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Comparative Phytochemical Screening of Leaves, Seeds and Roots of Moringa Plant (*Moringa oleifera* Lam)

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Abstract

This research conducted a comparative analysis of the bioactive chemicals in *Moringa* oleifera parts (leaves, seeds and roots). Phytochemical screening was conducted to identify and measure the essential bioactive compounds using qualitative and quantitative methodologies. The phytochemical profile of the various plant components was distinct with the leaves exhibiting significant levels of tannins (9.27± 0.18^{a} mg^{-}100g), flavonoids (4.98± 0.11^{b} mg^{-}100g), terpenoids (4.33± 0.29^{c} mg^{-}100g), and steroids (3.18 ± 0.23^{d} mg^{-}100g). The seeds contained notable number of alkaloids, with a concentration of 91.66 mg^{-}100g. Additionally, they included flavonoids at a concentration of 74.23± 0.22^{b} mg^{-}100g, tannins (32.28 ± 0.10^{c} mg^{-}100g), and saponins (32.91 ± 0.04^{c} mg^{-}100g). The roots had the most elevated amounts of tannins, measuring at a concentration of 38.15 ± 0.25^{a} mg^{-}100g, and phenolic acids, measuring at a concentration of 4.01 ± 0.15^{b} mg^{-}100g. The bioactive components of leaves, seeds, and roots exhibited significant differences at $p \leq 0.05$. Leaves provided promising qualities as both a nutritional supplement and an abundant reservoir of innate antioxidants. Roots contain a significant amount of tannin, suggesting their possible use in traditional medicine while the seeds indicated wide range of health benefits, making them important in both traditional medicine and modern pharmacology. The research showed the distinct medicinal and nutritional benefits of each individual part of the Moringa plant, promoting Moringa as a functional food and herbal remedy, and encouraging sustainable harvesting and utilization of all parts of the plant, emphasizing their potential uses in nutrition, traditional medicine, and pharmacology

Keywords: *Moringa oleifera*, Root, Seed, Leaves, Phytochemical screening, Bioactive ingredients

Introduction

Plants are incredible sources of natural products or compounds that can greatly influence our health and well-being. These remarkable compounds, called plant bioactive compounds, are not necessary for plant to survive but serve vital ecological roles (Sharma *et al*., 2019). Known as secondary metabolites or phytochemicals, they differ from primary compounds that

support the plant to grow and develop. Their diversity leads to a wide range of biological effects, including antioxidant, antimicrobial, anti-inflammatory, and even cancer-preventive properties. Antioxidants, for instance, help neutralize free radicals, which are unstable molecules that damage cells and contribute to chronic diseases. Compounds like flavonoids and phenolic acids, found in fruits, vegetables, and beverages such as tea, are prime examples of antioxidants (Maheswari, 2013). Curcumin, a well-known bioactive compound in turmeric, is celebrated for its anti-inflammatory effects, quercetin and kaempferol found in moringa which are anti-oxidant, anti-inflammatory and cardioprotective, while certain plant bioactives may also offer potential in cancer prevention or management (Gopalakrishnan *et al*, 2017).

Among those natural products, there are plant extracts of either pure compounds or small Turnstile complexes from standardized extract show new vistas in drug discovery owing to incredible chemical universe (Chopra and Dingra, 2021). World Health Organization (WHO, 1993) reported that, over 80% of the world's population uses traditional medicine for their primary health care. The use of traditional herbal medicines is particularly prevalent in Asia, and this long history of human interactions with the environment has led to a rich heritage whereby plants such as Aspidosperma are used for natural health care. Medicinal plants are highly characterized by the presence of antibacterial, antifungal anticancer and anti-inflammatory features that make them invaluable in an effort to fight chronic diseases as well other infections globally (Ravichandran *et al*., 2023). Men were driven to ethnopharmacognosy when the chemically synthesized drugs became associated with adverse effect of their own and microbial resistance. Fortunately, they found literally thousands of phytochemicals from plants as safe and much more effective alternatives with fewer harm (Pareek *et al*., 2023).

