

BIOTECHNOLOGICAL EVALUATION OF PHYTOCHEMICAL AND ANTIMICROBIAL PROPERTIES OF AVOCADO (*Persea americana*) SEED AND LEAF EXTRACTS

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ABSTRACT

This study evaluated the phytochemical and antimicrobial properties of seed and leaf extracts of Avocado with a view to determining their biotechnological and pharmaceutical potentials. Fresh avocado leaves and seeds were collected from within and around the study area, identified, processed, and extracted using ethanol and aqueous solvents. Standard phytochemical screening methods were employed to detect the presence of bioactive compounds, while antimicrobial activities of the extracts were determined using the agar well diffusion method against selected bacterial and fungal isolates including *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Candida albicans*. The phytochemical analysis revealed the presence of alkaloids, flavonoids, tannins, phenols, glycosides, saponins, terpenoids, and steroids in both seed and leaf extracts. Flavonoids, alkaloids, tannins, and phenols were found to occur in relatively higher concentrations. The antimicrobial evaluation showed that both extracts exhibited inhibitory effects against the tested microorganisms, with increased activity observed at higher extract concentrations. Avocado leaf extracts demonstrated greater antimicrobial activity than seed extracts, particularly against *Candida albicans* and *Staphylococcus aureus*. Statistical analysis showed significant differences ($P < 0.05$) among the antimicrobial activities of the extracts. The findings of the study established that avocado seeds and leaves possess important phytochemical constituents responsible for their antimicrobial properties. The study therefore contributed to knowledge by providing scientific evidence supporting the medicinal importance of avocado plant parts and their possible application in biotechnology, pharmaceutical production, herbal medicine formulation, and natural antimicrobial development.

Key words: Antimicrobial Activity, Avocado, Biotechnology, Phytochemicals, *Persea americana*

1.0 INTRODUCTION

Medicinal plants have continued to play significant roles in human healthcare systems across the world, especially in developing countries where access to orthodox medicine may be limited or expensive. The World Health Organization estimated that a large proportion of the global population depends directly on medicinal plants and plant-derived products for primary healthcare needs. These plants contain numerous bioactive compounds such as alkaloids, flavonoids, tannins, saponins, terpenoids, glycosides, and phenolic compounds that possess therapeutic potentials against various human pathogens (WHO, 2021). The increasing emergence of antimicrobial resistance among pathogenic microorganisms has intensified the global search for alternative antimicrobial agents from natural plant sources. One plant that has attracted considerable scientific and medicinal attention is avocado pear, scientifically known as Avocado. Avocado belongs to the family Lauraceae and is widely cultivated in tropical and subtropical regions of the world, including Nigeria. The plant is valued not only for its nutritional importance but also for its

medicinal and industrial applications. Different parts of the avocado plant, including the fruits, seeds, leaves, bark, and peels, have been utilized traditionally for the treatment of several ailments such as diarrhea, hypertension, inflammation, skin infections, diabetes, and microbial diseases (Dreher and Davenport, 2013).

The avocado fruit is highly nutritious and rich in vitamins, minerals, dietary fiber, monounsaturated fatty acids, and antioxidants. However, while the pulp is widely consumed, the seeds and leaves are often discarded as agricultural waste despite their rich phytochemical constituents. Recent scientific investigations have revealed that avocado seeds and leaves contain significant quantities of phenolic compounds, flavonoids, saponins, tannins, steroids, and alkaloids that possess strong antimicrobial, antioxidant, anti-inflammatory, and anticancer properties (Araújo *et al.*, 2018). This discovery has stimulated interest in the biotechnological exploitation of avocado plant parts for pharmaceutical and medicinal applications.

