# Phytochemical Composition, Metabolite Profiling and Antioxidant Properties of Different Parts of *Bombax ceiba L.*: A Comparative Study

**[1]Akash Kiran Suryawanshi [2]Dr. Jagdish Tukaram Jadhav**
[1]Department. of Botany M.S.G. College Malegaon Camp, Nashik.
Email id : akashs9552@gmail.com
[2]Associate Professor, Department. of Botany M.S.G. College Malegaon Camp, Nashik.
Email id : drjtjadhav@gmail.com
***Corresponding Author : Akash Kiran Suryawanshi Email id : akashs9552@gmail.com***

**Abstract**
The medicinal herb Bombax ceiba L. is utilised extensively in traditional healthcare systems to treat a variety of illnesses. The goal of the current study was to assess the phytochemical profile, physicochemical traits, primary and secondary metabolites, and antioxidant capacity of several Bombax ceiba sections, such as the bark, leaves, flowers, and roots. To determine the plant's primary bioactive components, preliminary phytochemical screening was carried out. Standard analytical techniques were used to quantify primary metabolites, such as total soluble sugar, proteins, lipids, and amino acids, as well as secondary metabolites, such as total phenolics, flavonoids, alkaloids, tannins, saponins, and terpenoids. The quality, purity, and authenticity of the plant material were evaluated using physicochemical characteristics such as ash values, moisture content, and extractive values. DPPH, nitric oxide, and hydroxyl radical scavenging tests were used to assess the antioxidant activity of various solvent extracts. The findings showed that the various plant parts and extracts varied significantly in terms of physicochemical properties, metabolite concentration, and antioxidant activity. Higher concentrations of phenolic and flavonoid chemicals in extracts showed improved free radical scavenging activity, indicating a favourable relationship between phytochemical composition and antioxidant capacity. These results underline Bombax ceiba's potential as a viable source of natural antioxidants and bioactive chemicals for upcoming therapeutic applications while also supporting the plant's traditional medicinal usage.

**Keywords:**
Bombax ceiba; Phytochemical screening; Physicochemical evaluation; Primary metabolites; Secondary metabolites; Phenolic compounds
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## Introduction

Medicinal plants have been an integral part of healthcare systems for a very long time, and they still are now. Their abundance of bioactive chemicals, including tannins, alkaloids, flavonoids, terpenoids, and glycosides, gives them a broad spectrum of pharmacological actions, such as antioxidant, anti-inflammatory, antibacterial, and anticancer properties (El-Saadony et al., 2025). Because of their cultural acceptability, ease of access, and low cost, medicinal plants continue to be an important part of healthcare in underdeveloped nations. Traditional plant-based systems provide primary healthcare for almost 80% of the world's population, according to estimates from the World Health Organization. Ayurveda, Siddha, and Unani are traditional systems that 70–80% of the Indian population follows. These systems are based on a wealth of biodiversity and ancient ethnomedicinal knowledge (Awoke et al., 2024).

A medicinal plant's potential for therapeutic use is heavily dependent on its metabolites, both primary and secondary. Basic cellular processes and plant development rely on primary metabolites such carbohydrates, proteins, lipids, and nucleic acids. Secondary metabolites,

on the other hand, comprising phenolic chemicals, alkaloids, tannins, terpenoids, saponins, and flavonoids, are primarily accountable for pharmacological actions including anti-inflammatory, anticancer, antibacterial, and antioxidant properties. To a considerable extent, the therapeutic potential and potential use of plant species in drug development are defined by the existence and variability of these metabolites (Salam et al., 2023; Mitra et al., 2023).

An essential part of standardising and controlling the quality of crude herbal medications is their physicochemical examination. Essential information on the purity, identity, and stability of plant material may be gleaned from parameters including moisture content, ash value, and extractive value. While extractive values show how many active ingredients are soluble in various solvents, ash values show the overall inorganic concentration and potential contamination. Preventing microbiological deterioration and determining shelf life are both heavily influenced by moisture content. All of these factors work together to guarantee that herbal medicines are reliable, genuine, and of high quality (Alam et al., 2015; Prakash et al., 2019).

Cancer, diabetes, inflammation, cardiovascular disease, and ageing are just a few of the chronic and degenerative illnesses linked to oxidative stress. Cellular damage occurs as a result of an imbalance between the creation of free radicals and the antioxidant defence mechanism (Chandimali et al., 2025; Pizzino et al., 2017). Antioxidants, especially phenolics and flavonoids found in plants, are vital in protecting cells from damage caused by free radicals. To give a thorough evaluation of the antioxidant's ability to suppress free radicals, this study used three different radical scavenging assays: DPPH, nitric oxide, and hydroxyl. (Gulcin et al., 2023).

The silk cotton tree, scientifically known as Bombax ceiba L. and belonging to the Bombacaceae family, is a massive deciduous tree that grows all throughout the subtropical and tropical zones of the world, including India (Verma et al., 2014). "Traditional medical systems like Ayurveda, Siddha, and Unani make extensive use of this plant as a remedy for a wide range of medical conditions, including but not limited to: microbial infections, pain, liver disorders, hypertension, fever, dysentery, inflammation of the urinary tract, skin diseases, gynaecological disorders, and piles. There are several medicinal uses for this plant's various parts. Its roots and blossoms are used for diuretics, laxatives, tonics, and restorative purposes. The leaves and bark, on the other hand, are used to cure skin problems and gastrointestinal diseases (Karole et al., 2017; Verma et al., 2014). Numerous bioactive components have been identified by phytochemical research. These include: naphthaquinones, coumarins, xanthones, quercetin, rutin, mangiferin, lupeol, scopolin, chlorogenic acid, vanillic acid, and ceibanaphthaquinone, among many more. Many of the plant's pharmacological effects may be attributable to these chemicals. Consequently, this research set out to assess the antioxidant capacity and qualitative and quantitative phytochemical content of several Bmbax ceiba sections sourced from the Bhopal area of Madhya Pradesh (Taher et al., 2024; Dash et al., 2025).

Despite the widespread usage of Bombax ceiba in ethnomedicinal systems, there has been a lack of thorough scientific research that thoroughly examine the plant's physicochemical properties, quantify its primary and secondary metabolites, and profile its antioxidants. There is a dearth of comprehensive comparison research as

much of it focuses on isolated plant components or conducts preliminary

phytochemical screening. Additionally, there is a dearth of documentation about the systematic evaluation of bark, leaves, flowers, and roots utilising various solvent extracts within a single experimental framework. In light of this, the current investigation set out to assess the physicochemical properties, phytochemical components, and quantitative assessment of main and secondary metabolites of various Bombax ceiba sections. Additionally, the radical scavenging capability of various extracts was determined by evaluating their antioxidant activity using numerous in vitro models.

## Materials and Methods Plant Materials

The different parts of the plant *Bombax ceiba* were collected from local area of Nashik, Maharashtra, India.

### *Chemicals and reagents*

This study only made use of analytical-grade chemicals and reagents. The following chemicals were purchased from Merck India Ltd. in Mumbai, India: sodium carbonate, acetic acid, ammonia, pyridine, potassium dihydrogen phosphate, ferric chloride, chloroform, and ethanol. Sigma-Aldrich supplied the ascorbic acid and 1,1-diphenyl-2-picrylhydrazyl (DPPH), while HiMedia Laboratories Pvt. Ltd. of Mumbai, India supplied the dipotassium hydrogen phosphate. The following chemicals were also purchased from HiMedia Laboratories Pvt. Ltd., Mumbai, India: hydrochloric acid (HCl), gallic acid, sodium carbonate ($Na_2CO_3$), quercetin, and aluminium chloride ($AlCl_3$). Magnesium sulphate, sodium hydroxide, and sulfuric acid were bought from Loba Chemie Pvt. Ltd. in Mumbai, India. Without further purification, all reagents were utilised in their original form.

### Extraction of Plant Material

Powdered bark, leaves, flowers, and roots were defatted in petroleum ether at 60-80°C, and then a Soxhlet extractor was used to extract ethanol and methanol in that order. One hundred grammes of the powdered substance was macerated in distilled water with a trace amount of chloroform added to prevent the growth of fungi in order to achieve an aqueous extraction. For seven days, the mixture was shaken occasionally. The extraction process began with muslin cloth and vacuum filtering to remove impurities, and then continued with rotating vacuum evaporation to concentrate the mixture under decreased pressure. Prior to storage for future analysis, the concentrated extract was dried on a water bath maintained at 40-50°C.

### Phytochemical Analysis

A preliminary phytochemical screening was conducted on the bark, leaf, flower, and root extracts to detect the presence of bioactive components. Alkaloids, glycosides, carbohydrates, phytosterols, fixed oils and fats, tannins, alkaloids, amino acids, proteins, and flavonoids were all detected qualitatively by utilising standard phytochemical procedures as stated in the literature (Farnsworth, 1968).

### Determination of Primary Metabolites

#### *Total Soluble Sugars*

According to Hedge and Hofreiter's anthrone technique, we were able to measure the samples' total soluble sugar content (1962). For a quick rundown, 1 millilitre of the sample solution was mixed with 4 millilitres of newly made anthrone reagent and let to boil in a water bath for 8 minutes. Upon reaching room temperature, the absorbance was measured at 630 nm in comparison to a reagent blank using a UV-Visible spectrophotometer. There were three independent measurements taken to determine the total soluble sugar content, which was then reported as milligrammes per gramme (mg/g) of sample using a standard calibration curve.

