizomes were thoroughly washed with tap water followed by distilled water to remove adhering soil particles and impurities. The cleaned rhizomes were shade-dried at room temperature and then crushed into coarse powder using a mechanical grinder. The powdered material was stored in clean air-tight containers for further experimental studies.

2.2. Chemicals, Reagents and Apparatus

All chemicals and reagents used during the investigation were of analytical grade. The reagents included hydrochloric acid (HCl), sodium hydroxide (NaOH), acetic acid (CH_3COOH), ammonium hydroxide (NH_4OH), ethanol, and distilled water. Standard synthetic indicators such as phenolphthalein, methyl orange, and methyl red were used for comparative titration studies.

For phytochemical screening, Mayer's reagent, Dragendorff's reagent, Wagner's reagent, ferric chloride solution, lead acetate solution, sodium hydroxide solution, foam test reagents, and Salkowski reagents were employed. Whatman filter paper and universal pH strips were used during the preparation and evaluation of herbal pH paper.

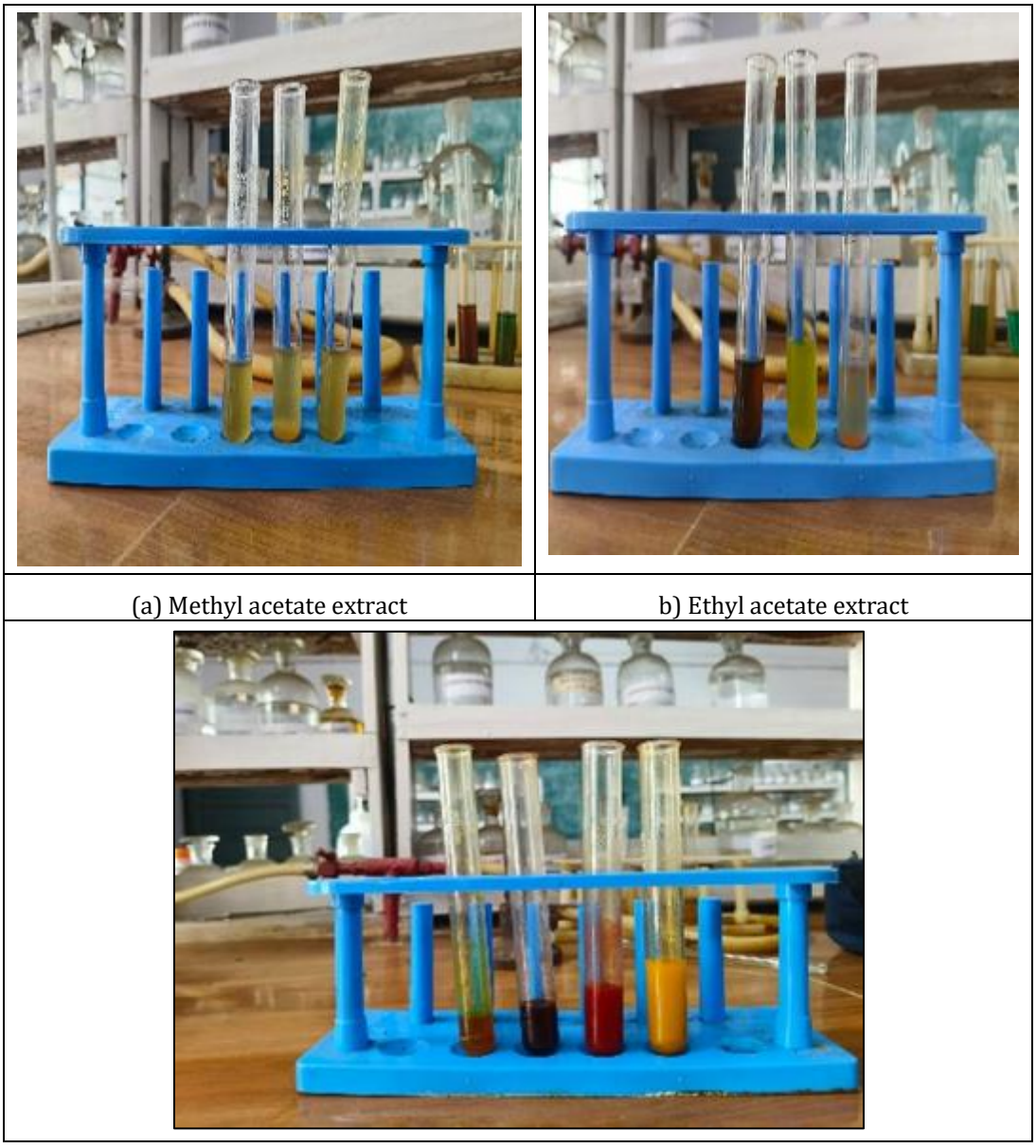
The apparatus used in the study included burette, pipette, conical flask, volumetric flask, measuring cylinder, dropper, glass rod, retort stand with clamp, water bath, heating mantle, and electronic weighing balance.

