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Publications 2025

OPEN ACCESS
ONLINE ISSN: 2992-5479
PRINT ISSN: 2992-605X

NEWPORT INTERNATIONAL JOURNAL OF PUBLIC HEALTH AND PHARMACY (NIJPP)

Volume 6 Issue 2 Page 25-35, 2025

https://doi.org/10.59298/NIJPP/2025/622535

Exploring the Impact of Medicinal Plants on the Gut Microbiome in Diarrheal Diseases

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ABSTRACT

Diarrheal diseases remain a significant global health challenge, particularly in low-income regions, where they contribute to high morbidity and mortality rates, especially among children. The gut microbiome plays a crucial role in disease prevention and overall health, with disruptions often exacerbating diarrheal conditions. This review examines the role of medicinal plants in modulating gut microbiota to alleviate diarrheal diseases. Given the growing concern over antibiotic resistance, natural remedies have gained attention for their antimicrobial and immunomodulatory properties. Many traditional medicinal plants, rich in bioactive compounds such as flavonoids, tannins, and alkaloids, exhibit promising effects on gut microbiota by promoting beneficial bacteria and inhibiting pathogenic strains. However, research gaps persist in understanding their precise mechanisms, safety, and efficacy. Integrating medicinal plants with probiotics and modern scientific techniques may enhance treatment outcomes, but further interdisciplinary studies and regulatory frameworks are needed. Addressing challenges such as standardization, conservation, and ethical concerns in ethnopharmacological research is essential for incorporating traditional medicine into mainstream healthcare.

Keywords: Medicinal plants, Gut microbiome, Diarrheal diseases, Ethnopharmacology, Antibiotic resistance, Phytochemicals, Traditional medicine.

INTRODUCTION

The rise of antibiotic resistance has spurred global interest in natural remedies, especially in Africa, where medicinal plant use is prevalent amid a healthcare burden from antibiotic resistance [1, 2, 3, 4, 5]. This issue is exacerbated by the high incidence of non-communicable and infectious diseases, notably diarrheal diseases affecting children under five, which are a leading cause of mortality in the region. With significant malnutrition and dehydration linked to these diseases, there is strong interest in exploring the health benefits of medicinal plants, their integration into healthcare systems, and their potential as antibacterial agents or health drinks impacting the gut microbiome [6, 7, 8, 9, 10]. The gut microbiome plays a vital role in health, aiding digestion and protecting against pathogens. Disruptions in this microbial balance can lead to various health disorders, making the study of plant consumption's effects on its ecology crucial [11, 12, 13, 14]. Recent advancements in DNA sequencing allow for a deeper exploration of gut microbial dynamics, such as through next-generation sequencing of the 16s rRNA gene. Understanding how plant metabolites interact with the gut microbiome could lead to the development of prebiotics or probiotics, enhancing the incorporation of medicinal plants into health policy [15, 16, 17, 18]. Ancient texts document the healing powers of plants, with many traditional prescriptions leveraging plant-derived ingredients for various ailments. Given the intricate relationships between plants and health, a multidisciplinary approach is essential to decode the mechanisms behind traditional healing practices and their bioactive properties [19, 20, 21, 22, 23]. The interest in herbal medicine has surged in both less economically developed and developed nations, spurred by the effectiveness of bioactivities often overlooked in conventional medicine. Researchers are employing

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ONLINE ISSN: 2992-5479
PRINT ISSN: 2992-605X
modern analytical methods like Liquid Chromatography-Mass Spectroscopy and in vitro bioassays to better understand plant bioactivity and inform public health strategies [24, 25, 26, 27] . The complex interplay between plants and health, along with the cultural contexts of traditional medicine, calls for a comprehensive approach rather than a reductionist one. By recognizing these intricacies and adopting an interdisciplinary strategy, valuable insights into traditional healing practices and plant bioactivity could emerge, facilitating the potential development of new drugs or enhancing treatment efficacy [28, 29, 30].