#### *Protein Content*

We used the technique outlined by Lowry et al. to measure the protein concentration (1957). To summarise, 1 millilitre of the sample was mixed with half a millilitre of 0.1 N sodium hydroxide, and then 5 millilitres of alkaline copper reagent were added. Thirty minutes were given for the reaction mixture to stand at room temperature. Next, 0.5 mL of Folin-Ciocalteu reagent was added, and the mixture was left to incubate at room temperature for another 10 minutes. After that, a UV-Visible

spectrophotometer was used to detect the absorbance at 660 nm, with a blank reagent acting as the reference. We measured everything three times, and we reported the protein concentration as milligrammes per gramme of sample.

***Total free amino acids***

Moore and Stein's ninhydrin technique was used to assess the total free amino acid concentration (1948). Just to recap, 1 millilitre of the material was added to a test tube along with 1 millilitre of ninhydrin reagent. For 20 minutes, the reaction mixture was brought to a boil in a water bath in order to bring out the colour. The mixture was incubated at room temperature for 15 minutes after cooling, and 5 mL of a diluent was added, which included equal quantities of distilled water and n-propanol. A reagent blank was used to measure absorbance at 570 nm using a UV-Visible spectrophotometer. Each assay was repeated three times, and the total free amino acid concentration was reported as milligrammes per gramme of material.

***Total Lipid Content***

In order to find the total lipid content, we used Folch et alapproach. .'s (1957). To summarise, a 1-gram powder of dried leaves was mixed with 20 millilitres of a 1:2 chloroform mixture and left to homogenise for 10 minutes. The first extract was obtained by aggressively shaking the homogenate and filtering it. After stirring the residual residue for 30 minutes, 25 mL of the same solvent solution was used for re-extraction. Filtration through activated charcoal was then performed to remove any pigments. In order to remove non-lipid impurities and facilitate phase separation, the two filtrates were combined and treated with a 0.9% sodium chloride solution. After collecting the lipid fraction, it was dried to a consistent weight in a desiccator. The total lipid content was then determined by gravimetric analysis.

**Determination of Secondary Metabolites**

***Total Phenolic Content***

The Folin-Ciocalteu colorimetric test was used to assess the total phenolic content. For the most part, a 25 mL volumetric flask was used to combine 1 mL of plant extract with 9 mL of distilled water. Then, 1 millilitre of Folin-Ciocalteu reagent was added, and everything was mixed well. After 5 minutes of reaction time, 10 millilitres of a sodium carbonate solution with a concentration of 7% was added, and 25 millilitres of distilled water was used to bring the total volume to the desired level. To create a calibration curve, standard solutions of gallic acid ranging from 10 to 100 µg/mL were made and treated using the same parameters. After 90 minutes of incubation at room temperature, the reaction mixtures were tested for absorbance at 550 nm using a UV-Visible spectrophotometer in comparison to a reagent blank. The gallic acid standard curve was used to quantify the total phenolic content, which is represented as milligrammes of gallic acid equivalents (GAE) per gramme of extract (Ghasemzadeh et al., 2010; Thim-Uam et al., 2025).

***Total flavonoid content***

The aluminium chloride colorimetric technique was used to determine the total flavonoid concentration. To summarise, a 10 mL volumetric flask was used to combine 1 mL of the extract with 4 mL of distilled water. Then, after waiting 5 minutes, the liquid was spiked with 0.3 mL of a 5% sodium nitrite solution. Then, after another 5 minutes of incubation, 0.3 mL of a 10% aluminium chloride solution was added. The next step was to add 2 mL of 1 M sodium hydroxide to finish the reaction. Distilled water was used to adjust the volume to 10 mL. A

calibration curve was constructed by preparing and treating in the same way quercetin standard solutions ranging from 10-100 µg/mL. By comparing the absorbance of the sample and standard solutions at 510 nm with that of a reagent blank, a UV-Visible spectrophotometer was employed. Milligrams of quercetin equivalents per gramme of extract was used to quantify total flavonoid concentration, which was determined using the quercetin standard curve (Chang et al., 2002; Pourmorad et al., 2006).

***Determination of Total Alkaloid Content***

In order to determine the total alkaloid content, the bromocresol green technique was employed. It was diluted with dimethyl sulfoxide, acidified with 1 mL of 2 N hydrochloric acid, and filtered after dissolving 1 mg of the plant extract. Five millilitres of bromocresol green reagent and five millilitres of phosphate buffer were added to the filtrate after it had been transferred to a separating funnel. Vibrant shaking was used to extract the mixture with 1-4 mL of chloroform. A 10 mL volumetric flask was used to collect the chloroform layer, and the volume was adjusted using chloroform. A calibration curve was generated by preparing and processing standard atropine solutions (10-80 µg/mL) under the same circumstances. Using a UV-Visible spectrophotometer, the sample and standard solutions were measured at 470 nm in comparison to a reagent blank. Measured in milligrammes of atropine equivalents per gramme of extract, total alkaloid content was determined using the atropine standard curve. (Fazel et al., 2008; Ajanal et al., 2012).

***Total Tannin Content***

The Folin-Ciocalteu colorimetric technique was used to quantify the total tannin concentration. To summarise, a 10 mL volumetric flask was used, which already contained 7.5 mL of distilled water, to transfer 0.1 mL of the sample extract. Then, 0.5% sodium carbonate solution and 0.5% Folin-Ciocalteu reagent were added, and 10 millilitres of distilled water were added to make the final volume. Following a thorough mixing, the reaction mixture was let to remain at room temperature for half an hour. The same procedure was used to create and treat gallic acid standard solutions ranging from 5-60 µg/mL in order to establish a calibration curve. Using a UV-Visible spectrophotometer, the absorbance of the sample and standard solutions was measured at 725 nm in comparison to a reagent blank. Based on the gallic acid standard curve, the total tannin content was determined and is shown as milligrammes of gallic acid equivalents (GAE) per gramme of extract. (AfifyAel-M et al., 2012; Marinova et al., 2005).

***Total Saponin Content***

The colorimetric technique of vanillin-sulphuric acid, as reported by Makkar et al. (1993) and Khatoon et al. (2022) with slight adjustments, was used to assess the total saponin content. In a nutshell, 1/2 cup of plant extract and 1/4 cup of distilled water were combined. Then, 1/4 cup of vanillin reagent, made by dissolving 800 milligrammes of vanillin in 10 millilitres of 99.5% ethanol, was added. The next step was to add 2.5 mL of 72% sulphuric acid, and then to incubate the mixture in a water bath set at 60°C for 10 minutes. The tubes were quickly immersed in ice-cold water after incubation to stop the reaction. The last steps involved using a UV-Visible spectrophotometer to measure absorbance at 544 nm. Milligrams of diosgenin equivalents (DE) per gramme of extract was used to represent the total saponin content, which was determined using a diosgenin standard calibration curve.

***Total Terpenoids***

The technique used to measure total terpene concentration was somewhat modified from that of Malik et al. (2017). In a nutshell, Whatman filter

paper was used to filter out 100 mg of dried plant extract (Wi) after it had been soaked in 9 mL of ethanol for 24 hours. The resulting filtrate was then extracted using 10 mL of petroleum ether after being transferred to a separating funnel. A pre-weighed glass vial was used to collect the petroleum ether portion and allow it to evaporate until dry. The following calculation was used to compute the percentage yield of total terpenoids based on the weight of the dried terpenoid residue (Wf):

Terpenoid content (%) = [(Wf − Wi) / Wi] × 100

**Physicochemical Parameters**

***Total Ash Content***

In order to find the total ash content, the powdered plant material was burned. In a nutshell, a 2 g sample that had been precisely measured was put into a pre-weighed silica crucible and cooked in a muffle furnace at 600 ± 15 °C until the carbon was removed and a consistent weight was achieved. Finally, the crucible was weighed after cooling in a desiccator. (Anasane & Chaturvedi, 2017).

The weight of total ash was calculated using the following equation:

Weight of Total Ash (Wt) = Wi – Wc

% Acid Insoluble Ash= Wa/Ws X 100 Wa = Weight of acid-insoluble ash (g)

Wi = weight of the crucible containing ash after incineration (g); Wc = weight of the empty crucible before incineration (g)

The percentage of total ash was calculated as:

Total Ash Content (%) = Wt/Ws X100

Wt = weight of total ash (g); Ws = weight of the plant sample taken for analysis (g)

***Acid Insoluble Ash Content***

The sample's whole ash was mixed with 25 mL of boiling 2 M hydrochloric acid while stirring vigorously. The acid-insoluble residue was collected by filtering the resultant combination using ashless filter paper. The residue-containing filter paper was heated to 100 °C in a hot-air oven for 15 minutes, then cooled and weighed. (Anasane & Chaturvedi, 2017)

The weight of acid-insoluble ash was calculated using the following equation:

Weight of Acid Insoluble Ash (Wa) = Wi − Wf

Wi = Weight of the filter paper containing the insoluble residue after drying (g); Wf = Weight of the empty filter paper (g)

The percentage of acid-insoluble ash was determined as:

Ws = Weight of the plant sample used for analysis (g)

***Water-Soluble Ash Content***

We combined the sample's entire ash with 25 mL of hot distilled water and gave it a good swirl. Specifically, the mixture was passed through ashless filter paper in order to extract the insoluble residue. Next, the residue-containing filter paper was heated to 100 °C for 15 minutes in a hot-air oven, cooled, and then weighed. (Anasane & Chaturvedi, 2017).