In many cases, people claim the benefit of certain natural or herbal products. However, clinical trials must demonstrate the quality, efficacy, potency, and effectiveness of a bioactive compound to verify this traditional claim. Clinical trials to understand the pharmacokinetics, bioavailability, usefulness, safety, and drug interactions of newly developed bioactive compounds and their formulations (extracts) require careful evaluation (Pichini *et al*., 2023). Clinical trials are carefully planned to safeguard the health of the participants as well as answer specific research questions by evaluating for both immediate and long-term side effects and their outcomes are measured before the drug is widely applied to patients (Pichini *et al*., 2023). According to the World Health Organization (WHO, 1993), nearly 20,000 medicinal plants exist in 91 countries including 12 mega biodiversity countries. The premier steps to utilize the biologically active compound from plant resources are extraction, pharmacological screening, isolation and characterization of the bioactive compound, toxicological evaluatio n, and clinical evaluation (Abubakar and Haque, 2020). Moringa (*Moringa oleifera* Lam) is a prominent plant species within the Moringaceae family. Its taxonomic *classification* can be found in Table 1 below. Commonly referred to as the drumstick tree, it is also known as the miracle tree. Every part of the plant has a specific use, particularly for its medicinal properties. Moringa is a rich source of nutrients and bioactive compounds, cultivated in Asia and Africa for its wide-ranging benefits. It has

traditionally been used to treat ulcers, aid in wound healing, and combat conditions such as cancer, obesity, anemia, and liver disease. The plant has tuberous roots, which are highly resistant to drought and arid environments (Gupta *et al*., 2018). Various parts of the plant, including leaves, roots, seeds, and green pods, are valuable in the production of medicinal preparations, nutraceuticals, water purification, and biodiesel (Ruiz *et al*., 2019). Moringa is packed with essential phytochemicals like tannins, alkaloids, steroids, and reducing sugars, and is a rich source of bioactive compounds such as phenols, glucosinolates, tocopherols, carotenoids, and ascorbic acid. The plant is an extraordinary plant, celebrated for its exceptional nutritional and medicinal benefits, as well as its various industrial uses. Its cultivation is widespread, and its versatility allows it to play a crucial role in improving global health, enhancing agricultural practices, and supporting sustainable development (Atreya *et al*., 2023).

These bioactive compounds make Moringa a powerful medicinal plant, known for its ability to reduce inflammation, support immune health, and even offer potential in cancer prevention (Sharma *et al*., 2020). It is one of the astonishing plants that have been noted for its abundances in nutritional and medicinal values, in addition to a wealth of other industrial uses. Therefore, with respect to its broad extent of cultivation and utilization, the plant stands out amongst the many in the roles that it plays in enhancing the health of populations globally, furtherance of agriculture, and, by extension, sustainable development (Atreya *et al.*, 2023). A comparative analysis was carried out on the different bioactive components found in the leaves, seeds, and roots of the Moringa plant. From this information, the nutritional values of these parts of the plan twere outlined. Resultantly, properties related to each part of the Moringa plant were it identify, so that it could play its full potential role in the fields of Neutriciticals, Nutraceuticals, Agriculture and Pharmaceuticals.

Understanding the phytochemical profiles of various Moringa parts is essential for developing targeted treatments and optimizing its use across medicinal, nutritional, and cosmetic fields. Comparative studies enhance our knowledge of which parts of the plant are most beneficial for specific health applications, paving the way for functional foods and pharmaceutical products (Moyo *et al*., 2015; Siddhuraju *et al*., 2002). A detailed comparative analysis of leaves, seeds, and roots of *Moringa oleifera* is important for identifying their unique bioactive compounds and therapeutic potential. This foundational research is vital for advancing traditional medicine, nutraceuticals, and modern health practices, setting the stage for more in-depth studies and practical applications

Materials and Methods

2.1.1. Sample Collection, Treatment/ Preparation and Extraction.

Fresh leaves, mature seeds, and roots from healthy Moringa plant were meticulously collected from the Agricultural farm of Kwara State University, Malete, Kwara State, Nigeria in well labelled sterile zip lock bags, and were identified by Mr B.O Ajayi, with voucher number ‘’KSU-MOR-06-16-2024) in the Department of Plant Biology, University of Ilorin, Ilorin, Kwara State, Nigeria, Nigeria.

