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Assessment of Phytoremediation Potential, Microbial Activities, and Toxicological Effects of Selected Plant Extracts in Albino Rat

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Abstract

This review examines the phytoremediation potential, microbial activities, and toxicological effects associated with selected plant extracts in albino rats. It focuses on five plants: Moringa oleifera, Azadirachta indica, Ocimum gratissimum, Vernonia amygdalina, and Hibiscus sabdariffa. Literature was reviewed to explain the principles and mechanisms of phytoremediation, including phytoextraction, phytostabilisation, rhizodegradation, and plant–microorganism interactions. The review also considers the phytochemical constituents and reported antioxidant, antimicrobial, and biological properties of the selected plants. Evidence indicates that plant-associated microorganisms can support pollutant degradation and improve remediation processes, while plant extracts may influence microbial growth and activity. However, the environmental remediation capacity of whole plants should be distinguished from the medicinal or antimicrobial effects of their extracts. The review further discusses toxicological findings from studies involving albino rats, with attention to dose, exposure duration, haematological and biochemical indices, organ function, and histopathological changes. Available evidence suggests that biological effects vary according to plant species, plant part, extraction method, and administered dose. It also shows that beneficial properties do not necessarily establish safety at every dose. The review concludes that these plants possess promising biological and environmental applications, but further pollutant-specific remediation studies and well-controlled toxicity assessments are required to establish their efficacy and safety.

Keywords: Phytoremediation, plant extracts, microbial activities, toxicological effects, rats.

1.0 INTRODUCTION

Environmental pollution has become one of the major challenges confronting human health, ecological stability and sustainable development (Obruche et al., 2025). Rapid industrialisation, urbanisation, agricultural activities, mining operations and improper waste disposal have contributed significantly to the release of harmful substances into the environment. These substances include heavy metals, petroleum hydrocarbons, pesticides, industrial chemicals and other persistent organic pollutants (Odimgbe et al., 2026). Their accumulation in soil and water can reduce environmental quality, affect biodiversity and create potential pathways for human and animal exposure (United Nations Environment Programme [UNEP], 2021). Conventional methods of environmental remediation, including excavation, chemical treatment, soil washing and physical separation, are often effective but may involve considerable financial costs, energy consumption and secondary environmental disturbances (Umudi et al., 2025). These limitations have encouraged research into environmentally friendly and sustainable remediation technologies. One of such approaches is phytoremediation, which involves the use of plants and their associated microorganisms to remove, immobilise, degrade or detoxify pollutants in contaminated environments (Ali et al., 2013; Raskin et al., 1997). Phytoremediation has attracted considerable scientific interest because of its relatively low cost, environmental compatibility and potential application to large areas of contaminated land. Different plant species possess varying abilities to absorb, accumulate, transform or stabilise pollutants. Some plants can accumulate heavy metals in their roots and shoots, while others promote the degradation of organic contaminants through enzymatic activities and interactions with microorganisms in the rhizosphere (Ekpo et al., 2023). These properties make plant-based remediation an important component of sustainable environmental management. Apart from their environmental applications, plants are important sources of biologically active compounds. Many medicinal plants contain secondary metabolites such as flavonoids, alkaloids, tannins, saponins, terpenoids and phenolic compounds. These substances contribute to their antioxidant, antimicrobial, anti-inflammatory and other pharmacological activities (Atanasov et al., 2021). Consequently, plant extracts have become important subjects of research in pharmacology, microbiology, toxicology and environmental science (Umudi et al., 2025). Five plants of particular interest in this review are Moringa oleifera, Azadirachta indica, Ocimum gratissimum, Vernonia amygdalina and Hibiscus sabdariffa. These plants are widely recognised for their medicinal, nutritional and biological properties. Their leaves, seeds, flowers and other plant parts contain different phytochemical constituents that may influence their biological activities. For instance, Moringa oleifera contains phenolic compounds, flavonoids and glucosinolates, while Azadirachta indica contains limonoids and other biologically active compounds. Similarly, Ocimum gratissimum, Vernonia amygdalina and Hibiscus sabdariffa possess phytochemicals associated with antioxidant and antimicrobial activities.

The relationship between plants and microorganisms is another important aspect of phytoremediation research. Microorganisms inhabiting the root region of plants can contribute to pollutant degradation, nutrient cycling and plant growth. Some bacteria and fungi produce enzymes that transform harmful organic compounds into less toxic substances, while others improve the availability or immobilisation of certain heavy metals. These interactions can enhance the overall efficiency of plant-assisted environmental remediation. However, the biological usefulness of plant extracts does not automatically establish their safety. Certain phytochemicals may produce beneficial effects at appropriate concentrations but may cause toxicity when administered at excessive doses or over prolonged periods. Toxicological studies using albino rats provide useful information on the possible effects of plant extracts on haematological parameters, biochemical markers, liver and kidney functions, and tissue structures. Such investigations are important for identifying possible adverse effects and establishing appropriate safety limits. Therefore, this review examines the phytoremediation potential, microbial activities and toxicological effects of extracts obtained from Moringa

oleifera, Azadirachta indica, Ocimum gratissimum, Vernonia amygdalina and Hibiscus sabdariffa. It brings together available scientific evidence to explain their environmental applications, phytochemical properties, interactions with microorganisms and possible biological effects in albino rats.

1.2 Overview of Phytoremediation and Plant-Based Products

Phytoremediation is an environmentally sustainable technology that uses green plants and their associated microorganisms to manage contaminated soil, water and sediments. It operates through several biological and chemical processes, including pollutant absorption, accumulation, transformation, degradation and immobilization (Obruche et al., 2019). The effectiveness of the process depends on plant characteristics, pollutant concentration, soil conditions, environmental factors and the activities of associated microorganisms. The concept of phytoremediation is based on the ability of certain plants to tolerate and interact with environmental contaminants. Some plants absorb pollutants through their roots and transport them to above-ground tissues, where they may accumulate. Others release root exudates that influence pollutant mobility and stimulate microorganisms capable of degrading organic contaminants. Phytoremediation is therefore not restricted to the direct uptake of pollutants but also involves complex interactions between plants, soil and microbial communities (Ali et al., 2013). Several mechanisms are involved in phytoremediation. Phytoextraction involves the uptake and accumulation of contaminants in plant tissues, while phytostabilisation reduces the mobility and bioavailability of pollutants in contaminated soil. Rhizodegradation involves the breakdown of organic contaminants by microorganisms stimulated by plant roots. Phytodegradation occurs when plants absorb and enzymatically transform pollutants, whereas rhizofiltration involves the removal of contaminants from polluted water through plant roots. Plant-based products, on the other hand, refer to substances obtained from different plant parts through extraction and processing. These products may contain phenolic compounds, flavonoids, alkaloids, tannins, saponins, terpenoids and other secondary metabolites. They are widely investigated for their antimicrobial, antioxidant and pharmacological properties (Itodo et al., 2021). The five plants selected for this review have different biological and environmental characteristics. Moringa oleifera is recognised for its nutritional value and the water-clarification properties of its seed proteins. Azadirachta indica is known for its insecticidal and antimicrobial properties. Ocimum gratissimum contains essential oils and phenolic compounds associated with antimicrobial activities (Ekpo et al., 2025). Vernonia amygdalina is valued for its antioxidant and medicinal properties, while Hibiscus sabdariffa contains anthocyanins and other phenolic compounds. Although these plants possess useful biological properties, their suitability for phytoremediation depends on the particular plant part, pollutant type and environmental conditions. Their extracts may also differ considerably in chemical composition depending on extraction solvents, geographical origin, maturity and processing techniques. Therefore, findings from medicinal studies should not automatically be interpreted as evidence of environmental remediation efficiency.