2.3. Extraction of *Curcuma aromatica* Rhizomes

Approximately 50 g of dried rhizome powder was separately extracted using solvents of varying polarity including methyl acetate, ethyl acetate, dichloromethane (DCM), carbon tetrachloride (CCl_4), and distilled hot water. In some extraction systems, the solvent mixture was prepared in the ratio of 7:3 (v/v), consisting of 70 mL solvent and 30 mL distilled water.

Each extraction was carried out in a 500 mL conical flask. The flasks were sealed with rubber corks and shaken gently for approximately 20 minutes. The mixtures were then allowed to stand at room temperature for 48 hours to 4 days to ensure effective extraction of phytochemical constituents. (Trease and Evans, 2009).

After extraction, the mixtures were filtered through Whatman filter paper, and the filtrates were collected in clean air-tight containers. The percentage yield of each extract was calculated and recorded for comparative analysis.



(a) Methyl acetate extract

b) Ethyl acetate extract

Figure 2 Different solvent extracts of *Curcuma aromatica* rhizomes obtained using solvents of varying polarity

2.4. Preparation of Natural Indicator

For the preparation of the natural indicator solution, 10 g of dried and powdered rhizome of *Curcuma aromatica* was mixed with 100 mL of ethanol in a conical flask. The mixture was shaken thoroughly and allowed to stand for 24–48 hours for efficient extraction of colouring compounds.

The extract was then filtered to obtain a clear, yellow-coloured solution, which was used as a natural acid–base indicator. The indicator exhibited a characteristic colour transition from yellow in acidic medium to reddish-brown in alkaline medium, demonstrating its pH-responsive behaviour and suitability for acid–base titration experiments.

2.5. Preparation of Herbal pH Paper

Clean and dry strips of Whatman filter paper were cut into uniform sizes and immersed in the prepared ethanolic extract of *Curcuma aromatica* for a few minutes to allow proper absorption of the indicator solution. The soaked strips were removed and dried at room temperature under dust-free conditions.

After drying, the prepared pH strips developed a yellow colour and were stored in sealed air-tight containers for further pH analysis studies.

3. Qualitative Phytochemical Analysis of Plant Extracts

The different solvent extracts of *Curcuma aromatica* were subjected to standard qualitative phytochemical screening for the detection of major classes of bioactive compounds including carbohydrates, alkaloids, flavonoids, terpenoids, steroids, tannins, phenolic compounds, saponins, proteins, amino acids, fats, oils, and glycosides. The ethanolic extract was also evaluated for its natural pH-responsive indicator activity. The extract exhibited yellow colour in acidic medium and reddish-brown colour in alkaline medium, indicating its suitability as a natural acid–base indicator.

3.1. Detection of Carbohydrates in *Curcuma aromatica* Rhizome Extracts

3.1.1. Molisch's Test (Alcoholic α-Naphthol Test)

Two millilitres of plant extract were mixed with Molisch's reagent followed by careful addition of concentrated sulfuric acid along the wall of the test tube. Formation of a violet ring at the junction confirmed the presence of carbohydrates.

3.1.2. Fehling's Test

Equal volumes of Fehling's solution A and B were mixed with the extract and heated in a boiling water bath. Formation of a brick-red precipitate indicated reducing sugars.

3.1.3. Benedict's Test

The extract was treated with Benedict's reagent and heated in a water bath. Colour change from green to yellow or red confirmed reducing sugars.

3.1.4. Barfoed's Test

The extract was mixed with Barfoed's reagent and heated. Formation of a red precipitate indicated monosaccharides.

3.1.5. Seliwanoff's Test

The extract was treated with Seliwanoff's reagent and heated in a water bath. Appearance of rose-red coloration confirmed ketose sugars. (Harborne, 1998; Trease and Evans, 2009)

3.2. Detection of Alkaloids

The extracts were dissolved in dilute hydrochloric acid, shaken thoroughly, and filtered. The filtrates were subjected to various alkaloid tests.

3.2.1. Mayer's Test

Addition of Mayer's reagent produced a creamy white precipitate indicating the presence of alkaloids.

3.2.2. Dragendorff's Test

Treatment with Dragendorff's reagent resulted in formation of orange to reddish-brown precipitate confirming alkaloids.

3.2.3. Hager's Test

Addition of Hager's reagent produced yellow precipitate indicating the presence of alkaloids.