2.1.2. The leaves were destalked washed and shade dried at ambient temperature (25°C to 32°C) with constant turning averts fungal growth, the seeds were deshelled, air dried for two weeks and pulverized using an electric grinder while the roots were cut into small piece, washed and dried. Each dried part was milled into powdery form using an electric blender (Sreelatha and Jeyaram, 2009). Each milled part was stored in well labeled airtight containers and kept in the refrigerator at 40 º C for phytochemical screening.

40.0 gm of dried milled leaves, seeds and roots of *Moringa oleifera* were extracted successively with 300 ml of methanol in an orbital shaker for 24 hrs. at room temperature. The extracts were filtered using Whatman No.1 filter paper to remove extractable substances, at every 3 hrs interval. Each extract was then evaporated with rotary evaporator and the dried extracts were stored at 4°C in well labeled different sterile containers.

Gas Chromatography-Mass Spectroscopy (GC-MS) Extraction of Moringa (Leaves, root and Seed)

The bioactive compounds of Moringa leaves, root and seed (methanol extract) were extracted by GC-MS analysis using an Agilent Technologies 7890A capillary gas chromatograph, along with a mass spectrometer system. GC was equipped with a 30 m × 0.25 mm × 0.25 μm DB-5 capillary column. Initially, the instrument was maintained at a temperature of 100 °C for 2 min and 6 s. The temperature was risen to 300 °C at the rate of 25 °C/min and maintained for 20 min at the end of this period. The injection port temperature and the helium flow rate were ensured to be 250 °C and 1.5 mL/min, respectively. The ionization voltage was 70 eV. The sample was injected in split mode at 5:1. The MS scan range was set at 35–550 (*m*/*z*). The fragmentation patterns of mass spectra were compared with those stored in the using W8N05ST Library MS database. The percentage of each compound was calculated from the relative peak area of each compound in the chromatogram. The concept of integration used the Chem Station integrated algorithms. Qualitative test were then carried out on the cool solution. Major phytoconstitutents in the test plant extracts such as alkaloids, saponins, tannin, flavonoids, glycosides, terpenoids and, phenol, were tested according to standard methods (Onwukeame *et al*., 2007).

Qualitative Analysis of Phytochemical Compounds in *Moringa oleifera* Parts

Test for Alkaloids**:** About 1.0 ml of 1% HCL was added to 3ml of each of the extracts in a test tube. The mixture was heated for 20mins with continuous shaking in a water bath cooled and filtered and the process repeated for other extract samples. 1ml of each filtrate was added to 0.5ml of Mayer's reagent. 1.0 ml of each filtrate was added to 0.5 ml of Wagner's reagent. The formation of cream (with Mayer's reagent) or presence of turbidity was regarded as the presence of alkaloids in any of the sample part.

Test for Saponins: The Frothing test was conducted according to Iwu, *et al*. (2018). 3.0 ml of each extract and dilute with 2ml of distilled water was added in a test tube. The mixture was shaken vigorously. The Emulsion Test was also according to Iwu, *et al*., (2018). 3.0 ml of each extract was added to 5 drop of Olive oil in a test tube and the content was vigorously shaken. The appearance of formation of soluble emulsion in the extracts was indicative the presence of saponins

Test for Flavonoids: Three methods were used to determine the presence of flavonoids in the plant part sample. A total of 5 ml of 10% ammonia solution was added to a portion of the aqueous filtrate from the plant extract. This was followed by addition of concentrated H_2S0_4. A yellow coloration observed in each extract was used to validate the presence of flavonoids. A few drops of 1% aluminium solution were added in two ml of each filtrate. A yellow coloration was investigated for the presence of flavonoids. Five milliliters of 20% NaOH was added to an equal volume of the water extract. Yellow solution was obtained, which indicated the presence of flavonoids.

Test for Steroids: 5.0 drops of concentrated H_2SO_4 were added to 1ml of each extract in a separate test tube.