Biotechnology involves the application of biological systems, organisms, or biological processes in the development of useful products and technologies for human welfare. In plant biotechnology, medicinal plants are increasingly evaluated for their bioactive compounds, genetic properties, antimicrobial activities, and pharmaceutical potentials. Biotechnological approaches such as phytochemical screening, antimicrobial susceptibility testing, extraction technologies, fermentation, molecular characterization, and bioassays have become important tools in evaluating medicinal plants for therapeutic purposes. Phytochemicals are naturally occurring secondary metabolites found in plants which serve protective functions against pathogens, pests, and environmental stress. These compounds are responsible for many pharmacological activities observed in medicinal plants. Phenolic compounds and flavonoids, for instance, exhibit strong antioxidant and antimicrobial effects by interfering with microbial cell walls, proteins, and nucleic acids (Okwu and Okwu, 2004). The presence of these compounds in avocado seeds and leaves suggests their potential usefulness in combating infectious diseases caused by pathogenic bacteria and fungi. Microbial infections remain a major public health concern worldwide. The rapid increase in antibiotic-resistant microorganisms has reduced the effectiveness of many synthetic antimicrobial drugs. Pathogens such as *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Candida albicans* have developed resistance to several conventional antibiotics, thereby creating a serious challenge in disease management (Ventola, 2015). Consequently, researchers are exploring plant-based antimicrobial agents as safer, cheaper, and environmentally friendly alternatives.

Avocado seed and leaf extracts have demonstrated inhibitory effects against several pathogenic microorganisms. Studies have shown that ethanol, methanol, aqueous, and acetone extracts of avocado plant parts possess varying degrees of antimicrobial activities against both Gram-positive and Gram-negative bacteria. These antimicrobial properties are attributed mainly to the synergistic effects of phytochemical constituents present in the extracts (Rodríguez-Carpena *et al.*, 2011). Furthermore, advances in biotechnology have enhanced the extraction, purification, and characterization of these bioactive compounds for medicinal and industrial applications. In Nigeria, avocado cultivation is common in many southern states, where the plant grows favorably under tropical climatic conditions.

Despite the abundance of avocado plants, limited scientific attention has been directed toward the comprehensive biotechnological evaluation of the phytochemical and antimicrobial properties of its seeds and leaves. Most local uses of the plant remain largely based on traditional knowledge without adequate scientific validation. Therefore, there is a need for detailed research to investigate the phytochemical composition and antimicrobial efficacy of avocado seed and leaf extracts using biotechnological techniques. This study was therefore designed to evaluate the

phytochemical constituents and antimicrobial properties of avocado (*Persea americana*) seed and leaf extracts. The findings from this study may contribute to the development of natural antimicrobial agents, pharmaceutical products, and industrial raw materials from avocado plant wastes.

2.0 MATERIALS AND METHODS

2.1 Study Area

This study was carried out in the Biotechnology and Microbiology Laboratories of the Department of Plant Science and Biotechnology. The avocado samples used for the research were collected from mature avocado trees growing within and around Federal College of Land Resources Technology in Owerri, Imo State, Nigeria. Owerri is located within the humid tropical rainforest zone of southeastern Nigeria and is characterized by high rainfall, moderate temperature, and fertile loamy soils suitable for the growth of avocado plants. The area experiences an average annual rainfall ranging from 2000 mm to 2500 mm and a temperature range of about 25°C to 30°C. The climatic conditions of the area support the cultivation and growth of various economic and medicinal plants including avocado (*Persea americana*). Laboratory analyses including phytochemical screening and antimicrobial susceptibility tests were conducted under controlled laboratory conditions.

2.2 Sample Collection

Fresh mature leaves and seeds of Avocado were collected from healthy avocado trees located within and around the study area. Mature fruits were harvested manually from the trees, after which the seeds were removed from the fruits. Fresh leaves free from disease symptoms, insect infestation, and physical damage were also collected directly from the trees. The collected samples were placed separately in clean sterile polythene bags and properly labeled according to the plant part collected. The samples were then transported immediately to the laboratory for further processing and analysis. Selected bacterial and fungal isolates used for the antimicrobial studies were obtained from the Microbiology Laboratory culture collection unit. The microorganisms used in the study included both Gram-positive and Gram-negative bacteria as well as fungal isolates of medical importance.

2.3 Sample Identification

The collected plant samples were identified and authenticated by a plant taxonomist in the Department of Plant Science and Biotechnology. The plant was confirmed to be *Persea americana* Mill., belonging to the family Lauraceae. The identification process was carried out using standard taxonomic keys, floristic manuals, and morphological characteristics such as leaf arrangement, fruit shape, seed morphology, and plant habit. Voucher specimens of the plant samples were prepared and deposited in the departmental herbarium for future reference and documentation. The microbial isolates used for the antimicrobial tests were

identified using standard microbiological methods including colony morphology, Gram staining reactions, biochemical tests, and microscopic examination.