3.2.4. Wagner's Test

Formation of reddish-brown precipitate after treatment with Wagner's reagent confirmed alkaloids. (Trease and Evans, 2009)

3.3. Detection of Terpenoids and Steroids

3.3.1. Salkowski's Test

The extract dissolved in chloroform was treated with concentrated sulfuric acid. Development of reddish-brown coloration indicated terpenoids, while red interface suggested sterols.

3.3.2. Liebermann–Burchard Test

The extract was treated with acetic anhydride, glacial acetic acid, and concentrated sulfuric acid. Formation of green coloration indicated steroids, whereas deep red colour confirmed triterpenoids. (Harborne, 1998)

3.4. Detection of Flavonoids

3.4.1. Lead Acetate Test

The extract was treated with 10% lead acetate solution. Formation of a yellow precipitate confirmed the presence of flavonoids in the rhizome extracts. The appearance of this precipitate indicated the presence of flavonoid compounds capable of forming complexes with lead ions.

3.4.2. Shinoda Test

A small quantity of magnesium turnings and a few drops of concentrated hydrochloric acid were added to the extract. Development of pink or reddish coloration confirmed the presence of flavonoids. The colour change occurred due to reduction reactions involving flavonoid compounds.

3.4.3. Alkaline Reagent Test

The extract was treated with sodium hydroxide solution, resulting in the formation of deep yellow coloration. Upon addition of dilute hydrochloric acid, the colour disappeared, confirming the presence of flavonoids. This reversible colour change is characteristic of flavonoid compounds under alkaline conditions. (Harborne, 1998; Trease and Evans, 2009)

3.4.4. Sulfuric Acid Test

Concentrated sulfuric acid was added carefully to the extract. Development of orange coloration indicated the presence of flavonoids in the rhizome extract. The observed colour change confirmed the occurrence of acid-sensitive flavonoid constituents.

3.5. Detection of Tannins and Phenolic Compounds

3.5.1. Ferric Chloride Test

A few drops of ferric chloride solution were added to the extract dissolved in distilled water. Development of blue-green or violet coloration confirmed the presence of tannins and phenolic compounds. The colour formation occurred due to complex formation between phenolic groups and ferric ions. (Harborne, 1998)

3.5.2. Lead Acetate Test

The aqueous extract was treated with lead acetate solution. Formation of white precipitate indicated the presence of phenolic compounds. This reaction demonstrated the interaction of phenolic constituents with lead ions.

3.5.3. Gelatin Test

The extract solution was mixed with gelatin solution containing sodium chloride. Formation of precipitate confirmed the presence of tannins in the extract. The precipitate was produced due to binding of tannins with proteins present in gelatin.

3.5.4. Alkaline Reagent Test

Addition of sodium hydroxide solution to the extract produced yellow or reddish coloration. The observed colour change indicated the presence of tannins and phenolic compounds. These compounds readily undergo colour reactions in alkaline medium.

3.6. Detection of Saponins

3.6.1. Froth Test

The extract was shaken vigorously with distilled water in a graduated cylinder. Persistent froth formation that remained stable for several minutes indicated the presence of saponins. The stable foam formation is a characteristic property of saponin compounds.

3.6.2. Emulsion Test

A few drops of oil were added to the froth solution and shaken thoroughly. Formation of stable emulsion confirmed the presence of saponins in the extract. The emulsifying property is due to the surface-active nature of saponins. (Trease and Evans, 2009)

3.7. Detection of Fats and Oils

3.7.1. Acrolein Test

The extract was heated with potassium bisulfate in a dry test tube. Formation of pungent irritating odour confirmed the presence of fats and oils. The characteristic smell was due to the formation of acrolein from glycerol-containing lipids.

3.7.2. Solubility Test

The extract was tested for solubility in chloroform and ethanol. The observed solubility in these organic solvents indicated the presence of fats and oily constituents in the rhizome extracts. This confirmed the existence of non-polar lipid compounds in *Curcuma aromatica*. (Trease and Evans, 2009)

3.8. Detection of Proteins and Amino Acids

3.8.1. Biuret Test

The extract was treated with sodium hydroxide solution followed by copper sulfate solution. Development of violet coloration confirmed the presence of proteins. The colour formation resulted from the interaction between peptide bonds and copper ions in alkaline medium.

3.8.2. Ninhydrin Test

The extract was heated with ninhydrin reagent in a water bath. Appearance of blue coloration indicated the presence of amino acids. This reaction occurred due to the interaction of free amino groups with ninhydrin. (Harborne, 1998; Trease and Evans, 2009)

3.8.3. Xanthoproteic Test

The extract was treated with concentrated nitric acid and heated gently. Development of yellow coloration confirmed the presence of aromatic amino acids. The colour change occurred due to nitration reactions involving aromatic rings.