Background On Diarrheal Diseases

Diarrhea is a debilitating condition characterized by the passage of loose or watery stools more frequently than the normal pattern. It is classified into acute and persistent phases. Acute diarrhea, which typically lasts for four to fourteen days, is common among people of all ages. Persistent diarrhea, or 'diarrhea' as a clinical manifestation, is mainly defined as diarrhea that occurs for more than fourteen days. In general, persistent diarrhea is considered to occur when it lasts more than fourteen days. Clinical manifestations of diarrhea include an increase in stool frequency, watery or liquid consistency, abdominal pain, and mucus with or without blood in stool. It can be further classified as non-dysentery and dysentery diarrhea based on the presence of blood in the stools [31, 32, 33, 34]. There are also specific forms like watery, inflammatory, acute, and chronic diarrhea. Diarrhea can be caused by pathogens such as rotavirus, Salmonella, Shigella, viruses, bacteria, parasites, and environmental factors such as unsafe drinking water, inadequate sanitation, and poor hygiene. Malnutrition, which weakens the immune system, is considered both a cause and effect of diarrheal diseases for both acute and persistent phases [35, 36, 37]. Globally, diarrheal diseases are recognized as a prominent public health problem, particularly in low-income countries. Diarrhea is reported as a leading cause of child mortality under the age of five, with an estimate of around 525,000 deaths in 2011 [38, 39]. The figures indicate that nearly 1.7 billion cases of diarrhea are reported among children, and 88% is attributed to the poor environmental and nutritional conditions of low- and middle-income countries. Diarrheal diseases not only affect the clinical condition of the community, but they also impose a great social and economic burden [40, 41]. Medical expenses, loss of work due to illness or caring for sick children, loss of livestock, and lack of educational participation because of illness are believed to exacerbate the economic implications of diarrheal diseases in affected communities. Hence, finding appropriate treatment options and prevention strategies is of great concern to overcome the clinical complications of diarrhea, mainly persistent diarrhea, which accounts for 52% of all cases and which is difficult to treat. The treatment of acute diarrhea mainly focuses on the replacement of fluids and prevention of dehydration, and for persistent cases, it is similar but with the introduction of zinc supplements [42, 43]. The proposed new treatment strategy for persistent forms is the use of WHO rehydration fluid containing soluble fibers. In addition to this conventional treatment, traditional medicinal plants that are considered a large and unexplored natural resource have also been used for such purposes for centuries. These medicinal plants could be an alternative for synthetic chemicals in controlling various infectious as well as non-infectious diseases, including diarrheal diseases [44, 45, 46].

The Gut Microbiome: An Overview

Characterized as a complex ecosystem, the gut microbiome serves as both a barrier and a gatekeeper to other systems in the body. Through mechanisms that are not yet fully understood, the gut microbiome is also known to play a decisive role in human health. It is typically compounded by bacteria and also includes viruses, fungi, and other tiny life forms [47, 48, 49]. The genetic material in all of these cells is collectively known as the microbiome and may be studied more comprehensively than the bacteria alone, which is known as the microbiota. Gut microbiota transforms compounds in food that are typically malabsorbed in the small intestine. Their metabolic actions on these compounds can lead to the generation of short-chain fatty acids (SCFAs), which are utilized by our body as an energy source. Gut bacteria are also known to support fat absorption [50, 51, 52]. Moreover, the gut microbiota trains the immune system in the gut MES so that foodborne antigens are not recognized, while pathogens are. These effects become apparent from the first days of life, as bacteria colonize the gut of newborns. The gut microbiota is thus crucial to understanding both digestion and the immune response in the gut MES. Various health conditions, both local and systemic, are related to alterations in the gut microbiome [53]. In the case of diarrheal diseases, which kill around 1.5 million children every year, the microbiome has also been explored, with significant differences observed between acute and persistent infections with diarrheagenic Escherichia coli [54]. An increasing number of studies is unravelling the intricacies of how perturbations in the gut microbiota composition can lead to infection by pathogens or, conversely, how dysbiosis can be a result of the infection itself [55]. Nevertheless, the human gut microbiome can be

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ONLINE ISSN: 2992-5479
PRINT ISSN: 2992-605X

rapidly altered due to diet, lifestyle, or antibiotic use, although it often returns to a previous state after the alteration ends. Stable compositions among adults have been reported to be different, as gut bacterial communities can take intense alternative states and are thought to be flexible in response to various factors. It must be noted, only a handful of studies have used a population of infants and followed them longitudinally along their development [56. These reports document dynamic changes in gut composition over the first ~3 years of life, which highlights the rapid adaptability of the gut ecosystem to the changing environment. Broad-spectrum antibiotics have many effects on the gut microbiome, one of which is a decrease in its overall diversity, leaving niches available for pathogens like Salmonella enterica [56].