Test for Tannins: About 2.0 ml of each extract in a separate test tube were boiled gently for 2min and allowed to cool. 3 drop of 15% ferric chloride test solution was added to each extract. A blue color in the mixtures signified the presence of hydrolyzable tannin. For confirmation, 0.5 g of the extracts were added to 10 mL of freshly prepared potassium hydroxide (KOH) in a beaker, and shaken to dissolve. A dirty precipitate was indicative the presence of tannin

Test for Glycosides**:** About 1.0 ml of aqueous extract was mixed with 1ml of 20% solution of 3,5dinitrosalic acid in methanol and 1ml of a 5% aqueous NaOH was added. The formation of a brown ring of the interface was indicative of the presence of a deoxysugar of cardenolides

Test for Terpenoids: (Salkowski test): A total of 5 ml of each of methanolic plant part extract was mixed in 2 ml of chloroform, and concentrated H_2S0_4 (3 ml) was carefully added to separate the 2 layers distinctly. A reddish brown coloration of the interface was formed to confirm the presence of terpenoids**.**

Test for Phenols**:** A total of 0.5 g of each powdered plant samples was mixed with methanol containing 1% 1 ml of 1% $FeCl_3$ added to it. Brown haziness indicated the presence of phenols.

Quantitative Estimation of Phytochemicals Compounds in *Moringa oleifera* Parts

The quantitative analysis of each of the phytochemical present in the leaves, roots and stem of the test plants were determined by adopting standard protocols as follows:

Total Phenolic Content (TPC)

The total content of phenol in Moringa leaves, root and seed extracts was assessed following the method of Folin-Ciocalteau The Folin-Ciocalteau reagent (200 µL, 1 N) was added in the test tube containing 1 mL of the sample (10 mg/mL) extract. 1.8 mL deionized water was added and this was kept for 3 min at room temperature. This was followed by the addition of 400 µL of sodium carbonate (10% *v*/*v*) was added to the reaction mixture. Finally, the volume was made up to 4 mL by adding deionized water (600 µL). The mixture was placed in dark ambience for incubation for 1 h at room temperature. This was done in triplicates. The absorbance was measured against the blank (water) at 725 nm by the use of spectrophotometer. The Total Phenolic Content (TPC) was calculated from the calibration curve by plotting the value of absorbance against the concentration.

Total Flavonoid Content

Each plant extract in methanol was mixed with 0.1 mL of 10% aluminium chloride hexahydrate, 0.1 mL of 1 M potassium acetate and 2.8 mL of deionized water. After 40 minutes, it was incubated at the room

temperature. The flavonoids content was determined by the absorbance of the reaction mixture spectrophotometrically at 415 nm (Lin and Tang, 2007).

Total Alkaloids Content.

5 g of each sample was weighed into a 250 ml beaker and 200 ml of 10% acetic acid in ethanol was added, this was covered and allowed to stand for 4 hours. This was filtered and the extract was concentrated on a water bath to one-quarter of the original volume. Concentrated ammonium hydroxide was added drop wise to the extract until the precipitation was complete. The whole solution was allowed to settle and the precipitated was collected and washed with dilute ammonium hydroxide and then filtered. The residue is the alkaloid, which was dried and weighed to determine the total alkaloids content (Harbone, 1998).

Total Saponin Content.

20 g of each ground sample was put into a conical flask and 100 cm^3 of 20% aqueous ethanol was added. The samples were heated over a hot water bath for 4 hours with continuous stirring at about 55°C. The mixture was filtered and the residue re-extracted with another 200 ml 20% ethanol. The combined extracts were reduced to 40 ml over water bath at about 90°C. The concentrate was transferred into a 250 ml separating funnel and 20 ml of diethyl ether was added and shaken vigorously. The aqueous layer was recovered while the ether layer was discarded. The purification process was repeated. 60 ml of n-butanol was added. The combined n-butanol extracts were washed twice with 10 ml of 5% aqueous sodium chloride. The remaining solution was heated in a water bath. After evaporation the samples were dried in the oven to a constant weight and the saponin content was calculated as percentage (Obadoni and Ochuko, 2001).

Total Tannin Content (TTC)

Folin - Ciocalteu method (Harborne *et al.*, 1998) was used for determination of total tannin content in the moringa plant extract. About 0.1 ml of the plant extract was dispensed in 7.5 ml distilled water then 0.5 ml Folin reagent was added in the mixture. 1 ml of 35% Na_2CO_3 was added and was diluted to 10 ml with distilled water. The mixture was shaken well and kept at room temperature for 30 min. A set of reference standard solutions of gallic acid was prepared with a concentration of (20, 40, 60, 80 and 100 μg/ml). Absorbance for test and standard solutions were measured against the blank at 725 nm with an UV/Visible spectrophotometer.