2.4 Sample Preparation

The collected avocado leaves were washed thoroughly with distilled water to remove dirt and contaminants. The leaves were air-dried at room temperature for approximately two weeks until constant dry weight was obtained. The avocado seeds were removed from the fruits, washed with clean water, sliced into smaller pieces, and similarly air-dried under laboratory conditions. The dried leaf and seed samples were separately ground into fine powder using a clean electric blender. The powdered samples were stored in sterile airtight containers pending extraction procedures. Extraction of the phytochemical constituents was carried out using ethanol and aqueous solvents. About 100 g of each powdered sample was weighed separately using an electronic weighing balance and soaked in 500 ml of ethanol in sterile conical flasks. The mixtures were covered tightly and allowed to stand for 72 hours with intermittent shaking to facilitate proper extraction of bioactive compounds. After extraction, the mixtures were filtered using Whatman No. 1 filter paper. The filtrates obtained were concentrated using a rotary evaporator and later dried in a water bath at low temperature to obtain crude extracts. The extracts were stored in sterile sample bottles and refrigerated until required for phytochemical and antimicrobial analyses.

Phytochemical screening of the extracts was carried out to test for the presence of alkaloids, flavonoids, tannins, saponins, phenols, glycosides, steroids, and terpenoids using standard laboratory procedures. Test for alkaloids was carried out by adding Wagner's reagent to portions of the extract, where the formation of reddish-brown precipitate indicated the presence of alkaloids. Flavonoids were tested using sodium hydroxide solution, while tannins were detected using ferric chloride solution. Frothing test was used for the detection of saponins, whereas phenols were identified using ferric chloride reagent. For antimicrobial analysis, nutrient agar and potato dextrose agar media were prepared according to manufacturer's instructions and sterilized using an autoclave at 121°C for 15 minutes. Pure cultures of the test microorganisms were sub-cultured and standardized before inoculation.

The antimicrobial activity of the extracts was evaluated using the agar well diffusion method. Sterile swab sticks were used to inoculate the microbial suspensions uniformly onto prepared agar plates. Wells were created in the agar plates using sterile cork borers, after which different concentrations of the avocado seed and leaf extracts were introduced into the wells. The inoculated plates were incubated at appropriate temperatures for 24–48 hours depending on the organism involved. Zones of inhibition around the wells were measured in millimeters using a transparent ruler to determine antimicrobial activity.

2.5 Experimental Design

The study was conducted using a Completely Randomized Design (CRD). The experiment involved two major treatment groups consisting of avocado seed extracts and avocado leaf extracts. Different concentrations of each extract were prepared and tested against selected bacterial and fungal isolates. Each treatment was replicated three times to ensure accuracy and reliability of the results obtained. Control experiments were also included in the study. Standard antibiotics were used as positive controls, while sterile distilled water and extraction solvents served as negative controls during antimicrobial testing. The phytochemical analyses and antimicrobial assays were carried out sequentially according to the specific objectives of the study.

2.6 Data Collection

Data collection involved recording observations obtained from both phytochemical screening and antimicrobial susceptibility tests. During phytochemical analysis, the presence or absence of phytochemical constituents such as alkaloids, tannins, flavonoids, saponins, glycosides, terpenoids, steroids, and phenols was recorded based on observable color changes, precipitate formation, or frothing reactions. In the antimicrobial studies, data were collected by measuring the diameters of inhibition zones produced by the extracts against the test microorganisms. Measurements were recorded in millimeters using a transparent ruler after incubation periods. The antimicrobial activities of the extracts were compared based on the size of inhibition zones produced at different extract concentrations. Observations from the control treatments were also recorded for comparison and validation purposes. Photographic documentation of experimental procedures, microbial growth patterns, and inhibition zones was also carried out during the study.

2.7 Data Analysis

The data obtained from the phytochemical and antimicrobial analyses were organized into tables and presented using descriptive statistics. Mean values and standard deviations of inhibition zone diameters were calculated from replicate observations. The antimicrobial activities of the avocado seed and leaf extracts were compared statistically. Analysis of Variance (ANOVA) was used to determine whether significant differences existed among the treatment means at 5% probability level. Where significant differences were observed, mean separation was carried out using Duncan's Multiple Range Test (DMRT). The results obtained from the study were interpreted in relation to the phytochemical constituents present in the extracts and their antimicrobial effectiveness against the selected microorganisms. Conclusions were drawn based on the observed laboratory findings and statistical analyses.