3.8.4. Millon's Test

Millon's reagent was added to the extract and the mixture was heated. Formation of white precipitate turning brick red on boiling confirmed proteins. This test specifically indicated the presence of tyrosine-containing proteins.

3.9. Detection of Glycosides

3.9.1. Borntrager's Test

The extract was hydrolysed with dilute sulfuric acid, filtered, and treated with ammonia solution. Development of pink or red coloration indicated anthraquinone glycosides. The observed colour confirmed the liberation of anthraquinone derivatives after hydrolysis.

3.9.2. Legal's Test

The extract was treated with sodium nitroprusside and sodium hydroxide solution. Appearance of pink-red coloration confirmed the presence of cardiac glycosides. The reaction indicated the presence of active glycosidic constituents in the extract.

3.9.3. Keller–Killiani Test

The extract was treated with glacial acetic acid containing ferric chloride followed by concentrated sulfuric acid. Formation of blue coloration in the acetic acid layer indicated cardiac glycosides. The colour change confirmed deoxy sugar-containing glycosides.

3.9.4. Baljet's Test

The extract solution was treated with picric acid and sodium hydroxide solution. Development of yellow to orange coloration confirmed the presence of glycosides. The reaction demonstrated the presence of biologically active glycosidic compounds. (Trease and Evans, 2009)

4. Results and Discussion

4.1. Extractive Yield of *Curcuma aromatica* Rhizome Extracts

The powdered rhizomes of *Curcuma aromatica* (50 g) were extracted using solvents of progressively increasing polarity, namely methyl acetate, ethyl acetate, dichloromethane (DCM), carbon tetrachloride (CCl_4), and hot water. The extraction process yielded coloured extracts ranging from pale yellow to dark brown, indicating the presence of diverse phytochemical constituents. The variation in extractive yield suggested that solvent polarity significantly influenced the extraction efficiency of bioactive compounds. Moderately polar solvents such as ethyl acetate and methyl acetate exhibited comparatively higher extraction efficiency for flavonoids and phenolic compounds, whereas non-polar solvents mainly extracted lipophilic compounds such as oils and terpenoids.

Table 2 Extractive Yield of *Curcuma aromatica* Rhizome Extracts

Solvent/Fraction	Yield (g)	Characteristics
Methyl acetate	1.1 g	Yellow extract rich in phenolics
Ethyl acetate	1.3 g	Deep yellow extract containing flavonoids
Dichloromethane (DCM)	0.8 g	Yellowish extract containing terpenoids
Carbon tetrachloride (CCl_4)	0.5 g	Pale yellow oily extract
Hot water	0.9 g	Dark brown extract rich in polar compounds
Total	4.6 g	From 50 g powdered rhizome

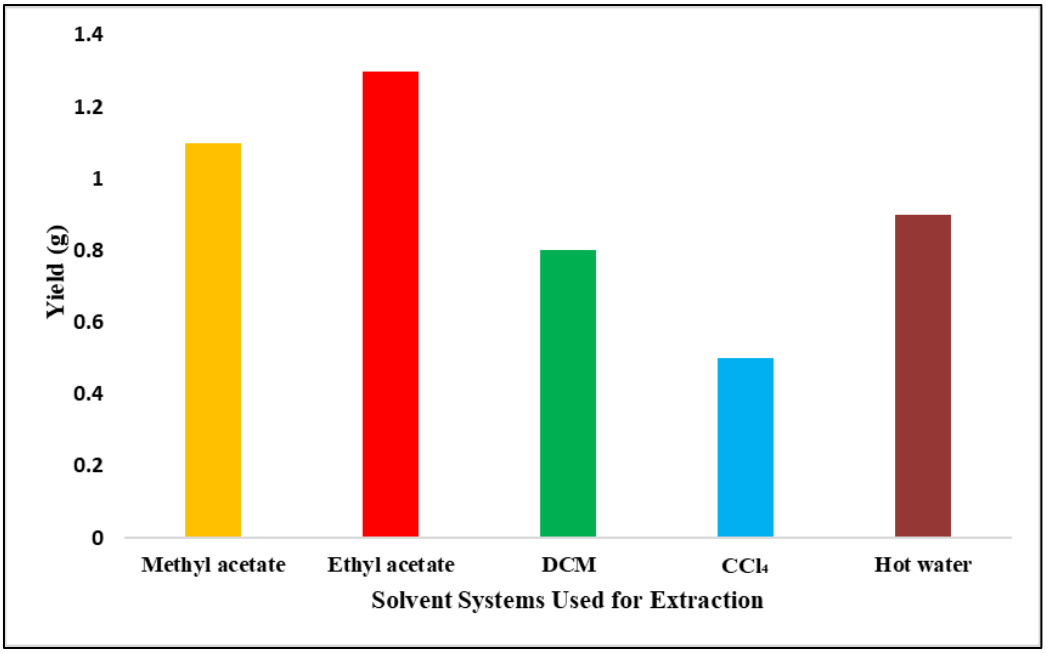


Figure 3 Extractive Yield of *Curcuma aromatica* Rhizome Extracts Using Different Solvent Systems