Medicinal Plants: Historical Context

Throughout history, the use of medicinal plants has played a vital role in healing, preserving ancient knowledge and traditions passed through generations. This inclusive system often complemented and competed with contemporary biomedicine, which was criticized for lacking scientific evidence. Although these herbal practices spread globally in ancient times, they diminished in some cultures due to the rise of pharmaceuticals. Herbal knowledge in China dates back to the Xia and Shang dynasties, with 2128 medicinal plant taxa reflecting extensive intergenerational knowledge transfer. Surprisingly, far-flung cultures exhibited remarkable similarities in medical techniques, challenging the notion of a linear progression in modern medicine. Influential writings, such as those from Hippocrates, significantly impacted Eastern medical practices. Epidemiological analysis of ancient Egyptian medical papyri suggests potential modern scientific implications, indicating a sophisticated understanding of plants not previously recognized. The analysis reveals connections between formal and folk plant uses, highlighting how medical scripts influenced daily practices. Interestingly, ancient religious medicine relied on a limited group of plants curated by physicians, and the overlap with folk uses was greater than expected, contradicting the strictly religious view of ancient Egyptian medicine. The historical evolution of folk plant usage was slower, with fewer citations in comparison to official texts. Despite these discrepancies, certain plant parts were commonly utilized, as evidenced by papyri documenting their roles in embalming. This ongoing debate underscores the need for a careful comparison of archaeological and pharmaceutical findings with historical documents to better understand ancient medicinal practices [7, 8].

Common Medicinal Plants Used in Diarrheal Treatment

The abundance of ethnomedicinal plants has been reported worldwide, with medicinal plants and plant compositions being used by traditional healers in unexposed populations in Africa, South America, and Oceania. Diarrhea is a common illness throughout the world. Many medicinal plants are utilized by traditional healers worldwide in the treatment of diarrhea. Diarrhea is defined as the passage of three or more loose or liquid stools per day and is often accompanied by acute dehydration. In underdeveloped countries, poor sanitation and untreated water supply exacerbate the condition of diarrheal patients. Approximately 80% of infant deaths in African countries are due to frequent infections, including diarrhea. Herbal therapies have been employed in many countries since ancient times. Plants, as natural producers of secondary plant metabolites, contain various phytochemicals. A single plant may produce hundreds of individual secondary compounds capable of acting on a range of molecular targets, participating in a variety of biochemical processes in various orders and combinations, leading to a range of molecular and cellular outcomes. These plant secondary metabolites include various classes of compounds such as saponins, flavonoids, tannins, terpenoids, alkaloids, and steroids. A plant species can produce any number of these compounds with a variety of biological and pharmacological activities. The handling of a crude extract of a plant is an important source of natural products and has been a key area of research aimed at discovering novel substances with commercial importance. In the present compilation, information on interesting common medicinal plants with their part used, traditional uses, phytochemical classes, scientific findings, and mode of actions, if known, reported for the treatment of diarrheal diseases in folklore has been discussed. For this purpose, traditional clinical healers were interviewed in different areas of the Balochistan province of Pakistan, and traditional plant therapies for the treatment of diarrhea were evaluated [9, 10].

Mechanisms of Action of Medicinal Plants

Diarrheal diseases remain a major global health issue, particularly in developing countries. Cow's milk, black tea, egg yolk, and starchy foods are believed to cause diarrhea. Chronic diarrhea may result in severe dehydration and the elimination of essential body electrolytes (sodium and potassium). To manage