1.3 Importance of Selected Plant Extracts in Environmental and Biological Studies

Plant extracts are important in environmental and biological research because they contain natural compounds capable of interacting with microorganisms, pollutants and biological tissues. Their chemical diversity provides opportunities for investigating antimicrobial activities, antioxidant mechanisms, pollutant transformation and possible toxicological effects. In environmental studies, some plant materials can contribute to pollutant removal through adsorption, coagulation, biosorption and other physicochemical interactions. For example, Moringa oleifera seeds contain cationic proteins that can assist in water clarification by promoting the aggregation of suspended particles. This property makes the plant useful in investigating low-cost water-treatment approaches. However, water clarification should be distinguished from the complete removal of dissolved toxic pollutants. The five selected plants also contain phytochemicals that may

influence microbial growth. Phenolic compounds, tannins, flavonoids and essential-oil constituents can interfere with microbial cell membranes, enzyme activities and other cellular processes. These activities are relevant to microbiological studies involving pathogenic organisms and environmental microorganisms. Another important area is antioxidant activity. Oxidative stress occurs when the production of reactive oxygen species exceeds the antioxidant defence capacity of biological systems. Certain plant-derived compounds can neutralise free radicals and contribute to the protection of cells against oxidative damage. Flavonoids, anthocyanins and phenolic acids are among the compounds commonly associated with these activities (Atanasov et al., 2021). The selected plants are also important in toxicological investigations. Although many plant extracts are traditionally consumed or used medicinally, their safety depends on dosage, duration of exposure, extraction method and chemical composition. Some compounds may produce adverse effects at high concentrations, while interactions among different constituents may influence their overall toxicity. Albino rats are frequently used in experimental toxicology because their physiological and biochemical responses can be investigated under controlled conditions. Parameters such as body weight, organ weight, packed cell volume, haemoglobin concentration, liver enzymes, kidney function markers and histopathological changes can provide information about possible toxic effects.

The importance of reviewing these five plants therefore lies in establishing a clearer understanding of their environmental usefulness and biological safety. Such an assessment can help identify promising plant materials for environmental applications while highlighting the need for appropriate toxicological evaluation before medicinal or other biological uses are recommended.

2.0 PHYTOREMEDIATION

2.1 Concept and Principles of Phytoremediation

Phytoremediation is the application of plants and their associated microorganisms to reduce, remove, immobilise or transform contaminants present in soil, water and sediments. It is considered a biological remediation technology because it relies mainly on natural plant processes and microbial activities rather than intensive mechanical or chemical treatment. The concept is based on the ability of plants to interact with contaminants through their roots, stems and leaves. Plant roots are particularly important because they provide the primary interface between the plant and contaminated soil or water. During growth, roots absorb water and nutrients and may also take up certain contaminants present in the surrounding environment.

According to Ali et al. (2013), phytoremediation can be applied to different categories of pollutants, including heavy metals and organic contaminants. Its effectiveness depends on the ability of selected plants to tolerate pollutants, develop adequate biomass and either accumulate or transform contaminants. One major principle of phytoremediation is phytoavailability, which refers to the proportion of a contaminant that is accessible for uptake by plant roots. Pollutants that are strongly bound to soil particles may be less available for plant absorption than those present in soluble forms. Soil pH, organic matter, moisture content and microbial activity can influence contaminant availability. Another principle is plant tolerance. Plants selected for phytoremediation should be capable of surviving in contaminated environments without experiencing severe growth inhibition. Tolerance may involve mechanisms such as metal chelation, sequestration in vacuoles, antioxidant defence and restricted transport of toxic substances to sensitive tissues. The third principle involves contaminant uptake and transformation. Certain plants absorb contaminants and accumulate them in roots or shoots, while others produce enzymes that transform organic pollutants into less harmful substances. In addition, root exudates can stimulate microorganisms that contribute to contaminant degradation.

Phytoremediation also depends on the relationship between plants and microorganisms. Bacteria and fungi associated with plant roots can improve nutrient availability, produce plant growth-promoting substances and degrade certain organic pollutants. These interactions can increase plant survival and improve remediation performance. Despite its advantages, phytoremediation has limitations. The process may be relatively slow, particularly when pollutants occur at high concentrations or at considerable soil depths. Its effectiveness may also be influenced by climatic conditions, seasonal variations and the availability of suitable plant species. Furthermore, harvested plant materials containing accumulated contaminants require appropriate management to prevent secondary pollution.

2.2 Types and Mechanisms of Phytoremediation

Phytoremediation involves several mechanisms through which plants and their associated microorganisms interact with environmental contaminants. The major mechanisms include the following.

Phytoextraction

Phytoextraction involves the absorption of contaminants, particularly heavy metals, from contaminated soil through plant roots and their subsequent accumulation in above-ground tissues. Plants used for this process may be harvested after accumulating sufficient quantities of contaminants. Repeated harvesting can gradually reduce the contaminant concentration in the soil.

Phytostabilisation

Phytostabilisation involves the use of plants to reduce the movement and bioavailability of contaminants in soil. Plant roots can bind soil particles, reduce erosion and restrict the migration of pollutants into groundwater. This process is particularly useful in areas contaminated with metals and metalloids that cannot easily be degraded.

Rhizofiltration

Rhizofiltration involves the removal of contaminants from polluted water through plant roots. Roots absorb or adsorb pollutants from water, thereby reducing their concentrations. This approach is particularly relevant to the treatment of wastewater containing certain heavy metals and other dissolved contaminants.

Phytodegradation

Phytodegradation refers to the breakdown or transformation of organic pollutants within plant tissues through enzymatic activities. Plants may produce enzymes such as peroxidases and oxygenases that participate in the transformation of certain organic chemicals.

Rhizodegradation

Rhizodegradation occurs when microorganisms in the root zone degrade organic pollutants. Plant roots release organic substances known as root exudates, which provide nutrients and energy for microbial communities. These substances can stimulate the growth of bacteria and fungi capable of degrading petroleum hydrocarbons, pesticides and other organic contaminants.

Phytovolatilisation

Phytovolatilisation involves the uptake of certain contaminants by plants, their transformation into volatile forms and their subsequent release into the atmosphere through transpiration. Although this mechanism may reduce contaminant concentrations in soil or water, it requires careful assessment because the released substances may still pose environmental risks. These mechanisms may operate simultaneously in

contaminated environments. The dominant process depends on plant species, pollutant characteristics, soil properties and environmental conditions (Ali et al., 2013).