4.2. Solubility Determination of Curcuma aromatica Rhizome Extracts

The solubility behaviour of different solvent extracts of *Curcuma aromatica* rhizomes was evaluated in various solvents including water, DMSO, diethyl ether, benzene, acetone, and hot water. The results indicated varying degrees of solubility depending upon the polarity of solvents and extract composition. The observations are presented in Table 3.

Table 3 Solubility Determination of Curcuma aromatica Rhizome Extracts

S. No.	Solvent System	Methyl Acetate Extract	Ethyl Acetate Extract	DCM Extract	CCl_4 Extract	Hot Water Extract
1.	Distilled Water	Slightly Soluble	Slightly Soluble	Insoluble	Insoluble	Soluble
2.	DMSO	Soluble	Soluble	Soluble	Soluble	Soluble
3.	Diethyl Ether	Soluble	Soluble	Soluble	Soluble	Slightly Soluble
4.	Benzene	Slightly Soluble	Soluble	Soluble	Soluble	Insoluble
5.	Acetone	Soluble	Soluble	Soluble	Soluble	Soluble

The solubility studies revealed that most solvent extracts of *Curcuma aromatica* showed good solubility in organic solvents such as DMSO, acetone, diethyl ether, and benzene, whereas limited solubility was observed in distilled water. The hot water extract exhibited higher solubility in polar solvents, indicating the presence of polar phytochemical constituents. These findings suggest that solvent polarity plays an important role in the dissolution behaviour of rhizome extracts.

4.3. Qualitative Phytochemical Screening

The qualitative phytochemical screening of different solvent extracts of *Curcuma aromatica* revealed the presence of several important bioactive secondary metabolites including alkaloids, flavonoids, terpenoids, tannins, phenolic compounds, saponins, carbohydrates, fats, and oils. However, proteins, amino acids, and glycosides were not detected under the present experimental conditions. The results demonstrated that solvent polarity significantly influenced the extraction efficiency of phytochemical constituents, with moderately polar solvents showing comparatively better extraction efficiency.

Table 4 Qualitative Phytochemical Screening of *Curcuma aromatica* Rhizome Extracts

Phytochemical	Methyl Acetate	Ethyl Acetate	DCM	CCl_4	Hot Water
Carbohydrates	+	–	–	–	+
Alkaloids	+	+	+	–	+
Terpenoids	+	+	+	+	–
Flavonoids	+	–	+	–	+
Tannins and Phenolics	+	–	–	–	+
Saponins	+	+	+	–	–
Fats and Oils	+	+	+	–	–
Proteins and Amino Acids	–	–	–	–	–
Glycosides	–	–	–	–	–

(+): Present (–): Absent

4.4. Natural Indicator Activity of Curcuma aromatica

The ethanolic rhizome extract of *Curcuma aromatica* exhibited characteristic pH-responsive colour changes under acidic and alkaline conditions. In acidic medium, the extract retained its yellow colour, whereas in alkaline medium it changed to reddish-brown or orange-red, confirming its suitability as a natural acid–base indicator.

The pH-responsive behaviour is mainly attributed to curcuminoids, and phenolic compounds present in the rhizomes, which undergo structural changes at different pH levels. The distinct colour transition observed during the study indicates that *Curcuma aromatica* extract can serve as an eco-friendly, biodegradable, and sustainable alternative to synthetic indicators commonly used in analytical laboratories. (Pathade et al., 2013; Singh et al., 2013)

4.5. Comparative Acid–Base Titration Studies

The analytical performance of *Curcuma aromatica* extract was evaluated through acid–base titration experiments involving strong acid–strong base, weak acid–strong base, and strong acid–weak base systems. Standard synthetic indicators such as phenolphthalein, methyl orange, and methyl red were used for comparative evaluation with the natural Jungli Haldi extract.