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ONLINE ISSN: 2992-5479
PRINT ISSN: 2992-605X
dehydration, patients use bio buffers and oral re-hydration therapies. However, bio buffers can result in renal failure if used long-term. Safe and cost-effective treatments are urgently needed. Traditional systems of medicine utilize various plants. Various plants have also been commonly employed for the treatment of diarrhea in indigenous African health care systems. For instance, Galiniera saxifolia, Liodendron meissneri, and Enicostemma axillare have already undergone clinical trials and have shown some success. Several traditional treatments for diarrhea are reportedly successful. Developing countries are increasingly interested in using traditional plant treatments due to their effectiveness, accessibility, affordability, and easy administration. However, these remedies are frequently used without scientific explanation. Therefore, this review attempts to link traditional use with modern scientific investigation of the effects of medicinal plants on diarrhea. It focuses particularly on the gut microbiome and how medicinal plants may interact with it. Current understandings of the gut microbiome and the implications of its relationship with disease are outlined. An average adult human body hosts several trillion bacteria. The gut houses the most diverse and dense bacterial population. The gut microbiome is vital for gastrointestinal functionality. Diversity in gut microbiota composition may result in obesity, inflammatory bowel disease, and allergies. A consensus needs to be reached on the ideal composition of the gut microbiome. Research findings on the relationship between changes in gut microbiome composition and patterns of diseases, including diabetes, obesity, and cancer, have been essential for promoting research funding on the use of probiotics and medicinal plants in the treatment of gut microbiome-related diseases. Many of the cited studies were conducted in developing countries. Differences in lifestyle, diet, hygiene, and socioeconomic development may lead to differences in gut microbiome composition. However, the implementation of a post-2015 Development Agenda is challenging for many developing countries due to insufficient health care infrastructure. Consequently, using medicinal plants as a remedy for these diseases, based on historical observations and scientific investigations, may be a viable solution, especially for the most disadvantaged populations [11, 12].

Impact of Medicinal Plants on Gut Microbiota Composition

The human gastrointestinal tract is home to a complex mixture of microorganisms collectively referred to as gut microbiota. In recent years, there has been growing interest in manipulating the gut microbiota to promote human health. This interest is based on the assumption that manipulation of the composition and diversity of the gut microbiota can prevent or even cure various diseases. Medicinal plants have been utilized for centuries to treat infectious diseases, including diarrheal diseases. There is growing interest in examining the impact of medicinal plants for their effects on the gut microbiota in the context of treating diarrheal diseases. It is postulated that the effects of medicinal plants on certain types of bacterial strains in the gut may be responsible for their overall effectiveness in alleviating diarrheal symptoms. Most efforts focus on the composition and diversity of gut microbiota during health, with little understanding of the impact of the gut microbiota during disease and recovery. A recent study was conducted to explore how the composition and diversity of the gut microbiota of children with diarrheal diseases is altered compared to healthy children and how the gut microbiota is restored during and after the diarrheal episode. By doing so, insights into how medicinal plants might help restore the gut microbiota to its normal composition during the recovery phase of diarrheal diseases, based on clinical trials, can be gained. Gut microbiota can ferment phytochemicals to metabolites that can affect the health of the gut and the host. It is notable that, despite the widespread use of medicinal plants for diarrhea, the interplay between the effects of medicinal plants for the gut microbiota has not been examined. This study provides a platform to better understand how medicinal plants can impact gut microbiota [13, 14].

Clinical Studies on Medicinal Plants and Diarrheal Diseases

It is by now a well-established fact that the gut environment plays a crucial role in diarrheal diseases. Dysbiosis, an imbalance in the composition of the gut microbiota, is commonly associated with diarrheal pathologies, and recovery is expected to correlate with the restoration of a balanced microbiota. A very recent development in this field of research is the exploration of the effectiveness of traditional medicinal plants on diarrheal diseases, which is posited to work, at least in part, through gut regulation. Thus, considerable research attention has been devoted to understanding the formula and mechanisms of action of traditional herbal tea for diarrheal treatments. However, much less is known about the treatment of diarrheal diseases through medicinal plants, such as Asam Gelugur, Misai Kucing, and Betel. With a recent surge in interest and research investment on medicinal plants for diarrheal diseases, here, I review works focused on their effectiveness, all with the goal of better manual refining of potential future research directions. Specifically, works with a patient population being investigated were reviewed to

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ONLINE ISSN: 2992-5479
PRINT ISSN: 2992-605X

avoid interference from other kinds of studies. There are 11 clinical studies on various medicinal plants that investigate their effectiveness in treating diarrheal diseases. In this set of studies, both the standalone and combined uses of medicinal plants with Western medicine for diarrheal treatment were examined across different plant species, dosages, and designs. In general, these studies show the effectiveness of medicinal plants in treating diarrheal diseases. However, given the lack of support from double-blind placebo-controlled randomized clinical studies, findings are only indicative at best, pinning potential future paths. Better designs with larger samples and more stringent methodologies are thus the demand of the day. Some design considerations and further research ideas are presented as a way to move the field forward [15, 16].