The weight of water-insoluble ash was calculated using the following equation:
Weight of Water-Insoluble Ash (Ww) = Wm − Wf
Wm = Weight of the filter paper containing the insoluble residue after drying (g); Wf = Weight of the empty filter paper (g)
The percentage of water-soluble ash was calculated as:
% Water Soluble Ash= Wt-Ww/Ws X100
Wt = Weight of total ash (g); Ww = Weight of water-insoluble ash (g); Ws = Weight of the plant sample used for analysis (g)

***Water-Soluble Extractives***

A closed conical flask was used to macerate five grammes of coarsely powdered air-dried medication with one hundred millilitres of water for twenty-four hours. The flask was shaken regularly during the first six hours, and then left to stand for the remaining eighteen hours. Grade 100 Whatman filter paper was used for this. A petri dish was used to evaporate 25 millilitres of the filtrate until it was dry, and then it was dried at 105°C and weighed. A calculation was made to determine the percentage of water-soluble extractive relative to the air-dried material.

Water-Soluble Extractive Value (% w/w) =Wr X 100 X 100/Ws X 25
Wr = Weight of dried residue obtained from 25 mL of filtrate (g); Ws = Weight of air-dried plant sample taken for extraction (g) (Mukharjee, 2008).

***Alcohol-Soluble Extractive Value***

A closed conical flask containing 5 grammes of coarsely powdered plant material that had been air-dried was filled with 100 millilitres of 70% ethanol for extraction. After 6 hours of occasional shaking, the mixture was left undisturbed for the remaining 24 hours of extraction. To keep the amount of ethanol in the solution as low as possible, it was filtered after extraction. A 25 mL portion of the filtrate was moved to a petri dish that had already been weighed and then dried by evaporation. We chilled and weighed the residue after drying it at 105 °C until it reached a steady weight. By applying the aforementioned procedure to the air-dried sample, we were able to determine the alcohol-soluble extractive value as a percentage (Indian Herbal Pharmacopoeia, 2002).

***Determination of Moisture Content***

The loss-on-drying technique was used to determine the moisture content. Basically, a pre-weighed petri dish was filled with 2 g of powdered plant material, and the starting weight was noted. After that, the sample-containing petri dish was heated to 100–105 °C in a hot-air oven for half an hour to dry it out. The material was reweighed after being dried and chilled to room temperature in a desiccator. The loss of water vapour during drying was accounted for by the weight reduction (Anasane & Chaturvedi, 2017).

The loss of water content was calculated using the following equation:
Loss of Water Content ($W_0$) = Wi − Wa

Wi = Weight of the petri plate containing the sample before drying (g); Wa = Weight of the petri plate containing the sample after drying (g)

The percentage moisture content was calculated as:

% Moisture Content= W0/Ws X 100

$W_0$ = Loss of water content (g); Ws = Weight of the plant sample taken for analysis (g)

**Antioxidant activity**

***DPPH Radical Scavenging Assay***

Using a slightly modified version of the DPPH (2,2-diphenyl-1-picrylhydrazyl) technique, we assessed the free radical scavenging activity of the extracts and their fractions. The samples were first dissolved in methanol at a concentration of 1000 µg/mL, and then diluted to achieve working concentrations between 100 and 1000 µg/mL. Each sample solution and the DPPH solution were mixed in equal volumes for the experiment (100 mM in methanol). For thirty minutes, the reaction mixtures were left to incubate at room temperature without illumination. The subsequent measurement of absorbance was taken at 517 nm by means of a UV-Visible spectrophotometer. Ascorbic acid served as the control substance. Using the following equation, we were able to determine the radical scavenging activity as a percentage inhibition:

% activity= Abs Con-Abs Test/Abs Con X 100 (Hussen & Endalew, 2023)

***Nitric oxide (NO•) scavenging assayA modified sodium nitroprusside-Griess reaction technique was used to assess the nitric oxide (NO•) scavenging ability of the fractions and extracts. In short, vials containing 1000 µL each of the test sample and 100 mM sodium nitroprusside solution were combined in test tubes. The sample was then subjected to different doses. To make nitric oxide production easier, the reaction mixtures were kept at 29°C for 2.5 hours. When the incubation period was over, each tube was given an equal amount of Griess reagent and mixed well. Using a UV-Visible spectrophotometer, the rapid production of a pink chromophore at 540 nm was used to detect the generation of nitrites. The gold standard antioxidant was ascorbic acid. Using the aforementioned method, we were able to determine the nitric oxide scavenging activity as a percentage inhibition (Kyada et al., 2023).***

***Hydroxyl radical (•OH) scavenging assay***

The test materials were evaluated for their ability to scavenge hydroxyl radicals (•OH) using a modified approach that had been previously published in research. We made many concentrations of the extracts and put them in different test tubes. The following were added to each tube: 1000 µL of an iron-EDTA solution (167 µM), 500 µL of 0.018 percent EDTA, 1000 µL of DMSO (0.85 percent produced in 100 mM phosphate buffer, pH 7.4), and 500 µL of 0.22 percent ascorbic acid. After a thorough mixing, the reaction mixtures were sealed and left to incubate in a water bath that was thermostatically controlled at 37 °C for 60 minutes. The addition of 1000 µL of ice-cold 17.5% trichloroacetic acid halted the reaction after incubation. Next, 3 millilitres of Nash reagent was added to every tube. Before adding glacial acetic acid and acetone, the Nash reagent was made by dissolving ammonium acetate in distilled water to a final volume of 1 L. The next step was to let the combinations sit at room temperature so the colours could develop. Utilizing a UV-Visible spectrophotometer, the production of the yellow chromophore was quantified at 412 nm. The reference standard was ascorbic acid. The hydroxyl radical scavenging activity was determined using the aforementioned formula and represented as a percentage of inhibition (Chen et al., 2019).

**Statistical analysis**

The results are expressed as the mean ± SD for three replicates. Linear regression analysis was used to calculate the $IC_{50}$ value.

**Results and Discussion**

| Plant Part | Extractive Values (%) | | | |
|---|---|---|---|---|
| | Petroleum Ether Extract | Ethanol Extract | Methanol Extract | Aqueous Extract |
| Bark | 4.52 | 10.26 | 9.68 | 11.98 |
| Leaves | 5.68 | 10.89 | 11.59 | 9.68 |
| Flowers | 5.89 | 12.86 | 13.85 | 10.37 |
| Roots | 2.14 | 9.47 | 10.19 | 10.28 |

***Extraction of Plant Material***

Different solvents resulted in different bark extractive yields. The aqueous extract had the greatest yield (11.98%), followed by the ethanolic extract (10.26%) and the methanolic extract (10.06%) of the solvents that were tested (9.68 percent ). With respect to yield, petroleum ether extract performed the worst (4.52 percent ). This research points to the presence of polar phytoconstituents in the bark, which are better extracted using polar solvents like water and alcohol than non-polar ones. The extractive yields in the leaves varied between 5.68 and 11.59%. In terms of yield, the methanolic extract came out on top with 11.59%, followed by the ethanolic extract with 10.89%, and finally the aqueous extract with 9.68%. In contrast, the petroleum ether extract only managed 5.68%. Methanol and ethanol have a higher extraction efficiency, suggesting that the leaves contain a lot of secondary metabolites that are either moderately polar or polar. When compared to extracts from other plant parts, the flower extracts showed significantly higher yields. Methanol produced the highest yield at 13.85%, followed by ethanol at 12.86%, and water at 10.37%; petroleum ether produced the lowest yield at 5.89%. The flowers are likely abundant in polar bioactive compounds, such as phenolics, flavonoids, and other soluble phytoconstituents, since methanol and ethanol performed better than water. The roots had an extractive yield between 2.14% and 10.28%. With a yield of 10.28%, the aqueous extract was the most productive, followed by the methanolic (10.19%) and ethanolic (10.2%) extracts (9.47 percent ). In terms of yield, petroleum ether extraction came out on the bottom (2.14 percent ). Based on these findings, polar solvents, such as water and alcohol, are better suited for extracting root components than non-polar solvents.

Table 1: Percentage extractive values of different solvent extracts of *Bombax ceiba* bark, leaves, flowers, and roots.

**Phytochemical Analysis**

Bombax ceiba's bark, leaves, flowers, and roots were subjected to a first phytochemical screening, which uncovered a wide range of bioactive components. The solvents used for extraction showed significant variance. A wide variety of plant components, including carbs, glycosides, tannins, phenolic compounds, proteins, amino acids, and flavonoids were consistently present in the phytochemical profiles of ethanolic and methanolic extracts. The leaves did not contain any alkaloids, but the bark, blossoms, and roots did. Most polar phytoconstituents were also present in the aqueous extracts, while alkaloids were often not. Phytosterols were the only phytochemical category absent from petroleum ether extracts, which mostly included fixed oils and fats and, in the roots, phytosterols. The results show that polar solvents, especially ethanol and methanol, are better at extracting a wide variety of phytochemicals from Bombax ceiba, suggesting that these solvents might be useful in future phytochemical and pharmacological studies.