2.3 Plants Commonly Used in Phytoremediation

Different plant species have been investigated for their ability to tolerate, accumulate or transform environmental pollutants. The choice of plant depends on its growth characteristics, root development, biomass production, pollutant tolerance and ability to interact with microorganisms. Brassica juncea, commonly known as Indian mustard, has been widely investigated for the uptake of certain heavy metals. Its ability to accumulate metals in above-ground tissues makes it useful in phytoextraction research. Helianthus annuus (sunflower) is another plant commonly studied for phytoremediation. Its extensive root system and relatively high biomass production make it suitable for investigating the removal of certain contaminants from soil and water. Pteris vittata, a fern species, is particularly recognised for its ability to accumulate arsenic. It has received considerable attention in studies involving arsenic-contaminated soils. Vetiveria zizanioides (vetiver grass) is known for its extensive root system, which contributes to soil stabilisation and the management of contaminated environments. Its root structure makes it useful in phytostabilisation research. The five plants considered in this review also possess biological properties that justify further environmental investigation. Moringa oleifera has been studied for its seed-based water-treatment properties and its ability to interact with suspended materials. Its use in water clarification provides a potential low-cost approach to preliminary treatment. Azadirachta indica has been investigated for its biological and pesticidal activities. Its different plant parts contain compounds that may influence microbial populations and certain biological processes. Ocimum gratissimum contains essential oils and phenolic constituents associated with antimicrobial activities. Its extracts may be relevant to studies of plant-derived antimicrobial agents and microbial interactions. Vernonia amygdalina contains several phytochemicals with antioxidant and antimicrobial properties. Its suitability for environmental remediation, however, requires direct investigation of pollutant uptake, accumulation and transformation.

Hibiscus sabdariffa is rich in anthocyanins and other phenolic compounds. Its biological activities have attracted interest in antioxidant and pharmacological research, although these properties alone do not establish its effectiveness in removing environmental pollutants. It is important to recognise that medicinal usefulness and phytoremediation efficiency are different characteristics. Therefore, the five selected plants should be evaluated individually for their environmental performance rather than assuming that their medicinal properties automatically make them effective phytoremediators.

2.4 Applications of Phytoremediation in Environmental Pollution Control

Phytoremediation has several potential applications in the management of environmental pollution. Its major applications include the treatment of contaminated soils, wastewater, industrial effluents and environments affected by petroleum-related activities.

Removal of heavy metals and organic pollutants Heavy metals such as lead, cadmium, chromium and arsenic can accumulate in soil and water through industrial activities, mining, agricultural chemicals and improper waste disposal. Certain plants can absorb these contaminants and accumulate them in their tissues. Others reduce their mobility through phytostabilisation. Organic pollutants may also be transformed through plant enzymatic activities and microbial degradation.

Management of petroleum-contaminated environments

Petroleum hydrocarbons released through oil spills and industrial activities can persist in soil and sediment. Plant roots can stimulate hydrocarbon-degrading microorganisms by releasing organic substances into the

rhizosphere. These microorganisms may break down petroleum compounds into simpler substances (Umudi et al., 2025). This process makes rhizodegradation an important mechanism in the management of petroleum-contaminated environments.

Treatment of contaminated water and industrial wastewater

Some plants can remove contaminants from water through root absorption and adsorption. Rhizofiltration is particularly useful in investigating the treatment of water containing selected metals. Plant-based materials, including Moringa oleifera seeds, may also assist in the clarification of turbid water through coagulation. However, clarification does not necessarily remove dissolved chemicals or eliminate all pathogenic microorganisms.

Remediation of polluted soils and aquatic ecosystems

Vegetation can improve soil stability, reduce erosion and restrict the movement of pollutants into surrounding environments. Aquatic plants may also absorb nutrients and selected contaminants from water bodies. These processes can contribute to the management of polluted wetlands, ponds and other aquatic ecosystems. The environmental importance of phytoremediation lies in its potential to provide relatively low-cost and environmentally compatible alternatives or complementary approaches to conventional remediation methods. Nevertheless, its success requires proper plant selection, monitoring of pollutant concentrations and appropriate disposal or management of contaminated biomass.

3.0 SELECTED PLANT EXTRACTS AND THEIR BIOACTIVE COMPONENTS

3.1 Overview of Selected Medicinal and Remediation Plants

Medicinal plants are important sources of naturally occurring compounds with diverse biological activities (Umudi et al., 2025). Their usefulness is associated with the presence of secondary metabolites that contribute to antioxidant, antimicrobial, anti-inflammatory and other pharmacological properties. The chemical composition of medicinal plants varies according to species, geographical location, environmental conditions, plant maturity and extraction procedures. The five plants considered in this review are Moringa oleifera, Azadirachta indica, Ocimum gratissimum, Vernonia amygdalina and Hibiscus sabdariffa.

Moringa oleifera

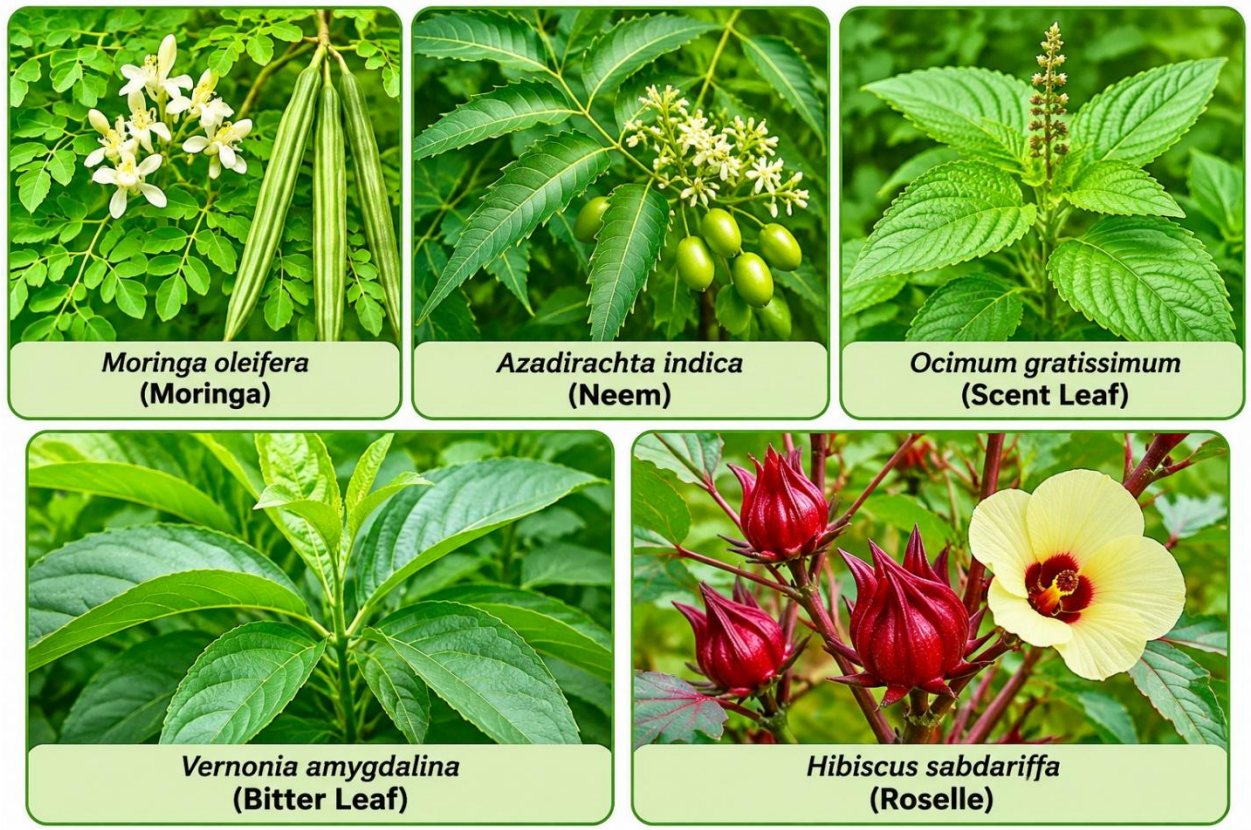


Figure 1: Botanical Images of the Five Selected Plants Used in the Study

MORINGA (FAMILY: MORINGACEAE)