In the titration experiments, 0.1 M hydrochloric acid (HCl), 0.1 M acetic acid (CH_3COOH), 0.1 M sodium hydroxide (NaOH), and 0.1 M ammonium hydroxide (NH_4OH) were used as standard solutions. A fixed volume (20 cm^3) of base solution was transferred into a conical flask, followed by the addition of two to three drops of indicator. The titration was continued until a distinct endpoint colour change was observed. Three concordant readings were recorded, and the mean titre values were calculated. The results demonstrated that the endpoint observations obtained using *Curcuma aromatica* extract were closely comparable to those obtained using standard synthetic indicators. (Vogel, 2000; Skoog et al., 2014)

Table 5 Comparative Titration Readings Using Synthetic and Natural Indicators

System	Indicator	Mean Titre (cm^3)
HCl vs NaOH	Phenolphthalein	9.17
	Methyl Red	9.20
	Methyl Orange	9.10
	Jungli Haldi Extract	9.23
CH_3COOH vs NaOH	Phenolphthalein	9.20
	Jungli Haldi Extract	9.10
HCl vs NH_4OH	Methyl Orange	9.13
	Jungli Haldi Extract	9.10

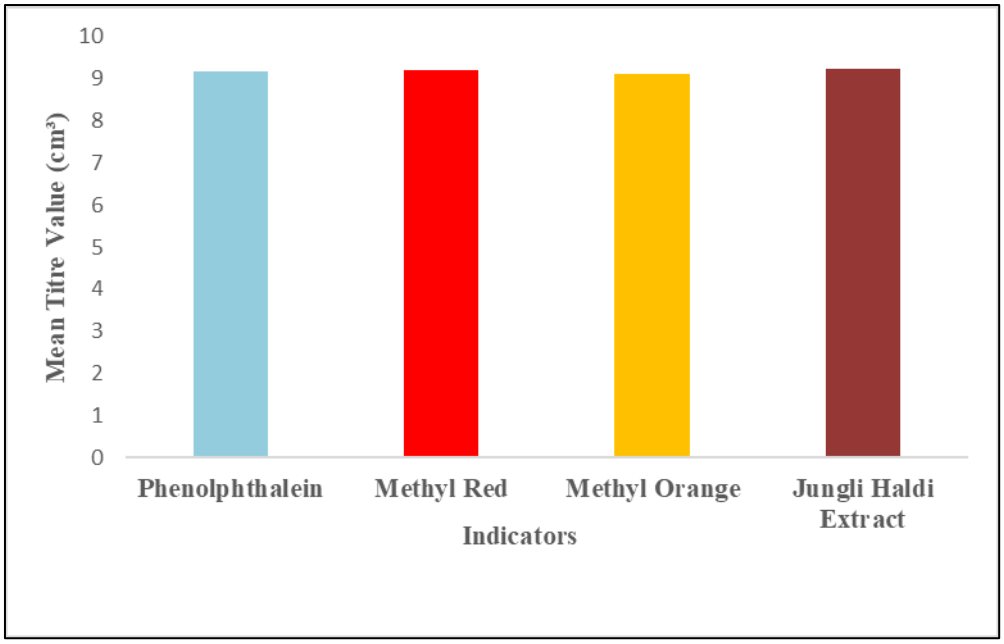
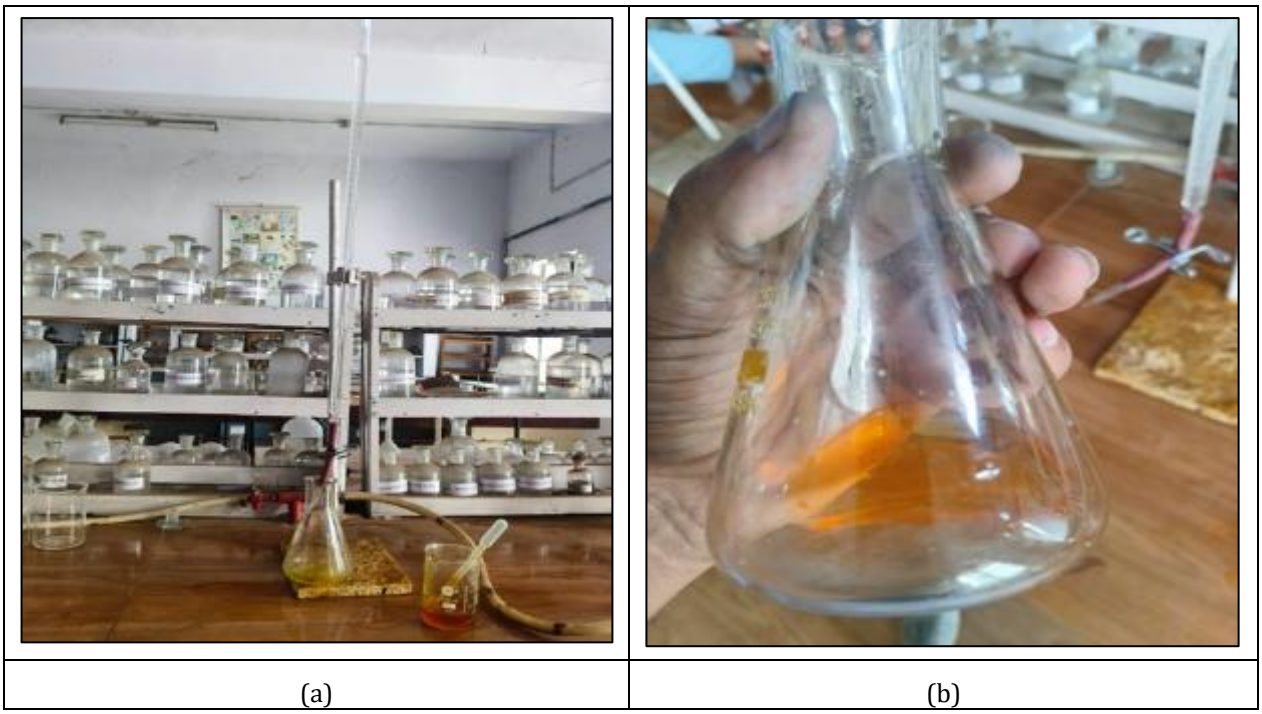