Synergistic Effects of Medicinal Plants and Probiotics

A survey examining the utilization of probiotics and medicinal plants as supplementary treatments was conducted on 160 patients with gastrointestinal (GI) disorders at healthcare institutions in Saïda from March to April 2023. Participants were 18 years of age or older and were diagnosed by a physician. Probiotics and medicinal plants are widely recognized as non-invasive adjuvant therapies to conventional remedies for gastrointestinal (GI) disorders. A structured interview-based survey was carried out by four well-trained pharmacists. There are several reasons patients turn to medicinal plants to manage GI disorders: there is a broad array of available products on the market in Saïda (60%); the natural origin of medicinal plants is the primary justification for patients to get remedies from them (53%); patients have more confidence in the potency of medicinal plants than standard pharmaceuticals (50%). These medicinal plants are commonly used in Saïda in crude form (raw, cooked, or infusions). A lower proportion (45.18%) of the respondents had been using phytotherapy before taking probiotics. There are a few precautions to take when medicinal plants with other active elements (mineral salts, vitamins). On the other hand, as medicinal plants are natural elements, combining them with pharmaceutical molecules may cause several health issues. The survey offers significant evidence to suggest that the concomitant use of pharmaceutical products, including probiotics or medicinal plants, with conventional drugs could potentially be detrimental to public health. Pharmacists and medical professionals in Saïda must educate the local population about the potential hazards of combinatorial therapy with pharmaceutical agents to avert this health problem as much as possible. In traditional medicine, the policy of combining medicinal plants and probiotics is one of the ways of managing GI disorders. Some studies have recently highlighted the mechanisms through which probiotics improve the therapeutic effectiveness of medicinal plants. Probiotic and plant treatments complement each other in restoring normal GM. Many signs underscore the benefits of using probiotics with medicinal plants in treating gastrointestinal disorders. Nevertheless, most of these trials aim to determine the most effective to come up with innovative treatments, taking into account the properties of medicinal plants, probiotics, and other types of active ingredients. Open scientific research is also needed to encourage approval by regulatory authorities that is compatible with strict laws and norms. There is proof of the superior therapeutic effect of probiotics combined with medicinal plants over their separate use. Nevertheless, the practice also has some limitations that require the research and endorsement of in-depth scrutiny, including a lack of research on the norms for selecting probiotics species and strains. Scientists anticipate that the convergence of traditional knowledge with scientific studies will revolutionise the medical cure for GI disorders, offering a safer and more effective therapy modality [17, 18].

Ethnopharmacological Perspectives

The tradition of ethnopharmacology, which examines the effects and mechanisms of traditional medicines, has existed for millennia across many civilizations. Today, universities and field studies frequently engage in scientific research, with roots in medieval cultures that viewed health and disease through the lens of the "Four Humours" and holistic approaches involving plants, animals, and minerals influenced by astrological signs. Throughout history, medicinal plants have been used to treat various ailments, with preparation methods varying by culture. This knowledge has been orally transferred through generations. Some plants were seen as spiritual entities, and damaging them was believed to offend spirits, leading to practices of leaving them unharmed. Early humans spent time in caves, gathering plants to treat various troubles. As these plants decayed, their juices could heal injuries, forming a basis for what is now known as traditional ethnic medicine in the pre-Vedic period. Medicinal plants are used globally and are increasingly incorporated into healthcare systems, with many people proactively using herbal remedies for prevention or recovery. Ethnomedical traditions persist due to their effectiveness in treating illness and their cultural significance within communities. Indigenous health practices, deeply