3.0 RESULTS

3.1 Phytochemical Constituents of Avocado Seed Extracts

The phytochemical screening of the seed extracts of Avocado revealed the presence of several important bioactive compounds. The analysis showed that alkaloids, flavonoids, tannins, saponins, phenols, glycosides, terpenoids, and steroids were present in the seed extracts. However, the intensity of occurrence varied among the phytochemical constituents identified. The results further showed that flavonoids, phenols, and tannins were strongly present in the avocado seed extracts, while glycosides and steroids were moderately present. Saponins and terpenoids were observed in smaller quantities. The detailed phytochemical constituents identified in the avocado seed extracts are presented in Table 1.

Table 1: Phytochemical Constituents of Avocado Seed Extracts

Phytochemical Constituent	Observation	Level of Presence
Alkaloids	Present	Moderate
Flavonoids	Present	High
Tannins	Present	High
Saponins	Present	Low
Phenols	Present	High
Glycosides	Present	Moderate
Terpenoids	Present	Low
Steroids	Present	Moderate

3.2 Phytochemical Constituents of Avocado Leaf Extracts

The phytochemical analysis of avocado leaf extracts also revealed the presence of important secondary metabolites. The study showed that the leaf extracts contained alkaloids, flavonoids, tannins, saponins, phenols, glycosides, terpenoids, and steroids. The findings indicated that flavonoids, phenols, and alkaloids were highly abundant in the leaf extracts. Tannins and glycosides were moderately present, whereas terpenoids and steroids occurred in lower concentrations. The phytochemical constituents identified in avocado leaf extracts are shown in Table 2.

Table 2: Phytochemical Constituents of Avocado Leaf Extracts

Phytochemical Constituent	Observation	Level of Presence
Alkaloids	Present	High
Flavonoids	Present	High
Tannins	Present	Moderate
Saponins	Present	Moderate
Phenols	Present	High
Glycosides	Present	Moderate
Terpenoids	Present	Low
Steroids	Present	Low

3.3 Antimicrobial Activities of Avocado Seed Extracts Against Selected Microorganisms

The antimicrobial evaluation of avocado seed extracts showed varying inhibitory effects against the selected pathogenic microorganisms. The extracts demonstrated noticeable antimicrobial activity against both bacterial and fungal isolates used in the study. The highest zones of inhibition were recorded against *Staphylococcus aureus* and *Candida albicans*, while lower inhibitory effects were observed against *Pseudomonas aeruginosa*. The antimicrobial activity increased with increasing extract concentration. The results of the antimicrobial activity of avocado seed extracts against selected microorganisms are presented in Table 3.

Table 3: Mean Zones of Inhibition (mm) Produced by Avocado Seed Extracts

Test Organism	25 mg/ml	50 mg/ml	75 mg/ml	100 mg/ml
<i>Staphylococcus aureus</i>	10.2 ± 0.4	14.5 ± 0.3	18.1 ± 0.5	22.4 ± 0.2
<i>Escherichia coli</i>	8.4 ± 0.2	11.7 ± 0.4	15.2 ± 0.3	19.0 ± 0.4
<i>Pseudomonas aeruginosa</i>	6.3 ± 0.3	9.5 ± 0.2	12.4 ± 0.4	15.8 ± 0.3
<i>Candida albicans</i>	11.1 ± 0.5	15.8 ± 0.4	19.4 ± 0.3	24.0 ± 0.5

3.4 Antimicrobial Activities of Avocado Leaf Extracts Against Selected Microorganisms

The results obtained from the antimicrobial analysis of avocado leaf extracts revealed that the extracts inhibited the growth of all the test microorganisms. The inhibitory effects varied depending on the concentration of the extracts and the susceptibility of the organisms. The highest antimicrobial activity was observed against *Candida albicans* and *Staphylococcus aureus*, while relatively lower inhibition was observed against *Pseudomonas aeruginosa*. Increased extract concentrations produced wider inhibition zones. The antimicrobial activities of avocado leaf extracts against the selected microorganisms are presented in Table 4.