Table 2: Preliminary phytochemical screening of different solvent extracts of

*Bombax ceiba* bark

| Phytochemical tests | Tests | Pet. Ether Extract | Ethanol Extract | Methanol Extract | Aqueous Extract |
|---|---|---|---|---|---|
| Alkaloids | Dragendorff's test | - | + | + | - |
| | Hager's test | - | + | - | - |
| | Wagner's test | - | + | + | - |
| Carbohydrates | Molisch's test | - | + | + | + |
| | Barfoed's test | - | + | + | + |
| | Wagner's test | - | + | + | + |
| Glycosides | Molisch's test | - | + | + | + |
| Phytosterols | Liebermann burchard's test | - | + | + | + |
| Fixed oils and fats | Spot test | + | - | - | - |
| | Saponification test | + | - | - | - |
| Saponins | Foam test | - | + | + | + |
| | Haemolysis test | - | + | + | + |
| Phenolic Compounds and Tannins | Ferric chloride test | - | + | + | + |
| | Lead acetate test | - | + | + | + |
| Proteins and amino acids | Biuret test | - | + | + | + |
| | Ninhydrin test | - | + | + | + |
| Flavonoids | Shinoda test | - | + | + | + |

Table 3: Preliminary phytochemical screening of different solvent extracts of *Bombax ceiba* leaves

| Phytochemical tests | Tests | | | | |
|---|---|---|---|---|---|
| Alkaloids | Dragendorff's test | | | | |
| | Hager's test | | | | |
| | Wagner's test | | | | |
| Carbohydrates | Molisch's test | | | | |
| | Benedict's test | | | | |
| | Wagner's test | | | | |
| Glycosides | Molisch's test | | | | |
| Phytosterols | Liebermann burchard's test | | | | |
| Fixed oils and fats | Spot test | | | | |
| | Saponification test | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | st | | | | |
| Saponins | Foam test | | | | |
| | Haemolysis test | | | | |
| Phenolic Compounds and Tanninins | Ferric chloride test | | | | |
| | Lead acetate test | | | | |
| Proteins and | Biuret test | | | | |
| | Ninhydr | | | | |
| aminoacids | in test | | | | |
| Flavonoids | Shinoda test | | | | |

Table 4: Preliminary phytochemical screening of different solvent extracts of *Bombax ceiba* flower

| Phytochemical tests | Tests | Pet. Ether Extract | Ethanol Extract | Methanol Extract | Aqueous Extract |
|---|---|---|---|---|---|
| Alkaloids | Dragendorff's test | - | + | + | - |
| | Hager's test | - | + | + | - |
| | Wagner's test | - | + | + | - |
| Carbohydrates | Molisch's test | - | + | + | + |
| | Barfoed's test | - | + | + | + |
| | Wagner's test | - | + | + | + |
| Glycosides | Molisch's test | - | + | + | + |
| Phytosterols | Liebermann burchard's test | - | + | + | + |
| Fixed oils and fats | Spot test | + | - | - | - |
| | Saponification test | + | - | - | - |
| Saponins | Foam test | - | + | + | + |
| | Haemolysis test | - | - | + | + |
| Phenolic Compounds and Tannins | Ferric chloride test | - | + | + | + |
| | Lead acetate test | - | + | + | + |
| Proteins and amino acids | Biuret test | - | + | + | + |
| | Ninhydrin test | - | + | + | + |
| Flavonoids | Shinoda test | - | + | + | + |

Table 4: Preliminary phytochemical screening of different solvent extracts of *Bombax ceiba* roots

| Phytochemical tests | Tests | | | | |
|---|---|---|---|---|---|
| Alkaloids | Dragendorff's test | | | | |
| | Hager's test | | | | |
| | Wagner's test | | | | |
| Carbohydrates | Molisch's test | | | | |
| | Barfoed's test | | | | |
| | Wagner's test | | | | |
| Glycosides | Molisch's test | | | | |
| Phytosterols | Liebermann burchard's test | | | | |
| Fixed oils and fats | Spot test | | | | |
| | Saponificatio | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | ntest | | | | |
| Saponins | Foam test | | | | |
| | Haemolysis test | | | | |
| Phenolic Compounds and Tannins | Ferric chloride test | | | | |
| | Lead acetate test | | | | |
| Proteins and aminoacids | Biuret test | | | | |
| | Ninhydrin test | | | | |
| Flavonoids | Shinoda test | | | | |

**Determination of Primary Metabolites**

The distribution of primary metabolites varied significantly across the various regions of Bombax ceiba, as shown by the quantitative study (Table 3). A total soluble sugar concentration of 124.71 ± 11.6 mg/g dry weight was found in the bark, while levels of 12.67 ± 2.0 mg/g in the flowers, 11.82 ± 2.2 mg/g in the leaves, and 6.63 ± 2.7 mg/g in the roots were much lower. The increased sugar concentration in the bark might be because of its function in storing and transporting carbohydrates, which aid in plant development and metabolic processes (Wingler & Henriques, 2022). The protein concentration in the flowers was the greatest at 54.33 ± 12.1 mg/g dry weight, followed by the roots at 24.27 ± 4.5 mg/g, the bark at 22.04 ± 6.4 mg/g, and the leaves at 15.49 ± 5.0 mg/g. Flowers with high protein content may be undergoing reproductive development or vigorous cellular metabolism, both of which need large amounts of structural and

enzymatic proteins (Borghi M et al., 2022). The leaves had the highest concentration of total free amino acids (52.81 ± 12.1 mg/g dry weight), but the flowers, bark, and roots had lower concentrations (6.70 ± 0.9 mg/g, 3.97 ± 0.8 mg/g, and 3.75 ± 1.3 mg/g, respectively). The importance of leaves in photosynthesis-related nitrogen uptake and amino acid production may explain this finding (Gunstone et al., 2007). Roots had the second-highest lipid content at 19.23 ± 3.7 mg/g, flowers at 18.68 ± 2.8 mg/g, and leaves at 9.03 ± 1.7 mg/g. Bark also had the greatest lipid content at 29.17 ± 3.1 mg/g dry weight. Bark tissues may have storage and protective functions because to the buildup of lipids, which are essential energy reserves and building blocks of cellular membranes (Torres et al., 2021). The fact that various portions of the plant have varied distributions of primary metabolites is indicative of the fact that each part has a unique physiological purpose and has unique metabolic needs.

Table 5: Quantitative Estimation of Primary Metabolites in Different Parts of *Bombax ceiba*

| Types of Primary Metabolites | Bark | Flower | Leaves | Roots |
|---|---|---|---|---|
| Total Soluble Sugar (mg/gm of dry weight) | 124.71±11.6 | 12.67±2.0 | 11.82±2.2 | 6.63±2.7 |
| Total Protein (mg/gm of dry weight) | 22.04±6.4 | 54.33±12.1 | 15.49±5.0 | 24.27±4.5 |
| Total free Amino acids (mg/gm of dry weight) | 3.97±0.8 | 6.70±0.9 | 52.81±12.1 | 3.75±1.3 |
| Total Lipids (mg/gm of dry weight) | 29.17±3.1 | 18.68±2.8 | 9.03±1.7 | 19.23±3.7 |

**Quantitative Estimation of Secondary Metabolites**

The distribution of secondary metabolites showed significant diversity across various regions of Bombax ceiba when quantitatively estimated (Table 6). The flower extract had the greatest total phenolic content (TPC) at 180.12 ± 11.8 mg gallic acid equivalents (GAE)/g, followed by the bark extract at 151.06 ± 20.0 mg GAE/g, the leaves extract at 137.47 ± 9.7 mg GAE/g, and the roots extract at 93.14 ± 15.4 mg GAE/g. The antioxidant, anti-inflammatory, and antibacterial properties of phenolic compounds have made them an important class of plant secondary metabolites. Flowers and bark have a higher concentration of phenolics, which means they may be more effective antioxidants. Phenolics are known to scavenge free radicals (Sun & Shahrajabian, 2023; Zhang et al., 2022).

In terms of total flavonoid content (TFC), a same pattern emerged, with the greatest concentration showing up in flowers (124.87 ± 10.3 mg quercetin equivalents (QE)/g dry extract), then in roots (55.23 ± 8.9 mg QE/g), bark (36.11 ± 9.9 mg QE/g), and finally in leaves (8.67 ± 1.8 mg QE/g). Flavonoids have several well-known health benefits, including reducing inflammation, protecting the heart, and warding off cancer. Bombax ceiba has long been thought to possess biological activity, and the high antioxidant capacity of floral extracts is likely at least in part due to the quantity of flavonoids found in flowers (Yin et al., 2022).

Different portions of the plant have significantly different total alkaloid contents. The alkaloid content was greatest in the flowers (27.27 ± 7.0 mg atropine equivalents/g dry extract), next in the roots (5.50 ± 1.9 mg/g), and finally in the bark (0.35 ±

0.1 mg/g). In contrast, the leaves did not contain any alkaloids. Analgesic, antibacterial, antimalarial, and neuropharmacological effects are common in alkaloids and other nitrogen-containing secondary metabolites (Heinrich et al., 2021). Flowers may have pharmacologically active chemicals due to their comparatively high alkaloid content.

The tannin content varied between 17.39 ± 4.4 and 85.35 ± 12.2 mg gallic acid equivalents (GAE)/g dry weight. The greatest quantity was found in flowers, followed by bark, leaves, and roots. Polyphenolic chemicals known as tannins aid in plant defence systems and have antibacterial, astringent, and antioxidant qualities (Cosme F, et al., 2025). On the other hand, with 63.71 ± 12.0 mg diosgenin equivalents/g dry weight, bark had the greatest total saponin content, while roots had 57.83 ± 7.9 mg/g, and flowers had the lowest amount at 10.83 ± 1.5 mg/g. Saponins have several beneficial properties, including reducing cholesterol levels, reducing inflammation, and modulating the immune system (Timilsena et al., 2023). Bark and roots have long been used for therapeutic purposes, which may be due to their high saponin concentration.

Of all the metabolites that were studied, terpenoids showed a wide range of concentrations, from 2.05 ± 0.3% in the roots to 12.92 ± 2.4% in the flowers. Roots (2.05 ± 0.3 percent), bark (2.64 ± 0.7 percent), and leaves (4.60 ± 1.0 percent) had lower terpenoid levels compared to flowers. Antioxidant, anti-inflammatory, antibacterial, and anticancer actions are among the many biological activities linked to terpenoids, a huge collection of plant secondary metabolites (Câmara et al., 2024). A review of the literature reveals that saponins are abundant in bark and roots, whereas phenolics, flavonoids, alkaloids, tannins, and terpenoids are more abundant in flowers".