Moringa oleifera is a multipurpose plant widely cultivated in tropical and subtropical regions. It is commonly known as the drumstick tree or miracle tree and is valued for its nutritional, medicinal and agricultural properties. Different parts of the plant, including the leaves, seeds, flowers, bark and roots, contain bioactive compounds (Erienu et al., 2022). The leaves are particularly rich in flavonoids, phenolic acids, vitamins and minerals. Important phytochemicals reported in the plant include quercetin, kaempferol, chlorogenic acid and glucosinolates. These compounds have been associated with antioxidant, anti-inflammatory and antimicrobial activities (Liu et al., 2022). The seeds are also important because they contain proteins capable of promoting coagulation and reducing turbidity in untreated water (Abeokuta et al., 2025). This property has generated interest in the use of Moringa oleifera as a plant-based material for water clarification. However, its effectiveness in removing dissolved heavy metals and organic pollutants requires separate assessment. Recent reviews have also highlighted the potential pharmacological benefits of Moringa oleifera, particularly in relation to oxidative stress, metabolic disorders and inflammatory conditions. Nevertheless, its safety depends on the plant part, extraction procedure and dosage used (Liu et al., 2022).

Azadirachta indica

Azadirachta indica, commonly known as neem, is an evergreen tree widely distributed in tropical regions, particularly in Africa and Asia. It has considerable medicinal, agricultural and environmental importance.

Various parts of the plant, including its leaves, seeds, bark, flowers and roots, are used in traditional preparations. Neem contains several bioactive compounds, particularly limonoids, flavonoids, tannins, phenolic acids and terpenoids. Important limonoids include azadirachtin, nimbin, salannin and nimbolide. These compounds are associated with the plant's insecticidal, antimicrobial, antioxidant and anti-inflammatory properties. Neem has attracted attention in environmental research because of its pesticidal properties and potential applications in sustainable agriculture. Its extracts are used in the formulation of botanical pesticides, which may provide alternatives to certain synthetic pesticides. However, the environmental behaviour and toxicity of neem-derived products must be evaluated before large-scale application. Patil et al. (2022) reported that neem possesses several pharmacological activities, including antioxidant and antidiabetic properties. The authors also emphasised the importance of further investigations into its toxicological characteristics and standardisation.

Ocimum gratissimum

SCENT LEAF (FAMILY: LAMIACEAE)

Ocimum gratissimum, commonly known as scent leaf or African basil, is an aromatic medicinal plant widely cultivated in West Africa. Its leaves are commonly used as a culinary spice and in traditional medicine. The plant is recognised for its essential oils and diverse phytochemical constituents. The major bioactive compounds reported in Ocimum gratissimum include eugenol, thymol, linalool, rosmarinic acid, caffeic acid, flavonoids and terpenoids. These compounds contribute to its characteristic aroma and biological activities. The essential oils obtained from the leaves have demonstrated antimicrobial activities against selected bacteria and fungi. Some of the reported mechanisms involve disruption of microbial cell membranes, interference with enzyme activities and alteration of cellular functions. According to the review by A review on the traditional uses, phytochemistry, and pharmacological activities of clove basil, Ocimum gratissimum possesses antioxidant, antimicrobial, anti-inflammatory and other pharmacological properties. However, differences in chemical composition among plant varieties and extraction methods may influence the effectiveness of its extracts (Akinmoladun et al., 2021).

Vernonia amygdalina

BITTER LEAF (FAMILY: ASTERACEAE)

Vernonia amygdalina is commonly known as bitter leaf and is widely distributed in tropical Africa. It is an important vegetable and medicinal plant, particularly in Nigeria, where its leaves are consumed as food and used in traditional preparations. The plant contains several phytochemical constituents, including flavonoids, saponins, tannins, alkaloids, terpenoids and sesquiterpene lactones. Important compounds associated with its biological properties include vernodalin, vernolide and other sesquiterpene lactones. These compounds have been investigated for their antioxidant, antimicrobial, anti-inflammatory and metabolic activities. The plant's antioxidant potential is particularly important because phenolic compounds and flavonoids may help reduce oxidative stress through free-radical scavenging mechanisms (Ugochukwu et al., 2025). A 2024 study by Adekemi et al. investigated the effects of aqueous Vernonia amygdalina leaf extract on liver markers in diabetic albino rats. The findings provide evidence of biological activity in an animal model, although results from diabetic animals cannot be directly interpreted as proof of safety in healthy animals (Festus-Amadi et al., 2021). The plant is therefore relevant to research involving phytochemical composition, antioxidant activities and toxicological assessment.

Hibiscus sabdariffa

ROSELLE (FAMILY: MALVACEAE)

Hibiscus sabdariffa, commonly known as roselle, is a tropical plant cultivated for its edible calyces, leaves and seeds. The red calyces are particularly important because they contain pigments and other compounds associated with nutritional and biological activities. The plant is rich in anthocyanins, flavonoids, organic acids and phenolic compounds. Important anthocyanins include delphinidin-3-sambubioside and cyanidin-3-sambubioside. These compounds contribute to the characteristic red colour of the calyces and are associated with antioxidant properties. The antioxidant activity of Hibiscus sabdariffa is related to the ability of its phenolic constituents to neutralise reactive oxygen species. Its extracts have also been investigated for possible antimicrobial, anti-inflammatory and cardiovascular effects.

Studies have shown that the phytochemical composition and antioxidant properties of roselle may vary according to genetic characteristics, environmental conditions and plant varieties (Hibiscus sabdariffa compositional study, 2022). Therefore, the plant remains an important subject of nutritional, pharmacological and toxicological research.

3.2 Phytochemical Constituents of Selected Plant Extracts

Phytochemicals are naturally occurring chemical substances produced by plants. They are generally classified as primary or secondary metabolites. Primary metabolites are directly involved in plant growth and development, while secondary metabolites contribute to defence, adaptation and interactions with other organisms (Ogwuche and Obruche, 2020). The major phytochemical groups found in the five selected plants include flavonoids, alkaloids, tannins, saponins, phenolic acids, terpenoids and anthocyanins. Flavonoids are polyphenolic compounds commonly associated with antioxidant and anti-inflammatory activities. They may reduce oxidative damage by neutralising free radicals and influencing cellular signalling pathways. Alkaloids are nitrogen-containing compounds with diverse biological activities. Depending on their chemical structures and concentrations, they may possess antimicrobial, analgesic or other pharmacological properties (Ikechukwu et al., 2026). Tannins are polyphenolic substances capable of binding proteins and other macromolecules. Their biological importance includes astringent and antimicrobial properties. Saponins are glycosides that possess surface-active properties. Some saponins can interact with microbial cell membranes and influence membrane permeability. Terpenoids are a diverse group of compounds involved in plant defence and aroma production. They are found in several medicinal plants, including neem and scent leaf. Anthocyanins are water-soluble pigments responsible for red, purple and blue colours in plants. They possess antioxidant properties and are particularly abundant in the calyces of Hibiscus sabdariffa.