Table 4: Mean Zones of Inhibition (mm) Produced by Avocado Leaf Extracts

Test Organism	25 mg/ml	50 mg/ml	75 mg/ml	100 mg/ml
<i>Staphylococcus aureus</i>	12.4 ± 0.3	16.2 ± 0.4	20.5 ± 0.2	25.1 ± 0.4
<i>Escherichia coli</i>	9.2 ± 0.4	13.6 ± 0.3	17.8 ± 0.4	21.7 ± 0.5
<i>Pseudomonas aeruginosa</i>	7.5 ± 0.2	10.8 ± 0.4	14.3 ± 0.3	17.2 ± 0.4
<i>Candida albicans</i>	13.0 ± 0.5	17.6 ± 0.2	22.1 ± 0.4	26.5 ± 0.3

3.5 Comparative Antimicrobial Activities of Seed and Leaf Extracts

The comparative analysis of the antimicrobial activities of avocado seed and leaf extracts showed that the leaf extracts generally produced higher zones of inhibition than the seed extracts against all the microorganisms tested. The results indicated that avocado leaf extracts exhibited stronger antimicrobial effects against *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Candida albicans* at all concentrations tested. The comparative antimicrobial activities of the seed and leaf extracts at 100 mg/ml concentration are presented in Table 5

Table 5: Comparative Antimicrobial Activities of Avocado Seed and Leaf Extracts at 100 mg/ml

Test Organism	Seed Extract (mm)	Leaf Extract (mm)
<i>Staphylococcus aureus</i>	22.4	25.1
<i>Escherichia coli</i>	19.0	21.7
<i>Pseudomonas aeruginosa</i>	15.8	17.2
<i>Candida albicans</i>	24.0	26.5

4.0 DISCUSSION

The findings of this study revealed that the seed extracts of Avocado contained important phytochemical constituents including alkaloids, flavonoids, tannins, saponins, phenols, glycosides, terpenoids, and steroids. The high occurrence of flavonoids, tannins, and phenols observed in the seed extracts suggested that avocado seeds possess considerable medicinal and antioxidant potentials. These phytochemicals are known to play important physiological and pharmacological roles in plants and humans. The presence of flavonoids in high concentration supported the findings of Rodríguez-Carpena *et al.* (2011), who reported that avocado seeds are rich in flavonoids and phenolic compounds capable of exerting antioxidant and antimicrobial activities. Flavonoids are known to inhibit microbial growth through disruption of microbial membranes and inhibition of nucleic acid synthesis. The high concentration of phenols observed in this study may therefore explain the antimicrobial effectiveness of the extracts against the tested microorganisms.

The detection of tannins in the seed extracts also agreed with the reports of Okwu and Okwu (2004), who stated that tannins possess antimicrobial properties due to their ability to precipitate proteins and interfere with microbial enzyme activities. The moderate presence of alkaloids and glycosides further suggested that avocado seeds may possess additional therapeutic potentials such as anti-inflammatory and antimicrobial activities. The low concentration of terpenoids and saponins observed in the present study may have resulted from environmental factors, extraction methods, solvent polarity, and plant maturity. According to Harborne (1998), phytochemical composition in plants may vary depending on climatic conditions, soil composition, and extraction techniques. The significant differences observed among the

phytochemical constituents indicated variability in the accumulation of secondary metabolites within avocado seeds. The findings of this study therefore confirmed that avocado seeds, often discarded as agricultural waste, contain valuable bioactive compounds that could be utilized in biotechnology, pharmaceutical production, and medicinal applications.

The phytochemical analysis of avocado leaf extracts revealed the presence of alkaloids, flavonoids, tannins, saponins, phenols, glycosides, terpenoids, and steroids. The high abundance of flavonoids, alkaloids, and phenols observed in the leaf extracts suggested that avocado leaves possess significant medicinal properties. The results obtained in this study were consistent with the findings of Adeyemi *et al.* (2018), who reported that avocado leaves contain high levels of flavonoids and phenolic compounds with antimicrobial and antioxidant properties. The abundance of these phytochemicals may have contributed significantly to the strong antimicrobial activities exhibited by the leaf extracts against the tested microorganisms. Alkaloids detected in the leaf extracts may have contributed to the inhibitory effects observed against bacterial and fungal isolates. Alkaloids are known to interfere with microbial DNA replication and protein synthesis, thereby reducing microbial growth and survival (Trease and Evans, 2002). The moderate occurrence of saponins and glycosides also supported the medicinal value of avocado leaves since these compounds have been associated with membrane permeability alteration and antimicrobial activities. The lower occurrence of terpenoids and steroids observed in the study may be associated with environmental conditions and genetic variations in avocado plants. According to Sofowora (2008), the biosynthesis and accumulation of phytochemicals in medicinal plants are influenced by ecological conditions, plant age, and harvesting periods. The significant differences observed in the phytochemical composition of avocado leaves further suggested selective accumulation of bioactive compounds in plant tissues. The results therefore indicated that avocado leaves could serve as important sources of medicinal phytochemicals for pharmaceutical and biotechnological applications.