Total Cardiac Glycosides

Cardiac glycoside content was assessed by the method of Pradhan *et al*. (2013).1 g of plant powdered sample was suspended in 25 ml of distilled H_2O. To this solution, 2 ml of concentrated H_2SO_4 was added. It was then refluxed for 6–8 h, cooled and extracted with chloroform (2 × 25 ml). The chloroform layer was then washed with distilled H_2O until it is acid-free. The chloroform extract was transferred to a pre-weighed beaker and dried on a water bath and then in an oven to a constant weight. The amount of dried extract represented the amount of cardiac glycosides in the plant sample.

Statistical Analysis

All experiments were carried out in triplicate. Data were expressed as mean ± standard deviation (STD) and Duncan Multiple Range Test analyzed the significant different amongst the bioactive compounds. Statistical Package of Social Sciences (SPSS) version 22 was used for the data

analysis. The obtained results (Total phenol, flavonoid, tannin, saponin, glycosides, alkaloids and terpenoids) in the plant parts was compared among the composition using a bar chart in order to observe the significant differences at the level of 5%.

Results

Qualitative Phytochemical Composition of the *Moringa oleifera* Plant Parts

Table 1 below shows the qualitative phytochemical analysis of various parts of the Moringa plant, that is, the leaves, seed and the root. There is variation in bioactive compound concentration between the leaves, seeds, and roots. The result showed that leaf of Moringa in this study contained all the bioactive compound in trace amount (+) except for tannin that recorded moderate amount(++) as shown in Table i below. The seeds on the other hand shows very higher amount of flavoniods, alkaloids, tannin and saponin (+++). However, the root indicated trace amount of all the phytochemicals except for tannins that reported highly presence in the extract. Steroids, cardiac glycosides, terpenoids, phenolic acids, and oxalates were present uniformly in trace amounts throughout the plant parts in this study as shown in Table 1 below.

Table 1: Qualitative Phytochemical Analysis of *Moringa oleifera* parts

TEST	Leave	Seed	Root
Flavonoids	+	+++	+
Alkaloids	+	+++	+
Tannins	++	+++	+++
Saponins	+	+++	+
Steroids	+	+	+
Cardiac Glycoside	+	+	+
Terpenoids	+	+	+
Phenolic Acid	+	+	+
Oxalate	+	+	+

KEY + = Present in trace form; ++ = Moderately present; +++ = Highly present

Quantitative Phytochemical Analysis of the Moringa Plant Parts

The quantitative determination of phytochemical components or bioactive compounds present in *Moringa oleifera* parts are presented in Table 2 below. The Table 2 reveals the distinct distribution patterns of bioactive compounds across leaves, seeds, and roots of moringa plant. The range of phytochemical or bioactive compounds in the leaves of the moringa samples was between 0.16 ± 0.05^{i} $mg^{-}100g$ and 9.27 ± 0.18^{a} $mg^{-}100g$, with cardiac glycosides recording the lowest concentration and tannins the highest concentration. Significant difference was recorded in the bioactive compounds concentration in the leaves. The concentration of the phytochemical compounds in the seeds ranged from 0.05 ± 0.00^{h} $mg^{-}100g$ to 91.66 ± 2.08^{a} $mg^{-}100g$ with lowest concentration recorded in phenolic acids and the highest in alkanoids as shown in Table 2 below.

The concentration of tannin and saponin in the seeds of the Moringa in this study are statistically the same as reported by Duncan Multiple Range Test as indicated in Table ii

below. Significant difference in the concentrations of phytochemicals was obtained in the seeds of the Monringa in this study. The root recorded the range of phytochemical concentration as 0.29 ± 0.01^{f} mg^{-}100g to 38.15 ± 0.25^{a} mg^{-}100g with oxalate being the least phytochemical in the root of the experimental sample parts and flavonoids were the most abundant (Table 2). The result in Table 2 shows significant difference in the amount of phytochemical compounds amongst the different parts of the moringa plant. It is also indicated that the leaves are abundant in flavonoid, the seeds in alkaloids and the roots in tannins. This shows significant difference in the amount of different bioactives in the parts of the part