Table 1: Selected Plants, Major Phytochemical Constituents and Reported Biological Activities

Selected plant	Major phytochemical constituents	Reported biological activities
Moringa oleifera	Flavonoids, quercetin, kaempferol, phenolic acids, glucosinolates	Antioxidant, antimicrobial, anti-inflammatory and water clarification
Azadirachta indica	Azadirachtin, nimbolide, nimbin, tannins, flavonoids and terpenoids	Antimicrobial, insecticidal, antioxidant and anti-inflammatory
Ocimum gratissimum	Eugenol, thymol, linalool, rosmarinic acid, flavonoids and tannins	Antimicrobial, antioxidant, antifungal and anti-inflammatory
Vernonia amygdalina	Sesquiterpene lactones, flavonoids, saponins, tannins and alkaloids	Antioxidant, antimicrobial, anti-inflammatory and metabolic activities
Hibiscus sabdariffa	Anthocyanins, delphinidin derivatives, cyanidin derivatives, flavonoids and organic acids	Antioxidant, antimicrobial, anti-inflammatory and cardiovascular-related activities

Compiled from Liu et al. (2022), Patil et al. (2022), Akinmoladun et al. (2021), and published phytochemical studies of Vernonia amygdalina and Hibiscus sabdariffa.

Table 1 presents the major phytochemical constituents and reported biological activities of the five selected plants. The table demonstrates that although the plants belong to different botanical families, they contain several classes of compounds with overlapping biological properties.

Moringa oleifera is characterised by its flavonoids, phenolic acids and glucosinolates, which are associated with antioxidant and anti-inflammatory activities. Its seed proteins also provide an additional environmental application through water clarification. Azadirachta indica contains important limonoids, particularly azadirachtin and nimbolide, which contribute to its insecticidal and other biological activities. Its chemical composition makes it relevant to investigations involving botanical pesticides and plant-derived antimicrobial agents. Similarly, Ocimum gratissimum contains essential-oil constituents such as eugenol and thymol. These compounds are particularly important in antimicrobial research because they may interfere with microbial membrane integrity and cellular processes. Vernonia amygdalina contains sesquiterpene lactones, flavonoids and other phenolic constituents. These compounds may contribute to the antioxidant and pharmacological activities reported for the plant. Its traditional consumption as a vegetable also makes its safety and biological properties important research considerations. Hibiscus sabdariffa differs from the other selected plants because of its high content of anthocyanins and organic acids, particularly in the calyces. These compounds contribute to its antioxidant properties and potential nutritional applications. Overall, the table indicates that the five plants possess diverse chemical constituents that may influence their biological activities. However, the presence of a particular phytochemical does not necessarily establish its effectiveness against a specific microorganism or pollutant. Quantitative phytochemical analysis and experimental evaluation are therefore necessary to determine the actual activity of each extract.

3.3 Antioxidant and Antimicrobial Properties of Plant Extracts

Antioxidant and antimicrobial properties are among the most investigated biological activities of medicinal plants. These properties are largely associated with their secondary metabolites, particularly phenolic compounds, flavonoids, tannins and essential oils.

Antioxidant properties

Antioxidants are substances capable of reducing or preventing oxidative damage by neutralising reactive oxygen species and other free radicals. Oxidative stress occurs when the production of reactive oxygen species exceeds the antioxidant defence capacity of biological systems. The selected plants contain compounds that may contribute to antioxidant protection. Moringa oleifera contains quercetin, kaempferol and chlorogenic acid, which have demonstrated free-radical-scavenging properties. These compounds may also influence antioxidant defence pathways. Azadirachta indica contains flavonoids and other phenolic compounds that contribute to its antioxidant potential. Similarly, Ocimum gratissimum contains rosmarinic acid, caffeic acid and eugenol, which have been investigated for their ability to reduce oxidative reactions.

Vernonia amygdalina contains flavonoids and phenolic compounds that may contribute to antioxidant activities. Hibiscus sabdariffa, particularly its red calyces, contains anthocyanins that are associated with free-radical-scavenging properties. The antioxidant activities of these plants are important in toxicological research because oxidative stress is one of the mechanisms through which certain environmental pollutants and toxic substances damage biological tissues.

Antimicrobial properties

Antimicrobial activity refers to the ability of a substance to inhibit or destroy microorganisms such as bacteria and fungi. Plant extracts may exhibit antimicrobial activities through several mechanisms, including disruption of microbial cell membranes, inhibition of enzymes, interference with protein synthesis and alteration of cellular metabolism. The essential oils of Ocimum gratissimum have demonstrated antimicrobial activities against selected bacterial and fungal organisms. Eugenol and thymol are among the compounds associated with these effects (Akinmoladun et al., 2021). Neem extracts have also been investigated for antibacterial and antifungal activities. Their biological effects are associated with limonoids, flavonoids and other secondary metabolites (Patil et al., 2022). Moringa oleifera contains phenolic compounds and other substances that have been investigated for antimicrobial activities. Likewise, Vernonia amygdalina and Hibiscus sabdariffa contain compounds that may inhibit selected microorganisms. The antimicrobial properties of these plants are relevant to environmental microbiology because plant-derived compounds can influence microbial populations. However, their effects may differ between beneficial environmental microorganisms and pathogenic organisms. Therefore, the concentration, extraction method and target microbial species must be considered when interpreting antimicrobial results.

3.4 Pharmacological and Biological Activities of Plant Extracts

The pharmacological activities of medicinal plants are associated with the interactions between their bioactive compounds and biological systems. The five selected plants have been investigated for different biological activities, including antioxidant, antimicrobial, anti-inflammatory, antidiabetic and hepatoprotective effects. Moringa oleifera has been investigated for its potential effects on blood glucose regulation, inflammatory processes and oxidative stress. Its leaves contain several nutrients and bioactive compounds that may contribute to these properties. Liu et al. (2022) identified a wide range of phytochemicals and pharmacological activities associated with the plant. Azadirachta indica has been studied for its possible antidiabetic, antimicrobial and anti-inflammatory properties. Patil et al. (2022) reported that neem extracts and isolated compounds have been investigated in relation to glucose regulation, lipid metabolism and oxidative stress. Ocimum gratissimum possesses several pharmacological properties, including antimicrobial, antioxidant, anti-inflammatory and antidiarrhoeal activities. Its essential oils and phenolic compounds are important contributors to these biological effects (Akinmoladun et al., 2021). Vernonia amygdalina has been investigated for its potential effects on blood glucose regulation, antioxidant defence and liver function. Adekemi et al. (2024) reported changes in serum liver markers following administration of aqueous leaf extract in streptozotocin-induced diabetic albino rats. Hibiscus sabdariffa has received attention for its antioxidant and cardiovascular-related activities. Its anthocyanins and phenolic compounds are important constituents associated with these properties. Although the pharmacological activities of these plants are promising, their effects depend on the chemical composition of the extracts, dosage, route of administration and duration of exposure. Consequently, biological effectiveness should be considered alongside toxicological evidence to establish their possible benefits and risks.