The antimicrobial evaluation of avocado seed extracts showed inhibitory effects against all the test microorganisms, although the degree of inhibition varied among the organisms. The extracts demonstrated greater antimicrobial activity against *Staphylococcus aureus* and *Candida albicans*, while *Pseudomonas aeruginosa* showed the least susceptibility. The observed increase in antimicrobial activity with increasing extract concentration indicated a concentration-dependent response. This trend suggested that higher concentrations of phytochemical constituents exerted stronger inhibitory effects on microbial growth. Similar observations were reported by Doughari *et al.* (2007), who noted that increased concentrations of plant extracts generally produce wider inhibition zones due to higher availability of bioactive compounds.

The higher susceptibility of *Staphylococcus aureus* observed in this study may be attributed to the relatively simple cell wall structure of Gram-positive bacteria, which allows easier penetration of phytochemicals into microbial cells. In contrast, the lower susceptibility of *Pseudomonas aeruginosa* may be associated with the complex outer membrane structure of Gram-negative bacteria, which limits permeability to antimicrobial agents. This observation agreed with the reports of Ventola (2015), who stated that Gram-negative bacteria often exhibit higher resistance to antimicrobial substances due to their lipopolysaccharide-rich outer membranes. The antifungal activity demonstrated against *Candida albicans* further confirmed the broad-spectrum antimicrobial potential of avocado seed extracts. Phenolic compounds and tannins present in the extracts may have contributed significantly to the inhibition of fungal growth through disruption of fungal cell membranes and interference with metabolic processes. The significant differences observed among the inhibition zones indicated that the antimicrobial effectiveness of avocado seed extracts depended on microbial susceptibility and extract concentration. The results therefore suggested that avocado seeds possess promising antimicrobial potentials that may be explored for herbal medicine and pharmaceutical development.

The antimicrobial analysis of avocado leaf extracts revealed strong inhibitory activities against all the tested microorganisms. The leaf extracts produced wider zones of inhibition than the seed extracts, indicating greater antimicrobial effectiveness. The stronger antimicrobial activity observed in avocado leaf extracts may be attributed to the higher abundance of flavonoids, alkaloids, and phenols identified during phytochemical screening. According to Cowan (1999), phenolic compounds and flavonoids possess strong antimicrobial activities because they disrupt microbial cell membranes, inhibit enzyme activity, and interfere with microbial metabolism. The high susceptibility of *Candida albicans* and *Staphylococcus aureus* observed in this study agreed with the findings of Adeyemi *et al.* (2018), who reported that avocado leaf extracts exhibited significant antimicrobial activities against bacterial and fungal pathogens. The results further suggested that avocado leaves possess potent antifungal and antibacterial properties that may be useful in the treatment of infectious diseases. The lower susceptibility of *Pseudomonas aeruginosa* observed in the study may be due to its intrinsic resistance mechanisms including biofilm formation, efflux pumps, and impermeable cell membranes. These mechanisms reduce the penetration and effectiveness of antimicrobial compounds. The concentration-dependent increase in inhibition zones observed in this study suggested that the antimicrobial potency of avocado leaf extracts increased with increasing extract concentration. This trend further confirmed that the phytochemical constituents present in the extracts were responsible for the antimicrobial effects observed. The statistically significant differences observed among the treatments indicated that avocado leaf extracts possess

considerable antimicrobial potentials that could be harnessed for medicinal and pharmaceutical purposes.

The comparative analysis carried out in this study showed that avocado leaf extracts generally exhibited stronger antimicrobial activities than avocado seed extracts against all the tested microorganisms. This difference may be attributed to the higher concentration of flavonoids, alkaloids, and phenolic compounds detected in the leaf extracts.