The seeds emerge as a potent source of flavonoids (74.23 ± 0.22^{b} mg^{-}100g), alkaloids (91.66 ± 2.08^{a} mg^{-}100g), and saponins (32.28 ± 0.10^{c} mg^{-}100g) which suggest the potential value of the seeds in pharmacological applications. The roots of Moringa contain the maximum amount of tannins at 32.91 ± 004^{c} mg^{-}100g and phenolic acid at 4.01 ± 0.15^{b} mg^{-}100g, proving a possible role related to plant defense mechanisms and antioxidant properties. Leaves contain the most steroids at 3.18 ± 0.23^{d} mg^{-}100g and terpenoids at 4.33 ± 0.29^{c} mg^{-}100g, which contribute to the structural integrity of the plant and its aromatic qualities. Cardiac glycosides are pretty low in all parts of this plant, although it must be noted that the seeds contain the highest concentration at 0.40 mg^{-}100g. Oxalates, otherwise regarded as antinutrients, have their highest concentrations in the seeds at 1.76 ± 0.01^{e} mg^{-}100g (Table 2)

Table 2: Quantitative Phytochemical Analysis of the *Moringa oleifera* Plant Parts **(**mg^{-}100g**)**

S/N	Type of phytochemicals	Leaves	Seed	Root
1.	Flavonoids	4.98 ± 0.11^{b}	74.23 ± 0.22^{b}	3.75 ± 0.15^{bc}
2.	Alkaloids	2.26 ± 0.04^{e}	91.66 ± 1.08^{a}	1.93 ± 0.02^{de}
3.	Tannins	9.27 ± 0.18^{a}	32.28 ± 0.10^{c}	38.15 ± 0.25^{a}
4.	Saponins	1.76 ± 0.14^{g}	32.91 ± 004^{c}	2.49 ± 0.11^{d}
5.	Steroids	3.18 ± 0.23^{d}	0.77 ± 0.16^{f}	0.59 ± 0.04^{e}
6.	Cardiac Glycoside	0.16 ± 0.05^{i}	0.40 ± 0.02^{g}	0.29 ± 0.01^{f}
7.	Terpenoid	4.33 ± 0.29^{c}	2.48 ± 0.04^{d}	1.79 ± 0.21^{e}
8.	Phenolic Acid	2.10 ± 0.05^{f}	0.05 ± 0.00^{h}	4.01 ± 0.15^{b}
9.	Oxalate	1.38 ± 0.22^{h}	1.76 ± 0.01^{e}	0.52 ± 0.04^{e}

Values with the same superscript along the same column are statistically the same at $p \leq 0.05$. Values represent Mean ±STD

The bar chart compares the concentration of the various phytochemicals (in mg^{-}100g) across three plant parts: roots, seeds, and leaves. It was observed that seeds generally have the highest concentration of most phytochemicals, particularly alkaloids, saponins, flavonoids, and tannins. Leaves have moderate levels of several phytochemicals such as phenolic acid, terpenoid, steroids, and flavonoids. Roots have higher tannins but lower concentrations