4.0 MICROBIAL ACTIVITIES AND ENVIRONMENTAL INTERACTIONS

4.1 Role of Microorganisms in Phytoremediation

Microorganisms play an important role in phytoremediation because they participate in the degradation, transformation and immobilisation of environmental pollutants. Bacteria and fungi are particularly important because of their metabolic diversity and ability to survive under different environmental conditions. The root region of plants, commonly referred to as the rhizosphere, provides a suitable environment for microbial

growth. Plant roots release organic substances such as sugars, amino acids, organic acids and other compounds into the surrounding soil. These substances serve as sources of nutrients and energy for microorganisms. Certain rhizosphere microorganisms possess enzymes capable of breaking down organic contaminants, including petroleum hydrocarbons, pesticides and other industrial chemicals. Through these enzymatic activities, harmful organic substances may be converted into simpler compounds. Microorganisms also contribute to the management of heavy metals. Although metals cannot be biologically degraded, microorganisms can alter their chemical forms, mobility and bioavailability. Some bacteria produce extracellular substances that bind metals, while others promote metal precipitation or immobilisation. Plant growth-promoting rhizobacteria are particularly important in phytoremediation. These bacteria can produce plant hormones, solubilise nutrients, fix atmospheric nitrogen and improve plant tolerance to environmental stress. Some also produce enzymes that reduce the harmful effects of pollutants on plants. Gamalero and Glick (2024) explained that plant growth-promoting bacteria can enhance phytoremediation by improving plant growth and tolerance in contaminated environments. Similarly, plant-associated microbial communities can influence the uptake, transformation and immobilisation of heavy metals (Sánchez-Jiménez et al., 2022). The major microbial groups involved in phytoremediation include:

- Bacteria: Genera such as Bacillus, Pseudomonas, Rhizobium and Arthrobacter are investigated for their roles in pollutant transformation and plant growth promotion.
- Fungi: Certain fungi, including species of Aspergillus, Penicillium and mycorrhizal fungi, contribute to organic pollutant degradation and metal immobilisation.
- Actinomycetes: These filamentous bacteria contribute to the decomposition of complex organic substances and nutrient cycling in soil.

The activities of these microorganisms are important because they can improve plant survival and increase the overall efficiency of phytoremediation.

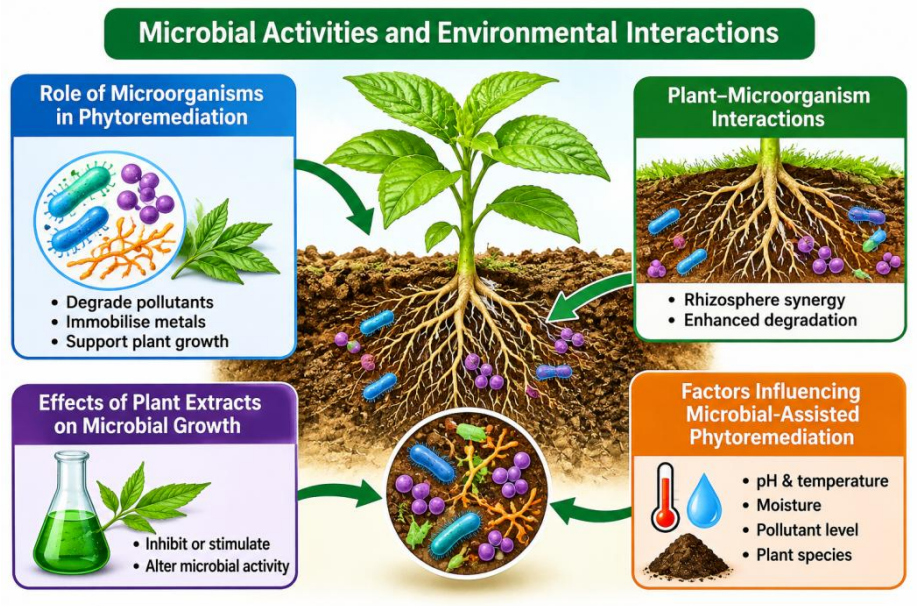


Figure 2: Microbial Activities and Plant–Microorganism Interactions in Phytoremediation

4.2 Plant–Microorganism Interactions in Pollutant Degradation

Plant–microorganism interactions involve complex relationships between plant roots and microorganisms inhabiting the surrounding environment. These interactions can be beneficial, harmful or neutral, depending on the organisms involved and environmental conditions.

In phytoremediation, beneficial interactions occur when microorganisms improve plant growth and increase the degradation or immobilisation of pollutants. Plant roots provide organic substances that support microbial growth, while microorganisms assist plants through nutrient mobilisation and pollutant transformation. One important interaction is the stimulation of pollutant-degrading microorganisms by root exudates. Root exudates contain organic compounds that can serve as carbon and energy sources for bacteria and fungi. These substances may increase microbial activity and promote the degradation of organic contaminants. Another interaction involves the production of microbial growth-promoting substances. Some bacteria produce indole-3-acetic acid, siderophores and other compounds that improve plant growth and nutrient availability. These activities may increase plant tolerance to contaminated conditions.

Mycorrhizal fungi also contribute to plant–microorganism interactions. They form associations with plant roots and extend the effective root absorption area through their fungal networks. These associations can improve water and nutrient uptake and influence the mobility of certain metals. Recent research has highlighted the importance of combining plants with beneficial microorganisms to improve environmental restoration. Gamalero and Glick (2024) reported that plant growth-promoting bacteria can enhance plant performance under toxic metal and organic pollutant stress. The systematic review by the authors of Interactions between beneficial soil microorganisms (PGPR and AMF) and host plants for environmental restoration (2024) also identified the importance of interactions between plant growth-promoting rhizobacteria and arbuscular mycorrhizal fungi. These findings demonstrate that successful phytoremediation may depend not only on the characteristics of the plant but also on the microbial community associated with its roots.

4.3 Effects of Plant Extracts on Microbial Growth and Activities

Plant extracts contain several bioactive compounds capable of influencing microbial growth and metabolism. Their effects may be inhibitory or stimulatory, depending on the concentration, chemical composition and sensitivity of the microorganisms. Phenolic compounds can interact with microbial cell membranes and proteins, resulting in changes in membrane permeability and cellular functions. Essential oils may also interfere with microbial metabolic activities and reduce the ability of certain organisms to multiply. Moringa oleifera contains phenolic compounds and other bioactive substances that have been investigated for antimicrobial activities. Its seed-derived proteins also possess coagulating properties that can influence suspended materials and microbial removal during water treatment. Azadirachta indica contains limonoids and other compounds associated with antimicrobial and pesticidal activities. Neem extracts may influence the growth of selected microorganisms, although their effects depend on the concentration and extraction method. Ocimum gratissimum is particularly important because of its essential-oil constituents, including eugenol and thymol. These compounds have been investigated for their inhibitory effects against selected bacterial and fungal organisms.

Vernonia amygdalina contains flavonoids, tannins and sesquiterpene lactones that may contribute to antimicrobial properties. Similarly, Hibiscus sabdariffa contains anthocyanins and phenolic compounds that have been investigated for their ability to influence microbial growth.

However, plant extracts may also affect beneficial microorganisms involved in nutrient cycling and pollutant degradation. For this reason, antimicrobial effectiveness should not be interpreted as universal environmental

usefulness. The concentration of the extract and its effects on beneficial microbial populations must be considered.

4.4 Factors Influencing Microbial-Assisted Phytoremediation

The effectiveness of microbial-assisted phytoremediation depends on several environmental, biological and chemical factors.

Soil pH: Soil pH influences nutrient availability, microbial growth and the mobility of heavy metals. Extreme pH conditions may reduce microbial diversity and affect plant development.

Temperature: Temperature influences microbial metabolic activities, enzyme production and plant growth. Suitable temperature conditions are necessary for effective pollutant degradation.

Moisture content: Adequate moisture supports microbial activity and nutrient transport. However, excessive waterlogging may reduce oxygen availability and influence the activities of aerobic microorganisms.

Pollutant concentration: High pollutant concentrations may inhibit plant growth and microbial activities. Certain microorganisms can tolerate specific pollutants, but their performance may decline when contaminant concentrations exceed their tolerance limits. Plant species and root development: Plants with extensive root systems may support larger microbial populations and provide greater opportunities for pollutant interaction.

Microbial diversity: The presence of different microbial groups can improve the range of pollutants that may be degraded or transformed. Microbial diversity also contributes to the stability of soil ecosystems.