The findings of this study agreed with the reports of Ibrahim *et al.* (2014), who observed that leaves of medicinal plants often contain higher concentrations of secondary metabolites than seeds due to their direct exposure to environmental stress and pathogen attack. Plants naturally synthesize more defensive phytochemicals in leaves as protective mechanisms against herbivores, microorganisms, and environmental stressors. The higher inhibition zones produced by leaf extracts suggested that avocado leaves may be more suitable for the development of antimicrobial formulations than avocado seeds. However, both plant parts demonstrated appreciable antimicrobial activities, indicating their pharmaceutical relevance. The significant differences observed between seed and leaf extracts further supported the hypothesis that phytochemical concentration influences antimicrobial effectiveness. The findings therefore highlighted the importance of phytochemical abundance in determining the therapeutic potential of medicinal plant extracts.

The results of this study revealed a positive relationship between phytochemical abundance and antimicrobial activity. Extracts containing higher levels of flavonoids, alkaloids, tannins, and phenols produced greater inhibition against the tested microorganisms. This finding supported the theory that phytochemicals act synergistically to inhibit microbial growth. According to Sofowora (2008), medicinal plants derive their antimicrobial properties from combinations of bioactive compounds rather than from single constituents alone. Flavonoids, tannins, alkaloids, and phenols may interact synergistically to disrupt microbial cell walls, inhibit enzymes, denature proteins, and interfere with nucleic acid synthesis. The significant correlation observed between phytochemical content and antimicrobial activity therefore provided scientific evidence supporting the medicinal importance of avocado seed and leaf extracts. The findings also validated the traditional use of avocado plant parts in the treatment of infections and related ailments. The stronger antimicrobial activity observed in leaf extracts further suggested that higher phytochemical abundance resulted in greater antimicrobial potency. This relationship highlighted the importance of phytochemical screening in identifying medicinal plants with therapeutic potential.

The findings of this study demonstrated that avocado seed and leaf extracts possess significant phytochemical and antimicrobial properties that could be exploited in biotechnology and pharmaceutical industries. The broad-spectrum antimicrobial activities observed against bacterial

and fungal isolates indicated that the extracts may serve as potential sources of natural antimicrobial agents. The presence of phenols, flavonoids, tannins, alkaloids, and glycosides suggested that the extracts could be useful in the formulation of herbal medicines, nutraceuticals, antioxidants, food preservatives, and cosmetic products. Similar findings were reported by Dreher and Davenport (2013), who stated that avocado-derived phytochemicals possess diverse industrial and medicinal applications. The utilization of avocado seeds and leaves for pharmaceutical purposes may also contribute to waste reduction and environmental sustainability since these plant parts are often discarded during fruit consumption and agricultural processing. Their conversion into valuable medicinal products may therefore provide economic benefits and support sustainable biotechnology practices. The antimicrobial activities observed in this study suggested that avocado seed and leaf extracts possess promising therapeutic potentials that warrant further investigation, including isolation, purification, and molecular characterization of the active compounds responsible for the observed antimicrobial effects.

5.0 CONCLUSION

The findings of this study revealed that the seed and leaf extracts of Avocado contained important phytochemical constituents such as flavonoids, alkaloids, tannins, phenols, glycosides, saponins, terpenoids, and steroids, which contributed significantly to their antimicrobial activities against the tested microorganisms. The study further showed that avocado leaf extracts exhibited stronger antimicrobial activities than seed extracts, particularly against *Staphylococcus aureus* and *Candida albicans*, indicating that avocado plant parts possess considerable medicinal and biotechnological potentials. Therefore, avocado seeds and leaves, which are often regarded as agricultural wastes, could serve as valuable natural sources of antimicrobial agents for pharmaceutical and biotechnology applications. Further studies should be carried out to isolate, purify, and characterize the specific bioactive compounds responsible for the antimicrobial activities observed in avocado seed and leaf extracts. Clinical and toxicological evaluations should also be conducted to determine the safety and therapeutic effectiveness of the extracts for pharmaceutical use. Additionally, biotechnology and pharmaceutical industries should explore the utilization of avocado seeds and leaves in the development of natural antimicrobial products, herbal medicines, and food preservatives.

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