of most other phytochemicals compared to seeds

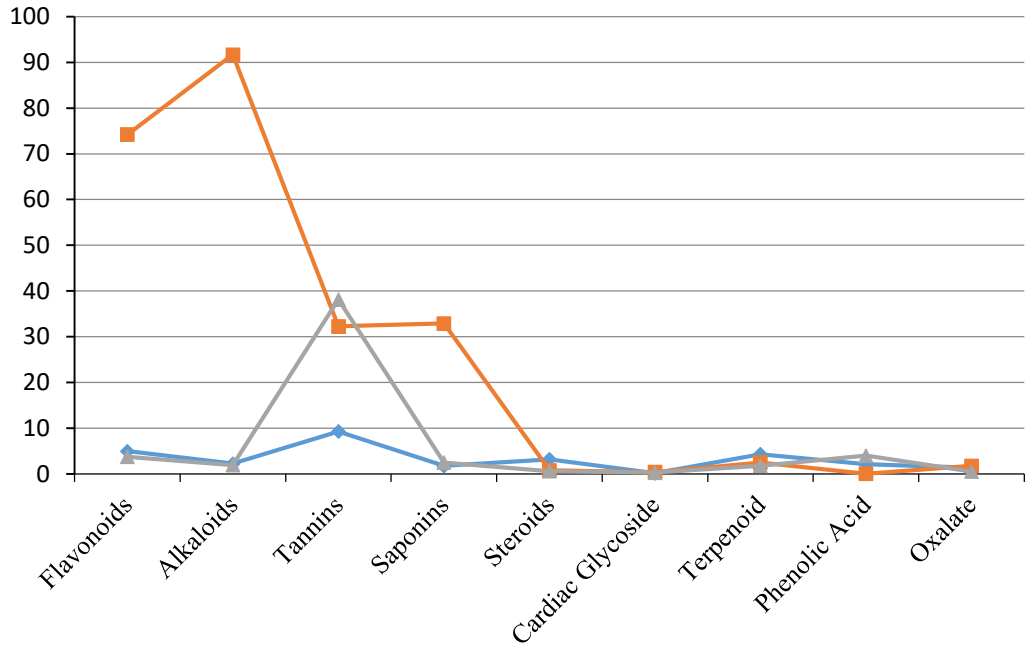

Figure 2: Comparison of the phytochemicals in Moringa Plant Parts *Parts*

Discussion

This research reveals significant distinctions in the concentration of bioactive compounds across the plant's components, showcasing the wide-ranging potential of the plant as both a nutritional supplement and a medicinal resource. The results of the qualitative and quantitative phytochemical analysis of this study agree with recent studies regarding the rich profile of bioactive compounds conveyed by Moringa plant extract. Recent work by Zaffer *et al.* (2023) reported a high flavonoid, alkaloid, and saponin concentration in Moringa seeds, pointing out their significant pharmacological potential with strong anti-oxidant and anti-inflammatory effect. According to the study of Zaffer *et al.* (2023), flavonoids, alkaloids, and saponins from moringa seeds were quantified at 72.50 mg^{-}100g, 90.20 mg^{-}100g, and 33.10 mg^{-}100g, respectively, values very close to those reported in this analysis. Results in the current study on the levels of tannins and phenolic acids of Moringa roots were high, and agreed with findings by Nguyen *et al.* (2022). This strong agreement of the studies underlines a reliability associated with such phytochemical measurements, reflecting a potential medicinal use for Moringa in various ways. On the other hand, reported tannin concentrations at 37.80 mg^{-}100g and phenolic acids at 4.05 mg^{-}100g in the root which significantly tallied with the values obtained in this study.

In the contrary, some of the recent studies by Zaffer *et al.* (2023) and Owusu *et al.* (2022) recorded values slightly different from the results obtained in this study. Another study by Patel *et al.* (2023)

recorded values of 4.10 mg^{-}100g for steroids and 5.20 mg/100g for terpenoids in leaves, in comparison with 3.18 mg^{-}100g for steroids and 4.33 mg^{-}100g obtained in this present study for terpenoids. According to Owusu *et al*. (2022) the Moringa seeds have a cardiac glycoside content of about 0.50 mg^{-}100g, this value is slightly higher than the concentration in this study (0.40 mg^{-} 100g). The values obtained in this study agreed with those obtained by some other researchers, while there were some significant differences in the quantity or values obtained in some of the phytochemical compounds in this study. These differences could have been due to the geographical locations. The region where Moringa is cultivated plays a very important role in determining its phytochemical content. Factors such as soil type, altitude, climate, and environmental conditions affect the metabolic activity of the plant, that is, the ability plant to synthesize specific bioactive compounds; Soil quality and nutrients, that is, the status, nutrient composition, pH, and mineral content of the soil have direct influence on the absorption capacity and rate at which plant to essential nutrients, this hence, affecting the concentration of phytochemicals in the different parts of the plant;

Growth stage and maturity is another factor of variance in results. The phytochemical composition of Moringa varies with its age and growth stage, whether as a seedling, mature tree, or post-harvest. Younger plants have been reported to possess higher levels of certain bioactive compounds than mature or older plants. Plant part analyzed, that is, different parts of the Moringa plant—leaves, seeds, roots, or pods have been reported to contain varying amounts of phytochemicals. Studies that focus on specific plant parts may report differing phytochemical profiles as reported in this study and some other researchers. Another factor of variance in result is the harvesting time and season. The time of year or day when Moringa is harvested can influence the concentration of its phytochemicals. Seasonal variations in factors such as temperature, light, and water availability affect the production of bioactive compounds. Processing and extraction methods Differences in extraction or processing techniques, such as the type of solvent, temperature, or extraction duration, can lead to variations in the types and amounts of phytochemicals detected. Genetic Variability: Genetic differences between Moringa cultivars or strains can result in variations in phytochemical composition. Storage and Handling: Post-harvest storage conditions, including temperature, light exposure, and storage duration, can cause genetic mutation, changes or degradation in the phytochemical composition of the plant over time.