Bombax ceiba has a wide variety of purported medicinal uses in traditional medicine, which may be explained by the fact that various plant sections accumulate secondary metabolites at varying rates. This suggests that different tissues have evolved to have varied metabolic needs.

Table 6: Quantitative Estimation of Secondary Metabolites in Different Parts of *Bombax ceiba*

| Types of Secondary Metabolites (Calibration curve equation; Coefficient of determination) | Bark | Flower | Leaves | Roots |
|---|---|---|---|---|
| Total Phenolics Content (mg Gallic Acid equivalents/gm of dry extract) (y=0.0044x+0.2016; $R^2$=0.997) | 151.06±20.0 | 180.12±11.8 | 137.47±9.7 | 93.14±15.4 |
| Total Flavonoid Content (mg Quercetin equivalents /gm of dry extract) (y=0.0055x+0.1471; $R^2$=0.9972) | 36.11±9.9 | 124.87±10.3 | 8.67±1.8 | 55.23±8.9 |
| Total Alkaloid Content (mg Atropine equivalents /gm of dry extract) (y=0.0019x+0.0072; $R^2$=0.9978) | 0.35±0.1 | 27.27±7.0 | 0.0±0.00 | 5.50±1.9 |
| Total Tannin Content (mg Gallic acid Equivalents /gm of dry weight) (y=0.0057x+0.0301; $R^2$=0.9933) | 77.66±17.4 | 85.35±12.2 | 35.06±8.5 | 17.39±4.4 |
| Total Saponin Content (mg Diosgenin Equivalents /gm of dry weight (y=0.0055x+0.0255; $R^2$=0.9992) | 63.71±12.0 | 10.83±1.5 | 33.93±6.3 | 57.83±7.9 |
| Total Terpenoids (%) | 2.64±0.7 | 12.92±2.4 | 4.60±1.0 | 2.05±0.3 |

**Physicochemical Evaluation of Different Parts of *Bombax ceiba***

There was a lot of variance among the many Bombax ceiba components that were analysed physically (Table 7). The leaves had the greatest total ash level, which represents the total inorganic residue in the plant material, at 14.13 ± 1.7%. Bark came in at 13.38 ± 1.3%, flowers at 6.77 ± 0.3%, and roots at 4.84 ± 0.1%. Leaves and bark may have accumulated more mineral elements due to their comparatively higher ash values. The bark had the largest amount of acid-insoluble ash (10.03 ± 0.2 percent), followed by the flowers (4.68 ± 0.2 percent), the leaves (1.65 ± 0.1 percent), and the roots (0.55 ± 0.1 percent). This ash is used to identify siliceous materials and foreign pollutants. These results indicate that, in comparison to other plant components, bark contains a greater amount of silica and insoluble inorganic materials (Mukherjee, 2019).

Ash concentration that could be dissolved in water ranged from 0.97 ± 0.1 percent in leaves to 4.64 ± 0.3 percent in roots. The existence of significant levels of water-soluble inorganic salts was indicated by the roots' highest water-soluble ash value, while the leaves had the lowest. These variations in ash levels can be helpful in authenticating crude medications since they are typically linked to tissue-specific mineral makeup (Mathipa et al., 2022).

There was a large variation in the extractive values among the various plant components. Roots (with a variation of ±1.1%) had the greatest water-soluble extractive value, followed by flowers (12.36 ±0.7%), leaves (5.71 ±0.5%), and bark (5.69 ±0.4%). Flowers had the lowest alcohol-soluble extractive value (4.24 ± 0.1 percent), whereas roots displayed the greatest (19.29 ± 1.4 percent). The amount of polar and moderately polar phytochemicals in plant material is generally indicated by the extractive values, which give an estimate of the amount of active components soluble in a given solvent (Chatepa et al., 2024). Roots appear to contain a larger concentration of extractable components than other plant sections, as shown by their higher extractive values.

From 6.48 ± 0.3 percent in the roots to 10.72 ± 0.6 percent in the blooms,

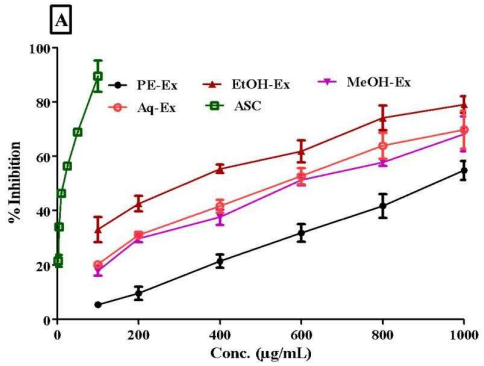
the moisture content varied. Good storage stability and reduced susceptibility to microbiological growth and enzymatic destruction are indicated by the comparatively low moisture levels reported in all plant sections. Because too much moisture can reduce the quality and shelf life of raw herbal ingredients, moisture content is a crucial quality metric (Al-Hamdani et al., 2022). The physicochemical characteristics measured in this study provide a great starting point for future work on identifying and standardising Bombax ceiba pieces and evaluating their quality.

Table 7: Physicochemical Parameters of Different Parts of Bombax ceiba

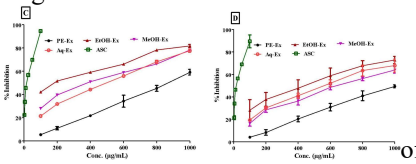
| Parameters-(w/w) | Bark | Flower | Leaves | Roots |
|---|---|---|---|---|
| Total Ash Content (%) | 13.38 ± 1.3 | 6.77 ± 0.3 | 14.13 ± 1.7 | 4.84 ± 0.1 |
| Acid Insoluble ash (%) | 10.03 ± 0.2 | 4.68 ± 0.2 | 1.65 ± 0.1 | 0.55 ± 0.1 |
| Water soluble ash (%) | 2.67 | 1.54 | 0.97 | 4.64 |
| Water Soluble Extractive Value (%) | 5.69 ± 0.4 | 12.36 ± 0.7 | 5.71 ± 0.5 | 15.57 ± 1.1 |
| Alcohol Extractive Value (%) | 6.43 ± 0.3 | 4.24 ± 0.1 | 4.56 ± 0.4 | 19.29 ± 1.4 |
| Moisture Content (%) | 9.61 ± 0.6 | 10.72 ± 0.6 | 8.26 ± 0.4 | 6.48 ± 0.3 |

**Anti-oxidant activity**

***DPPH Radical Scavenging Activity***




The free radical scavenging activity of petroleum ether, ethanol, methanol, and water-based extracts from various parts of the Bombax ceiba plant, including the bark, leaves, flowers, and roots, was assessed using the DPPH assay (Figure 1, A-D & Table-8). Antioxidant activity was concentration-dependent for all extracts; greater doses inhibited DPPH radicals more effectively. Of all the extracts tested, the one with the lowest $IC_{50}$ value (213.97 ± 20.3 µg/mL) was the ethanolic flower extract. The next ones were the ethanolic bark extract (364.87 ± 62.5 µg/mL), the ethanolic root extract (463.17 ± 131.7 µg/mL), and the methanolic leaf extract (570.23 ± 27.4 °g/mL). The activity ranged from 836.79 ± 38.5 to 1033.37 ± 43.0 µg/mL for petroleum ether extracts, which were the least active. With $IC_{50}$ values ranging from 26.42 to 27.63 µg/mL, ascorbic acid exhibited noticeably greater antioxidant activity. Flowers had the highest antioxidant activity, followed by bark, roots, and leaves, in that order, according to the lowest $IC_{50}$ values. There must be more antioxidant phytochemicals in the ethanolic bark and floral extracts because of their better action. Polar components contribute significantly to the antioxidant activity of B. ceiba, as evidenced by the increased efficacy of ethanol and methanol extracts compared to petroleum ether extracts. One way that flavonoids and phenolics protect against oxidative stress is by donating electrons and hydrogen to free radicals (Zahra et al., 2024). It is possible that the increased phenolic and flavonoid contents of flower and bark extracts are associated with their robust DPPH radical scavenging action. The function of phenolic compounds in reducing oxidative stress and free radical scavenging has been highlighted by previous research that found a favourable correlation between phenolic content and antioxidant activity (Baliyan et al., 2022). Bombax ceiba has strong antioxidant capacity, according to the DPPH assay results, especially in its bark and flowers; the ethanolic extracts showed the most action, though.

Figure 1: Effect of different extracts  of *Bombax ceiba* on DPPH radical scavenging activity: (A) Bark, (B) Leaves, (C) Flowers, and (D) Roots.