Figure 4 Comparative Titration Readings Using Synthetic and Natural Indicators



(a) (b)

Figure 5 Acid–base titration using *Curcuma aromatica* extract as a natural indicator

(a) Experimental titration setup for strong acid–strong base titration

(b) Endpoint colour change observed using Jungli Haldi extract

The *Curcuma aromatica* extract produced a distinct colour transition from yellow to reddish-brown at the titration endpoint, indicating its effectiveness as a natural acid–base indicator.

4.6. Determination of Molar and Mass Concentration

The molar concentration of the acid solutions used during the titration experiments was calculated using the standard neutralization equation**:**

$$C_a V_a = C_b V_b$$

Where:

- C_a= Concentration of acid
- V_a= Volume of acid
- C_b= Concentration of base
- V_b= Volume of base

The mass concentration of the acid solutions was calculated using the following equation:

Mass Concentration (g/dm^3) = Molar Concentration × Molar Mass

4.7. Evaluation of Herbal pH Paper

The herbal pH paper prepared from *Curcuma aromatica* extract displayed distinct and reproducible colour responses in acidic, neutral, and alkaline solutions. The strips remained yellow in acidic and neutral media, whereas reddish-brown or orange-red coloration developed in alkaline solutions.

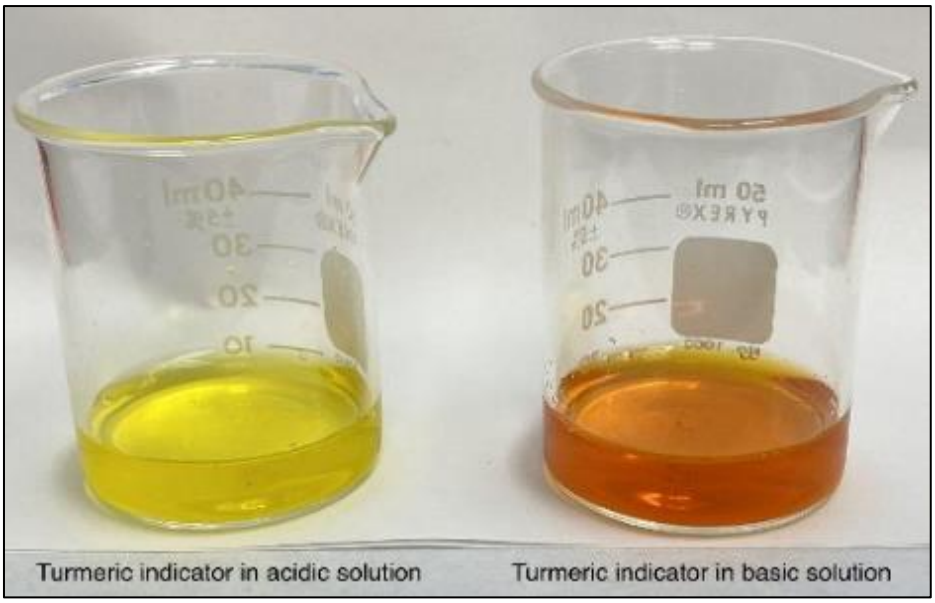


Figure 6 Colour response of *Curcuma aromatica* indicator in acidic and basic solutions