The study demonstrates that the leaves of Moringa oleifera have the highest concentrations of tannins, flavonoids, terpenoids, and steroids, all of which are bioactive compounds known for their antioxidant, anti-inflammatory, and antimicrobial properties. These compounds suggest that Moringa leaves could be a valuable addition to diets as a nutritional supplement, providing essential antioxidants that may help in fighting oxidative stress, which is a contributor to several chronic diseases. The leaves' significant levels of flavonoids further highlight their potential in improving immune function and offering cardiovascular benefits.

Seeds of *Moringa oleifera* on the other hand, exhibited a particularly high concentration of alkaloids, known for their medicinal

properties such as anti-cancer and anti-microbial effects. Additionally, the presence of flavonoids, tannins, and saponins positions Moringa seeds as a multi-functional food with a broad range of potential health benefits. The seeds could play an important role in both modern pharmacology and traditional medicine, especially in formulations aimed at boosting immunity, managing blood sugar levels, or offering cardiovascular protection. The high alkaloid concentration in particular suggests the seeds may be useful in treating ailments traditionally managed with alkaloid-rich plants.

The roots of Moringa likewise, contain high levels of tannins and phenolic acids, compounds known for their astringent and antioxidant properties. Tannins have long been used in traditional medicine for their ability to treat wounds, reduce inflammation, and manage diarrhea. This high concentration suggests that the roots of Moringa could have applications in herbal medicine, particularly in the treatment of gastrointestinal disorders, inflammation, and infections. The presence of phenolic acids may further enhance the roots' potential as a source of antioxidants, contributing to the reduction of oxidative damage in the body.

On the final note, a key finding in this research is the promotion of sustainable harvesting and the utilization of all parts of the Moringa plant. By encouraging the use of leaves, seeds, and roots, the study advocates for a holistic approach to Moringa, emphasizing its role as a functional food and herbal remedy. This approach not only maximizes the nutritional and medicinal value of the plant, but also promotes its sustainable cultivation and use. Furthermore, the ability of Moringa to grow in diverse environments and its low environmental impact make it a particularly attractive candidate for sustainable farming and food security in areas facing nutritional and medicinal resource challenges.

This comparative study provides a foundation for further research into the individual compounds found in Moringa, exploring their mechanisms of action and confirming their bioavailability and therapeutic potential. The findings also have implications for the development of Moringa-based supplements, pharmaceuticals, and functional foods. Future studies should focus on clinical trials to substantiate the health claims associated with Moringa and ensure its safety and efficacy for human consumption and medical use

Conclusion

The results of the phytochemical composition of the leaves, seeds, and roots of the Moringa plant (*Moringa oleifera*) in this study showed significant differences in their bioactive components profiles and potential health benefits. The result indicated that the leaves are highly rich in tannins, flavonoids, terpenoids and steroids making them potent sources of neuroprotective agent, anti-cancer anti-inflammatory, anti-microbial, anti-oxidants, cardiac protector and good dietary supplementation for nutritional enhancement. The seeds indicated high content of flavonoids, alkaloids, tannins and saponins which are vital compounds with wide range of health benefits, making them important in both traditional medicine and modern pharmacology while the roots are reportedly very rich in tannins, which confers them valuable in traditional medicine, food processing, and the pharmaceutical industry. Generally

speaking, each part of the Moringa plant is peculiar in its bioactive compounds bearing distinct health and nutritional benefits. However, this study showed that the seeds are outstanding in their therapeutic and nutritional values, and are safe for regular consumption. This project has been able to showcase the utilizing importance of the different parts of this valuable plant, based on their specific bioactive properties. Additionally, the high levels of flavonoids, alkaloids, and saponins in seeds, and significant amounts of tannins and phenolic acids in roots, underline the pharmacological potential of this plant. Steroids, however, differed in distribution, and oxalate content varied; therefore, further study is necessary.

Conflict of Interest

Competing Interests Statement**:** The authors confirmed that the authors did not receive support from any organization for the submitted work.

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