Nutrient availability: Nitrogen, phosphorus and other essential nutrients influence microbial growth and plant development. Nutrient deficiencies may reduce remediation efficiency. According to Sánchez-Jiménez et al. (2022), the interaction between plants, microorganisms and environmental conditions is an important determinant of heavy-metal remediation. Therefore, effective microbial-assisted phytoremediation requires consideration of both plant characteristics and the ecological conditions of the contaminated environment.

5.0: TOXICOLOGICAL EFFECTS OF SELECTED PLANT EXTRACTS IN ALBINO RATS

5.1 Overview of Toxicity Studies Using Albino Rats

Toxicology is the scientific study of the harmful effects of chemical substances on living organisms. In plant-based research, toxicological assessment is important for determining whether extracts obtained from medicinal plants are safe at particular concentrations and under specific exposure conditions. Although medicinal plants contain compounds with beneficial biological properties, they may also contain substances capable of producing adverse effects. The toxicity of plant extracts depends on several factors, including plant species, plant part, extraction solvent, chemical composition, administered dose and duration of exposure. Albino rats are commonly used in experimental toxicology because they provide useful information on physiological, biochemical and histological responses to chemical substances. Their use allows researchers to investigate possible changes in blood composition, organ functions, body weight and tissue structures under controlled experimental conditions. Toxicological investigations generally involve acute, subacute and chronic exposure studies. Acute toxicity studies assess the harmful effects of a single administration or short-term exposure, while repeated-dose studies examine the consequences of administering a substance over several days or weeks. Longer-term studies may investigate chronic toxicity and possible effects on reproduction and other biological systems. The major parameters commonly evaluated include body weight, food consumption, water intake, organ weight, haematological indices, liver enzymes, kidney function markers and

histopathological changes. The importance of these studies is to establish the safety profile of plant extracts and identify concentrations that may produce adverse effects. However, findings obtained from one extract should not automatically be applied to another preparation of the same plant because extraction methods and chemical compositions may differ.

5.2 Acute and Sub-Acute Toxicity of Plant Extracts

Acute toxicity refers to adverse effects that occur following a single exposure or short-term administration of a substance. It is commonly assessed through clinical observations, behavioural changes, mortality and other signs of toxicity. Subacute toxicity involves repeated exposure over a relatively short period, often around 14–28 days, although study durations may vary. These investigations help determine whether repeated administration produces changes in physiological and biochemical parameters.

Toxicity of Moringa oleifera

Moringa oleifera has been investigated in several animal studies because of its nutritional and pharmacological properties. However, its safety may differ depending on the plant part and extraction procedure.

Liu et al. (2022) reviewed the phytochemistry, pharmacology and toxicity of Moringa oleifera, highlighting the need for appropriate safety evaluation. A repeated-dose toxicity study of Moringa oleifera leaf infusion and powder reported that the infusion did not produce toxicity during the 28-day administration period. However, the powder preparation at certain doses produced biochemical and histological evidence of liver and kidney injury. This demonstrates that the physical preparation of plant material can influence its toxicological effects (Evaluation of acute toxicity, 28-day repeated dose toxicity, and genotoxicity of Moringa oleifera leaves infusion and powder, 2022).

Toxicity of Azadirachta indica

Neem extracts contain several biologically active compounds, some of which may produce adverse effects at particular doses. Its safety depends on the plant part, concentration, route of administration and duration of exposure. Patil et al. (2022) reviewed the pharmacological and toxicological properties of Azadirachta indica. Their findings highlight the importance of evaluating neem preparations carefully before considering their therapeutic applications.

In particular, neem seed oil should not be assumed to have the same safety profile as aqueous or alcoholic leaf extracts. The chemical composition of different preparations varies considerably.

Toxicity of Ocimum gratissimum

Ocimum gratissimum is widely consumed as a culinary plant and used in traditional medicine. Nevertheless, its extracts require toxicological assessment because essential oils and concentrated extracts may contain relatively high levels of biologically active compounds. Umar et al. (2019) investigated the phytochemical, antimicrobial and toxicological properties of scent-leaf extracts. Their findings indicated mild toxicity at higher doses, although the extracts showed a comparatively favourable safety profile under the tested oral administration conditions. Akinmoladun et al. (2021) also emphasised that further investigations are necessary to establish appropriate and safe doses of Ocimum gratissimum preparations.

Toxicity of Vernonia amygdalina

Vernonia amygdalina is widely consumed as a vegetable and used in traditional medicine. Its extracts have been investigated for their potential antioxidant and pharmacological activities.

Uduchi et al. (2022) examined the effects of ethanolic leaf extract on haematological parameters in albino rats. The study reported no significant adverse changes in most of the measured haematological indices, although some differences were observed in neutrophil counts. Adekemi et al. (2024) also investigated aqueous leaf extract in streptozotocin-induced diabetic albino rats. Their study examined changes in serum liver markers, providing further information on the biological effects of the extract. These findings suggest potential biological benefits, but they do not establish the safety of every extract or dose of the plant.

Toxicity of Hibiscus sabdariffa

Hibiscus sabdariffa is commonly consumed as a food ingredient and beverage. Its calyces contain anthocyanins and other phenolic compounds associated with antioxidant activities. Toxicological evidence reviewed in the literature suggests that certain aqueous and calyx preparations have demonstrated relatively favourable safety profiles in animal studies. However, differences in extract concentration, administration route and duration of exposure must be considered. The findings summarised in the 2025 review by Anyanwu et al. indicate that the toxicity profile of roselle preparations varies according to the plant part and method of administration. Therefore, its safety should be evaluated using standardised preparations and appropriate experimental conditions.

5.3 Effects on Haematological and Biochemical Parameters

Haematological and biochemical assessments are important components of toxicological investigations because they provide information about the effects of plant extracts on blood composition and internal organ functions.

Haematological parameters

Haematological parameters are measurements used to evaluate the cellular components of blood. They include red blood cell count, white blood cell count, haemoglobin concentration, packed cell volume and platelet count. Red blood cells are responsible for transporting oxygen throughout the body, while haemoglobin is the oxygen-carrying protein found within these cells. Packed cell volume indicates the proportion of blood occupied by red blood cells. White blood cells are involved in immune defence, while platelets contribute to blood clotting. Changes in these parameters may indicate possible toxic effects. For example, a reduction in haemoglobin and red blood cell counts may suggest anaemia, while alterations in white blood cell counts may indicate changes in immune function or inflammatory responses. Studies involving Vernonia amygdalina and Moringa oleifera have demonstrated the importance of monitoring haematological parameters when evaluating plant extracts in albino rats (Daniel et al., 2022; Uduchi et al., 2022).

Biochemical parameters

Biochemical parameters are used to assess the functional condition of organs and metabolic systems. Important parameters include alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), total protein, albumin, urea and creatinine.

ALT and AST are enzymes commonly used to evaluate liver injury. Increased serum activities may indicate damage to liver cells, although interpretation requires consideration of other clinical and experimental findings. ALP is associated with several tissues, including the liver and bones. Changes in its activity may indicate disturbances in liver or biliary function.

Urea and creatinine are commonly used as indicators of kidney function. Increased concentrations may suggest impaired renal filtration, although hydration status and other physiological factors can influence their

levels. The evaluation of these parameters is particularly important when investigating plant extracts because some phytochemicals may influence liver metabolism, kidney function and antioxidant defence mechanisms.

5.4 Effects on Liver, Kidney and Other Vital Organs

The liver and kidneys are particularly important organs in toxicological assessment because they are involved in the metabolism, transformation and elimination of substances introduced into the body.