(a) Yellow colour in acidic medium; **(b)** Orange-red colour in alkaline medium

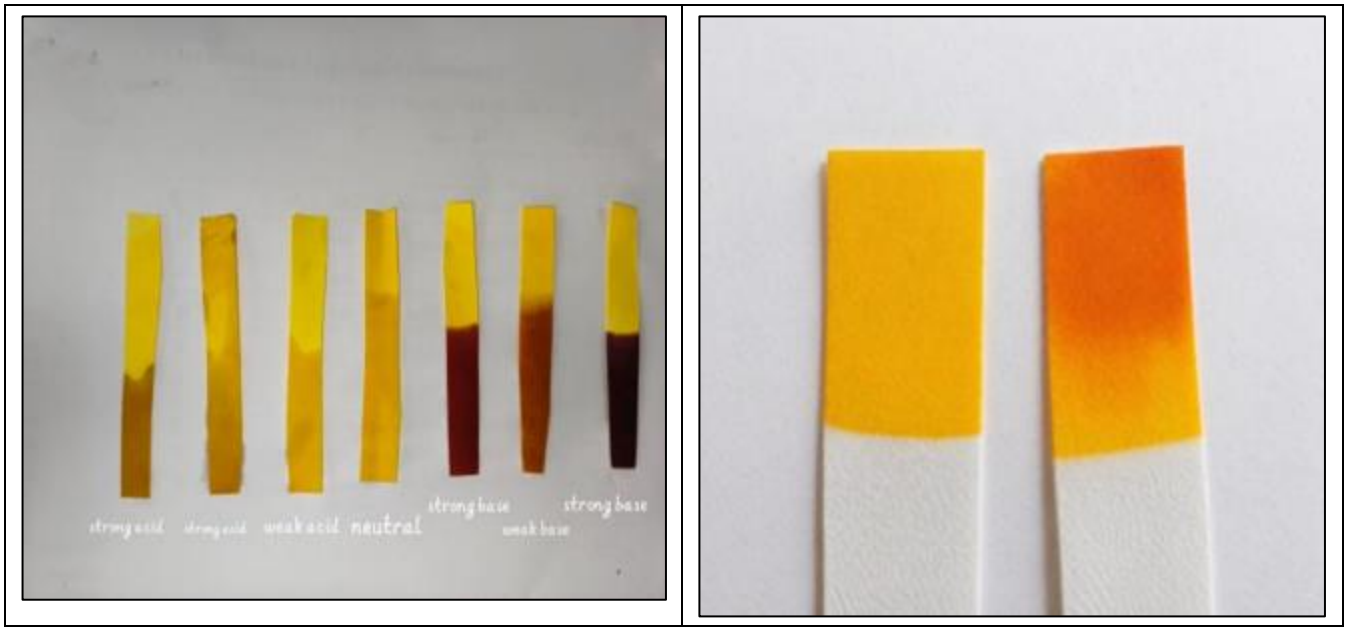


Figure 7 Herbal pH paper prepared using Jungli Haldi extract showing colour variations in different pH media

(a) Colour response of pH strips in strong acid, weak acid, neutral, strong base, and weak base solutions; **(b)** Comparative colour transition of acidic and basic pH strips

The prepared Jungli Haldi pH paper exhibited distinct and reproducible colour responses in acidic, neutral, and alkaline media. No significant colour change was observed in acidic solutions, whereas alkaline solutions produced reddish-brown to orange-red coloration due to the pH-responsive behaviour of curcuminoid pigments present in *Curcuma aromatica*. The results confirmed the suitability of the prepared herbal pH paper for rapid qualitative acid–base analysis. (Pathade et al., 2013; Singh et al., 2013)

5. Conclusion

The present investigation demonstrated that *Curcuma aromatica* rhizome extracts possess significant phytochemical constituents and promising natural indicator properties. Qualitative phytochemical screening confirmed the presence of important bioactive secondary metabolites including alkaloids, flavonoids, terpenoids, tannins, phenolic compounds, saponins, carbohydrates in different solvent extracts. The extraction efficiency and phytochemical distribution were found to depend largely on solvent polarity, with moderately polar solvents showing better extraction of diverse phytoconstituents.

The ethanolic extract of *Curcuma aromatica* exhibited remarkable pH-responsive behaviour by producing distinct colour changes in acidic and alkaline media. Comparative acid–base titration studies revealed that the endpoint observations and titre values obtained using the natural indicator were closely comparable to those obtained using standard synthetic indicators such as phenolphthalein, methyl orange, and methyl red. Furthermore, the herbal pH paper prepared from the extract displayed rapid, reproducible, and visually distinguishable colour responses under different pH conditions.

The findings of this study establish *Curcuma aromatica* as a valuable medicinal plant with dual significance in phytochemistry and green analytical chemistry. Its biodegradable, economical, non-toxic, and eco-friendly nature highlights its potential application as a sustainable alternative to synthetic acid–base indicators and conventional pH paper in educational laboratories and analytical practices. Further investigations involving isolation and characterization of active compounds may provide broader pharmaceutical and industrial applications of this plant.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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