***Nitric Oxide Radical Scavenging Activity***

The capacity of several Bombax ceiba extracts (flowers, roots, bark, leaves, and flowers) to suppress reactive nitrogen species was evaluated using the nitric oxide (NO) scavenging assay (Figure 2, A-D & Table-8). The ability of all extracts to neutralise nitric oxide produced in vitro was demonstrated by their concentration-dependent increase in nitric oxide radical scavenging activity. Out of all the extracts that were evaluated, the one with the lowest $IC_{50}$ value (169.42 ± 17.2 µg/mL) and the best nitric oxide scavenging activity was the ethanolic flower extract. The ethanolic bark extract came in second, with a value of 176.68 ± 8.0 µg/mL. Comparatively, the methanolic root extract exhibited much reduced activity (432.13 ± 23.8 µg/mL), in contrast to the moderate activity (313.48 ± 81.4 µg/mL) of the ethanolic

leaf extract. The plant portions that were extracted using petroleum ether had the lowest ability to scavenge nitric oxide, with $IC_{50}$ values that varied from 524.42 ± 22.1 to 908.65 ± 31.1 µg/mL. With $IC_{50}$ values ranging from 40.08 to 49.07 µg/mL, ascorbic acid demonstrated the highest level of activity. In terms of nitric oxide scavenging activity, the following plant parts had the most active extracts: flowers, bark, leaves, and roots. While NO plays a crucial role in many physiological processes, its overproduction can trigger the development of reactive nitrogen species like peroxynitrite, which in turn can cause inflammation and oxidative damage. Nitric oxide scavengers may, thus, help avoid inflammatory and oxidative stress-related diseases (Pacher et al, 2007; Andrabi et al., 2023). The fact that ethanolic extracts show more activity implies that ethanol is a good solvent for extracting the bioactive components that scavenge nitric oxide. It has been found that flavonoids and phenolic compounds can suppress the formation of nitric oxide and neutralise reactive nitrogen species by radical stabilisation and electron donation (Thapa et al., 2025; Zhang et al., 2022). Extracts from flowers and bark may have larger amounts of these antioxidant metabolites, which may explain their remarkable efficacy. All things considered, the results show that extracts from Bombax ceiba, especially the flowers and bark, have strong nitric oxide scavenging capabilities. The plant's phenolic and flavonoid components are probably responsible for its antioxidant properties, making it a possible natural source of bioactive chemicals for fighting oxidative and inflammatory stress.

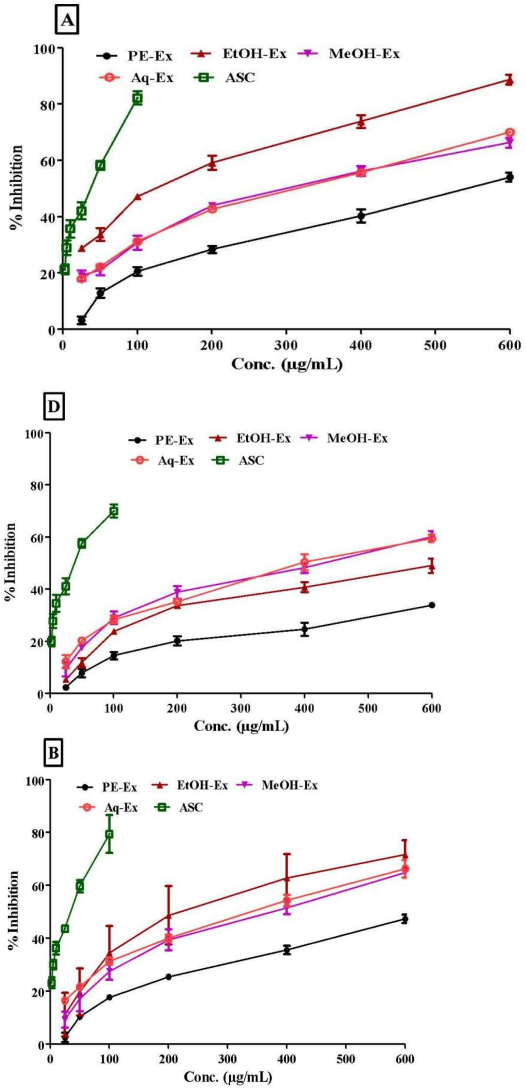
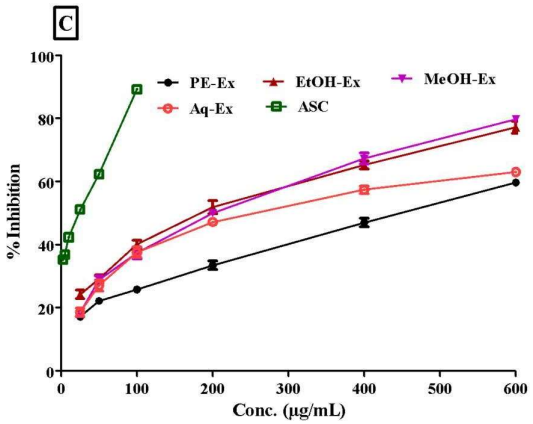



Figure 2: Effect of different extracts of *Bombax ceiba* on Nitric oxide radical scavenging activity: (A) Bark, (B) Leaves, (C) Flowers, and (D) Roots.

***Hydroxyl Radical Scavenging Activity***

In order to determine if the extracts of Bombax ceiba might provide protection against the hydroxyl radical (•OH) species, which is one of the most reactive oxygen species, the hydroxyl radical scavenging experiment was conducted (Figure 3, A-D & Table-8). Hydroxyl radicals cause oxidative damage and cellular dysfunction by attacking macromolecules in cells, including lipids, proteins, and DNA. Antioxidants play a crucial role in




protecting cells from free radicals. The hydroxyl radical scavenging activity of all of the extracts increased with increasing concentration. The following samples were tested: ethanolic bark extract (261.66 ± 22.2 µg/mL), methanolic flower extract (259.87 ± 12.6 µg/mL), and methanolic bark extract (268.92 ± 15.2 µg/mL). Of these, the ethanolic flower extract showed the highest activity among the tested samples, with an $IC_{50}$ value of 252.41 ± 17.0 µg/mL. When compared, the scavenging effects of extracts from leaves and roots were modest, but those from petroleum ether were the least active. The most powerful antioxidant, ascorbic acid, has $IC_{50}$ values between 26.27 and 30.55 µg/mL. When looking at the hydroxyl radical scavenging capacity of the most active extract from each plant section, the ranking was as follows: Flowers > Bark > Leaves > Roots. Flower and bark extracts appear to include more phytochemicals that can neutralise ROS, as they are more active than other plant parts. Hydrogen radical scavenging action is mainly due to polar components, as ethanolic and methanolic extracts are more efficient than petroleum ether extracts. Reducing oxidative damage to biological systems, phenolic substances and flavonoids limit hydroxyl radical-mediated oxidative processes by metal-chelating mechanisms, electron transfer, and hydrogen donation (Hassanpour & Doroudi, 2023). It is possible that extracts from flowers and bark might protect biomolecules from oxidative damage due to their high hydroxyl radical scavenging activity.

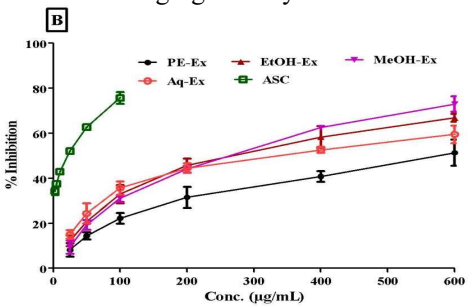
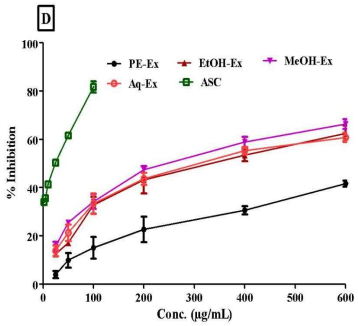
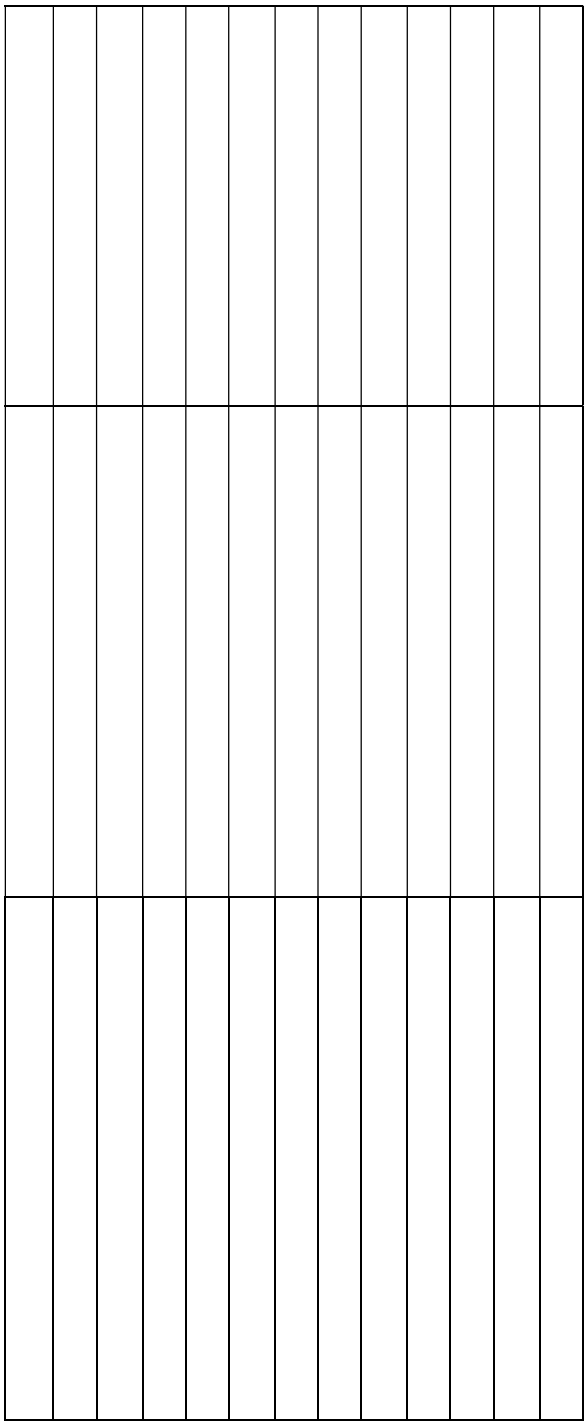