Effects on the liver

The liver performs several important functions, including detoxification, protein synthesis, metabolism of nutrients and regulation of blood chemicals. Plant extracts administered orally may be absorbed from the digestive tract and transported to the liver for metabolism. Some phytochemicals may provide antioxidant protection, while others may produce adverse effects at high concentrations. Liver toxicity may be indicated by increased serum liver enzymes, changes in organ weight and alterations in tissue structure. Moringa oleifera, Vernonia amygdalina and Hibiscus sabdariffa have been investigated for their potential effects on liver function. Some studies have reported protective effects under experimentally induced liver injury, while other studies have demonstrated that certain preparations may produce adverse effects depending on dose and duration.

Effects on the kidneys

The kidneys are responsible for filtering blood, regulating fluid balance and eliminating metabolic waste products. They also contribute to electrolyte regulation and maintenance of acid–base balance. Toxic substances may interfere with kidney function by damaging renal cells or affecting filtration processes. Changes in serum urea and creatinine are commonly investigated as possible indicators of renal impairment. The repeated-dose toxicity study of Moringa oleifera leaf powder reported biochemical and histological changes involving the kidneys at certain administered doses. This finding emphasises the importance of assessing the safety of concentrated plant preparations rather than assuming that naturally occurring substances are harmless.

Effects on other vital organs

Apart from the liver and kidneys, toxicological studies may examine the heart, lungs, spleen, reproductive organs and gastrointestinal tract. Changes in organ weight, tissue structure and physiological functions may provide additional evidence of toxicity. Reproductive organs are particularly important in prolonged exposure studies because some plant compounds may influence hormonal regulation and reproductive functions. Consequently, a comprehensive toxicological assessment should not rely solely on liver and kidney enzyme measurements but should include other relevant physiological and histological observations.

5.5 Histopathological Changes Associated with Plant Extract Exposure

Histopathology involves the microscopic examination of tissues to identify structural changes associated with disease, injury or exposure to potentially harmful substances. In toxicological investigations involving albino rats, histopathological examinations are commonly conducted on the liver, kidneys and other vital organs after administration of plant extracts. The liver may show changes such as hepatocyte degeneration, inflammation, congestion, fatty changes and necrosis when exposed to toxic substances. These changes may indicate disturbances in normal liver architecture and cellular function. The kidneys may exhibit tubular degeneration, glomerular changes, inflammatory infiltration and other structural abnormalities following exposure to certain toxic substances. The spleen may also be examined for changes in lymphoid tissues, while the heart and lungs may be evaluated for evidence of cellular injury or inflammation. Histopathological studies are

important because biochemical changes do not always provide a complete explanation of tissue injury. For example, some structural abnormalities may occur before substantial changes are detected in serum biochemical parameters. Research on Vernonia amygdalina has demonstrated its potential to ameliorate acetaminophen-induced liver damage in albino rats. Raimi et al. (2020) reported improvements in liver tissue architecture following treatment with aqueous leaf extract. This finding suggests possible hepatoprotective activity under the experimental conditions investigated. However, protective effects against an experimentally induced toxicant should not be interpreted as proof that the extract is completely harmless when administered alone. Similarly, histopathological findings from Moringa oleifera toxicity investigations demonstrate that the preparation and administered dose can influence tissue responses. Therefore, the evaluation of plant extracts should combine biochemical, haematological and histopathological assessments to provide a more reliable understanding of their safety.

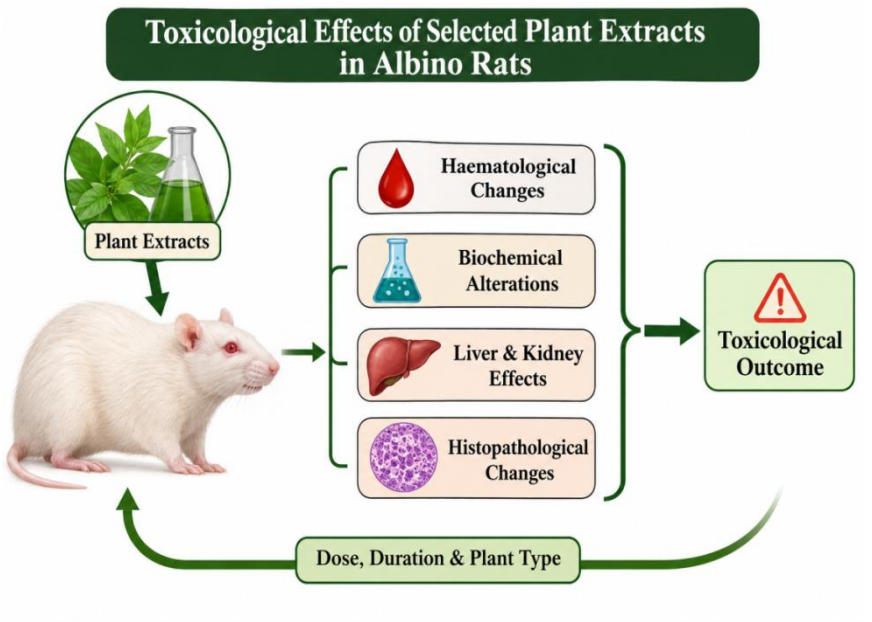


Figure 3: Toxicological Effects of Selected Plant Extracts in Albino Rats

6.0 CONCLUSION

This review examined the phytoremediation potential, microbial activities and toxicological effects of selected plant extracts, namely Moringa oleifera, Azadirachta indica, Ocimum gratissimum, Vernonia amygdalina and Hibiscus sabdariffa. The review established that these plants contain diverse phytochemical constituents with important environmental and biological properties. The findings from the reviewed literature indicate that phytoremediation provides an environmentally friendly approach to managing contaminated soil and water. Its effectiveness depends on the ability of plants to absorb, accumulate, immobilise or transform pollutants, as well as the activities of microorganisms associated with their roots. The interaction between plants and microorganisms is particularly important because microbial activities can improve plant growth, enhance pollutant degradation and influence the mobility of environmental contaminants. The five selected plants possess different phytochemical compositions. Moringa oleifera contains flavonoids, phenolic acids and glucosinolates, while Azadirachta indica contains limonoids and other bioactive compounds. Ocimum

gratissimum is characterised by essential oils such as eugenol and thymol, whereas Vernonia amygdalina contains sesquiterpene lactones and flavonoids. Hibiscus sabdariffa is particularly rich in anthocyanins and phenolic compounds. These constituents are associated with antioxidant, antimicrobial and other pharmacological activities. The review also established that the biological activities of plant extracts may have both beneficial and adverse effects depending on their chemical composition, dosage and duration of exposure. Toxicological studies involving albino rats provide useful information on their effects on haematological parameters, biochemical markers, liver and kidney functions, and tissue structures. Although several studies have reported promising biological activities and relatively favourable safety findings for some preparations, these results cannot be generalised to all extracts of the same plants. Differences in extraction methods, plant parts and administered concentrations may produce different biological responses. Furthermore, the medicinal and antimicrobial properties of these plants do not automatically establish their effectiveness as phytoremediators. Direct environmental studies are required to determine their abilities to remove or immobilise specific pollutants. In conclusion, the five selected plants represent important subjects for environmental and biological research because of their diverse phytochemical constituents and reported biological activities. Their potential applications in environmental management and medicine should be supported by standardised phytochemical investigations, microbial studies and comprehensive toxicological assessments.

Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship and publication of this article.

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