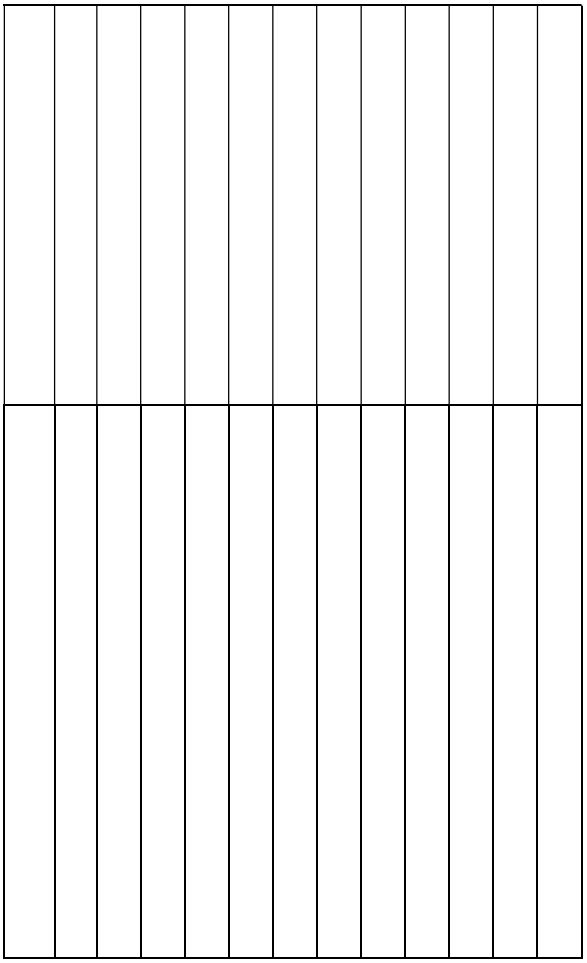

Figure 3: Effect of different extracts of *Bombax ceiba* on Hydroxyl radical scavenging activity: (A) Bark, (B) Leaves, (C) Flowers, and (D) Roots.

Table 8. $IC_{50}$ values of different extracts of *Bombax ceiba* in DPPH, Hydroxyl, and Nitric Oxide scavenging assays.

| | **Bark** | **Flower** | **Roots** | **Leaves** |
|---|---|---|---|---|







In DPPH, hydroxyl, and nitric oxide radical scavenging tests, Bombax ceiba showed strong antioxidant capacity in all four sections of the plant: bark, leaves, flowers, and roots. Antioxidant properties are primarily linked to polar phytoconstituents, as polar solvent extracts, especially ethanol and methanol, demonstrated greater activity than petroleum ether extracts. The highest activity was seen in extracts from flowers and bark, which may be due to the high concentration of bioactive phenolic and flavonoid components that scavenge free radicals. These results lend credence to the idea that B. ceiba might be a useful natural antioxidant.

**Conclusion**

This study examined several portions of Bombax ceiba for their antioxidant activity, phytochemical components, physicochemical characteristics, and primary and secondary metabolites (bark, leaves, flowers, and roots). Differential distribution of bioactive components inside the plant was suggested by the data, which showed significant changes in physicochemical attributes, extractive values, and metabolite composition among the plant sections. Quantitative study revealed different amounts of primary and secondary metabolites, including total soluble sugars, proteins, lipids, and amino acids, while preliminary phytochemical screening verified the existence of significant secondary metabolites (phenolics, flavonoids, alkaloids, tannins, saponins, and terpenoids). The different solvent extracts exhibited strong free radical scavenging ability, which was shown to correlate with the amount of phenolic and flavonoid compounds, according to antioxidant evaluations conducted using DPPH, nitric oxide, and hydroxyl radical scavenging tests. It appears that the antioxidant ingredients were efficiently extracted from the polar solvent extracts, as they displayed relatively higher antioxidant potential. The research concludes that Bombax ceiba is an excellent plant to use since it has natural bioactive chemicals that show promise as antioxidants. This research lends credence to its long-standing medical usage and lays the groundwork for future studies to identify, characterise, and potentially employ its active ingredients in therapeutic settings.

**References**


- AfifyAel-M, El-Beltagi HS, El-Salam SM, Omran AA. Biochemical changes in phenols, flavonoids, tannins, vitamin E, β-carotene and antioxidant activity during soaking of three white sorghum varieties. Asian Pac J Trop Biomed.,2012:2(3):203-9.

- Ajanal M, Gundkalle MB, Nayak SU. Estimation of total alkaloid in Chitrakadivati by UV-Spectrophotometer. Anc Sci Life.

2012 Apr;31(4):198-201. doi: 10.4103/0257-7941.107361.

- Alam F, Us Saqib QN. Pharmacognostic study and development of quality control parameters for fruit, bark and leaf of Zanthoxylum armatum (Rutaceae). Anc Sci Life. 2015 Jan-Mar;34(3):147-55. doi: 10.4103/0257-7941.157159.

- Al-Hamdani A, Jayasuriya H, Pathare PB, Al-Attabi Z. Drying Characteristics and Quality Analysis of Medicinal Herbs Dried by an Indirect Solar Dryer. Foods. 2022 Dec 19;11(24):4103. doi: 10.3390/foods11244103.
- Anasane P and Chaturvedi A: Pharmacognostic studies and qualitative analysis for phytosterols of the leaves of Bombax ceiba linn. Int J Pharm Sci Res 2017; 8(10): 4402-07.doi: 10.13040/IJPSR.0975-8232.8(10).4402-07.

- Andrabi SM, Sharma NS, Karan A, Shahriar SMS, Cordon B, Ma B, Xie J. Nitric Oxide: Physiological Functions, Delivery, and Biomedical Applications. Adv Sci (Weinh). 2023 Oct;10(30):e2303259. doi: 10.1002/advs.202303259.

- Awoke A, Gudesho G, Akmel F, Shanmugasundaram P. Traditionally used medicinal plants for human ailments and their threats in Guraferda District, Benchi-Sheko zone, Southwest Ethiopia. J Ethnobiol Ethnomed. 2024 Sep 2;20(1):82. doi: 10.1186/s13002-024-00709-5.

- Baliyan S, Mukherjee R, Priyadarshini A, Vibhuti A, Gupta A, Pandey RP, Chang CM. Determination of Antioxidants by DPPH Radical Scavenging Activity and Quantitative Phytochemical Analysis of Ficus religiosa. Molecules. 2022 Feb 16;27(4):1326. doi: 10.3390/molecules27041326.

- Borghi M, Perez de Souza L, Tohge T, Mi J, Melandri G, Proost S, Martins MCM, Al-Babili S, Bouwmeester HJ, Fernie AR. High-energy-level metabolism and transport occur at the transition from closed to open flowers. Plant Physiol. 2022 Aug 29;190(1):319-339. doi: 10.1093/plphys/kiac253.

- Buchanan BB, Gruissem W, Jones RL, editors. Biochemistry and molecular biology of plants. 2nd ed. Hoboken (NJ): Wiley-Blackwell; 2015.

- Câmara JS, Perestrelo R, Ferreira R, Berenguer CV, Pereira JAM, Castilho PC. Plant-Derived Terpenoids: A Plethora of Bioactive Compounds with Several Health Functions and Industrial Applications-A Comprehensive Overview. Molecules. 2024 Aug 15;29(16):3861. doi: 10.3390/molecules29163861.

- Chandimali N, Bak SG, Park EH, Lim HJ, Won YS, Kim EK, Park SI, Lee SJ. Free radicals and their impact on health and antioxidant defenses: a review. Cell Death Discov. 2025 Jan 24;11(1):19. doi: 10.1038/s41420-024-02278-8.

- Chang C, Yang M, Wen H, Chern J. Estimation of total flavonoid content in propolis by two complementary colometric methods. Journal of Food and Drug Analysis. 2002;10(3):178–182.

- Chatepa LEC, Mwamatope B, Chikowe I, Masamba KG. Effects of solvent extraction on the phytoconstituents and in vitro antioxidant activity properties of leaf extracts of the two selected medicinal plants from Malawi. BMC Complement Med Ther. 2024 Aug 27;24(1):317. doi: 10.1186/s12906-024-04619-7.

- Chen F, Huang G, Yang Z, Hou Y. Antioxidant activity of Momordica charantia polysaccharide and its derivatives. Int J Biol Macromol. 2019;138:673-680. doi:10.1016/j.ijbiomac.2019.07.129.

- Cosme F, Aires A, Pinto T,

Oliveira I, Vilela A, Gonçalves B. A Comprehensive Review of Bioactive Tannins in Foods and Beverages: Functional Properties, Health Benefits, and Sensory Qualities. Molecules. 2025 Feb 9;30(4):800. doi: 10.3390/molecules30040800.

- Dash S, Alam N, Samuel N, Bobde C, Dadsena J. Exploring the phytochemicals of Bombax ceiba (L.) flower extract using GC-MS: An updated study. J Pharmacogn Phytochem. 2025;14(5):473-478. doi:10.22271/phyto.2025.v14.i5f.15608.

- El-Saadony MT, Saad AM, Mohammed DM, Korma SA, Alshahrani MY, Ahmed AE, Ibrahim EH, Salem HM, Alkafaas SS, Saif AM, Elkafas SS, Fahmy MA, Abd El-Mageed TA, Abady MM, Assal HY, El-Tarabily MK, Mathew BT, AbuQamar SF, El-Tarabily KA, Ibrahim SA. Medicinal plants: bioactive compounds, biological activities, combating multidrug-resistant microorganisms, and human health benefits - a comprehensive review. Front Immunol. 2025 Apr 28;16:1491777. doi: 10.3389/fimmu.2025.1491777.

- Farnsworth NR. Biological and phytochemical screening of plants. J Pharm Sci 1966;55:225-76.

- Fazel S, Hamidreza M, Rouhollah G, Mohammadreza V. Spectrophotometric determination of total alkaloids in some Iranian medicinal plants. Thai J Pharm Sci.,2008:32:17-20.

- Folch J, Lees M, Solane-stanley GH. A simple method for the isolation and purification of total lipids from animal tissues. J Biol Chem. 1957; 226: 497-507.

- Ghasemzadeh AH, Hawa ZE, Asmah R. Antioxidant activities, total phenolics and flavonoids content in two varieties of Malaysia Young Ginger (Zingiber officinale Roscoe). Mol.,2010:15:4324-4333.

- Gulcin İ, Alwasel SH. DPPH Radical Scavenging Assay. Processes. 2023; 11(8):2248. https://doi.org/10.3390/pr11082248

- Gunstone FD, Harwood JL, editors. The lipid handbook. 3rd ed. Boca Raton (FL): CRC Press; 2007. doi:10.1201/9781420009675.

- 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 Jul-Aug;13(4):354-376. doi: 10.22038/AJP.2023.21774.

- Hedge JE, Hofreiter BT. In: Whistler RL, Be Miller JN, editors. Carbohydrate Chemistry. Vol. 17. New York: Academic Press; 1962. p. 1-19.

- Heinrich M, Mah J, Amirkia V. Alkaloids Used as Medicines: Structural Phytochemistry Meets Biodiversity-An Update and Forward Look. Molecules. 2021 Mar 25;26(7):1836. doi: 10.3390/molecules26071836.

- Hussen EM, Endalew SA. In vitro antioxidant and free-radical scavenging activities of polar leaf extracts of Vernonia amygdalina. BMC Complement Med Ther. 2023;23:146. doi:10.1186/s12906-023-03923-y.

- Indian Herbal Pharmacopoeia, Indian Drug Manufacturers' Association. Revised ed. 2002. pp. 493–4.

- Karole S, Gautam GK, Gupta S. Pharmacognostic and pharmacological profile of Bombax ceiba. Asian J Pharm Educ Res. 2017;6(3):16-27.

- Khatoon A, Jain S, Shukla K, Bapna RS. Phytochemical investigation and determination of total phenols, flavonoid, saponins and alkaloids concentration in root extract of Tabernaemontana divaricata R.Br. ex Roem. & Schult. J Pharm Negat

Results. 2022;13(Suppl 10):4822-4826.

- Kyada A, Rahamathulla M, Santani D, Vadia N, Baldaniya L, Rana M, et al. Phytochemical analysis, in vitro free radical scavenging, and LDL protective effects of different solvent fractions of Calotropis procera (R.) Br. root bark extract. Evid Based Complement Alternat Med. 2023;2023:6689595. doi:10.1155/2023/6689595.

- Lowry OH, Roseobrough NJ, Farr AL, Randall RJ. Protein measurements with the Folin's phenol reagent. J Biol Chem.,1957:193:265-75.

- Makkar HPS, Bluemmel M, Borowy NK, Becker K. Gravimetric determination of tannins and their correlations with chemical and protein precipitation methods. J Sci Food Agric. 1993;61(2):161-165.

- Malik SK, Ahmad M, Khan F. Qualtitative and quantitative estimation of terpenoid contents in some important plants of Punjab, Pakistan. Pakistan Journal of Science. 2017;69(2):150.

- Marinova D, Ribarova F, Atanassova M. Total Phenolics and Total Flavonoids in Bulgarian Fruits and Vegetables. J University Metallurgy,2005:40(3):255-260. ChemTechnol.

- Mathipa MM, Mphosi MS, Masoko P. Phytochemical profile, antioxidant potential, proximate and trace elements composition of leaves, stems and ashes from 12 Combretum spp. used as food additives. Int J Plant Biol. 2022;13(4):561-578. doi:10.3390/ijpb13040045.

- Mitra R, Ghosh S, Mukherjee G, Acharya Chowdhury A. Secondary metabolites: Treasure trove for future medicine. In: Mérillon JM, Ramawat KG, editors. Plant Specialized Metabolites. Reference Series in Phytochemistry. Cham (CH): Springer; 2023. doi:10.1007/978-3-031-30037-0_11-1.

- Moore S, Stein WH. Photometric methods for use in the chromatography of amino acids. J Bio Chem 1948;176:367-88.

- Mukharjee PK. Quality Control of Herbal Drugs. New Delhi: Business Horizons Pharmaceutical Publishers; 2008. p. 186.

- Mukherjee PK. Quality control and evaluation of herbal drugs: Evaluating natural products and traditional medicine. 2nd ed. Amsterdam: Elsevier; 2019.

- Pacher P, Beckman JS, Liaudet L. Nitric oxide and peroxynitrite in health and disease. Physiol Rev. 2007 Jan;87(1):315-424. doi: 10.1152/physrev.00029.2006.

- Pizzino G, Irrera N, Cucinotta M, Pallio G, Mannino F, Arcoraci V, Squadrito F, Altavilla D, Bitto A. Oxidative Stress: Harms and Benefits for Human Health. Oxid Med Cell Longev. 2017;2017:8416763. doi: 10.1155/2017/8416763. Epub 2017 Jul 27. PMID: 28819546; PMCID: PMC5551541.

- Pourmorad F, Hosseinimehr SJ, Shahabimajd N. Antioxidant activity, phenol and flavonoid contents of some selected Iranian medicinal plants. African Journal of Biotechnology. 2006;5(11):1142–1145.

- Prakash A, Janmeda P, Pathak P, et al. Development and standardization of quality control parameters of different parts of Trianthema portulacastrum L. SN Appl Sci. 2019;1:1108. doi:10.1007/s42452-019-1074-3.

- Salam U, Ullah S, Tang ZH, Elateeq AA, Khan Y, Khan J, Khan A, Ali S. Plant Metabolomics: An Overview of the Role of Primary and Secondary Metabolites against Different Environmental Stress Factors. Life (Basel). 2023 Mar 6;13(3):706. doi: 10.3390/life13030706.

- Sun W, Shahrajabian MH. Therapeutic Potential of Phenolic Compounds in Medicinal Plants-Natural Health Products for Human Health. Molecules. 2023 Feb 15;28(4):1845. doi: 10.3390/molecules28041845.

- Taher MA, Hossain MJ, Zahan MS, Hasan MM, Ferdous J, Rahman A, Khan M, Hosain MK, Rashid MA. Phyto-pharmacological and computational profiling of Bombax ceiba Linn. Leaves revealed pharmacological properties against oxidation, hyperglycemia, pain, and diarrhea. Heliyon. 2024 Jul 30;10(15):e35422. doi:

10.1016/j.heliyon.2024.e35422.

- Thapa I, Pandey A, Tiwari S, Awal SC. Evaluation of Bioactive Compounds, Antioxidant Activity, and Anticancer Potential of Wild Ganoderma lucidum Extracts from High-Altitude Regions of Nepal. Curr Issues Mol Biol. 2025 Aug 5;47(8):624. doi: 10.3390/cimb47080624.

- Thim-Uam A, Thepmalee C, Chaiwangyen W, Kangwan N, Chokchaisiri R, Nuntaboon P, Songkrao A, Onsa-Ard A. Phytochemical Screening and In Vitro Antioxidant and Anticancer Evaluation of Stem and Leaf Extracts of Cissampelos pareira L. Mediators Inflamm. 2025 Jul 11;2025:7555073. doi: 10.1155/mi/7555073.

- Timilsena YP, Phosanam A, Stockmann R. Perspectives on Saponins: Food Functionality and Applications. Int J Mol Sci. 2023 Aug 31;24(17):13538. doi: 10.3390/ijms241713538.

- Torres M, Parets S, Fernández-Díaz J, Beteta-Göbel R, Rodríguez-Lorca R, Román R, Lladó V, Rosselló CA, Fernández-García P, Escribá PV. Lipids in Pathophysiology and Development of the Membrane Lipid Therapy: New Bioactive Lipids. Membranes (Basel). 2021 Nov 24;11(12):919. doi: 10.3390/membranes11120919.

- Verma R, Devre K, Gangrade T, Gore S, Gour S. A pharmacognostic and pharmacological overview on Bombax ceiba. Sch Acad J Pharm. 2014;3(2):100-107.

- Wingler A, Henriques R. Sugars and the speed of life-Metabolic signals that determine plant growth, development and death. Physiol Plant. 2022 Mar;174(2):e13656. doi: 10.1111/ppl.13656.

- Yin K, Yang J, Wang F, Wang Z, Xiang P, Xie X, Sun J, He X, Zhang X. A preliminary study of the chemical composition and bioactivity of Bombax ceiba L. flower and its potential mechanism in treating type 2 diabetes mellitus using ultra-performance liquid chromatography quadrupole-time-flight mass spectrometry and network pharmacology analysis. Front Nutr. 2022 Oct 13;9:1018733. doi: 10.3389/fnut.2022.1018733.

- Zahra M, Abrahamse H, George BP. Flavonoids: Antioxidant Powerhouses and Their Role in Nanomedicine. Antioxidants (Basel). 2024 Jul 29;13(8):922. doi: 10.3390/antiox13080922.

- Zhang Y, Cai P, Cheng G, Zhang Y. A brief review of phenolic compounds identified from plants: Their extraction, analysis, and biological activity. Nat Prod Commun. 2022;17(1):1934578X211069721. doi:10.1177/1934578X211069721.

- Zhang Y, Cai P, Cheng G, Zhang Y. A brief review of phenolic compounds identified from plants: Their extraction, analysis, and biological activity. Nat Prod Commun. 2022;17(1):1-14.