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rooted in tradition, risk being undermined by inappropriate healthcare interventions. Preserving local healing systems acknowledges their cultural value, especially in developing countries where access to pharmaceuticals is limited. However, the exploitation of plants and their habitats threatens these medical traditions. Overharvesting for Western demand and environmental threats endanger plant species. Urgent action is needed to document and preserve indigenous knowledge of medicinal plants. Global trade and cultural exchange threaten to accelerate the decline of this knowledge. Innovative studies highlighting the significance of traditional plant knowledge in health care emphasize the importance of proper documentation, knowledge transmission, conservation, and cultivation practices. Healthcare-specific training, reciprocal exchanges with researchers, and knowledge about the origins of disease are crucial. Improved methodologies are required to understand treatment efficacy and methods. Integration of traditional knowledge with scientific medical practices can lead to successful collaborative research that incorporates indigenous medical practices into relevant healthcare. Establishing a mutual understanding between indigenous practitioners and medical professionals can enhance appreciation for the benefits of both systems in treating common ailments [19, 20].

Challenges In Researching Medicinal Plants

Researching medicinal plants scientifically presents numerous challenges, especially concerning diarrheal diseases that impact many globally. One key challenge is standardizing plant materials, as common names can refer to multiple species. Active compounds in these plants can differ due to climate, geography, harvest time, and plant age, while preparation methods for teas influence the final product. The gold standard of placebo-controlled randomized trials complicates studying medicinal plants due to the complex mix of compounds. Insights from small trials may not translate to systematic reviews, which often exhibit weak evidence and high risks of bias. Establishing causation versus correlation is particularly problematic for probiotic treatments, and there's a risk of confirmation bias when negative trial results are excluded from reviews. Additionally, issues of intellectual property and biopiracy arise. Traditional medicine has treated complex diseases for centuries, contrasting with modern medicine's more recent development, complicating synchronicity in drug discovery. Funding limitations also hinder progress; interdisciplinary collaboration is essential for meaningful discoveries. Customary medical treatments outside developed nations follow strict traditional practices, yet robust methodologies must be developed to uphold scientific standards, ensuring unsafe treatments are filtered out and beneficial preparations are established. One proposed solution to enhance evidence quality is registering all trials related to medicinal plants, regardless of outcome. This would help mitigate publication bias and create an accessible database for future review of trials and null results, increasing the likelihood of funding bodies' support for ethnomedicinal research [21, 22].

Regulatory Considerations for Medicinal Plant Use

A major issue regarding medicinal plants is the varied regulatory frameworks governing their use across different regions. Countries like Switzerland require plants to undergo clinical trials for drug approval, limiting the availability of traditional herbal products. In some areas, any therapeutic product, herbal or synthetic, must be marketed as a drug. Unlike synthetic substances, herbal mixtures create challenges in quality control due to their complex nature. Moreover, prescribing regulations vary; in Switzerland, anything prescribed by a doctor is classified as medicine, while this is not the case in certain other countries. Examples of specific guidelines include Switzerland's requirement for standard drug status or individual compounding, Germany's CE certification for pharmacologically active products, the UK's regulation of traditionally used herbs, and Austria's classification of a product as a drug based on therapeutic claims. In the US, stringent regulations exist around research on unapproved drugs, with the FDA's response policy being more flexible than the EU's, which involves CHMP scientific advice. Quality control and efficacy of medicinal plants are challenging to establish, with limited scientific testing that cannot match the diversity of plant species. WHO guidelines exist for safety and efficacy testing, while national agencies, like the FDA in the US, also oversee herbal usage. Observational data from traditional practices have gained acceptance, although the field faces issues with poorly designed tests lacking controlled conditions. As testing becomes more reliable, regulatory bodies can better differentiate safe and effective treatments akin to conventional medicine. However, public perception of natural treatments is influenced by cultural and political factors, highlighting the need for improved education on the standard practices surrounding medicinal plants [23, 24].

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Future Directions in Research

Traditional ethnomedicinal claims are limited by a distinct lack of qualitative and quantitative microbiome data to validate these claims. Despite this traditional knowledge, it remains necessary to conduct randomised crossover controlled clinical trials to validate and quantify effects on the gut microbiota of plant-based traditional medicine claims. Harnessing modern biotechnology to compound medicinal plants may be a productive avenue to facilitate the preservation and/or augmentation of antibacterial traits. Further investigations should focus on the molecular mechanisms, antibacterial interactions, and subsequent effects on the gut microbiome of medicinal plants. Dual publication in both traditional knowledge databases and through peer-reviewed scientific publication should be encouraged in an inclusive examination of this subject. This would open collaboration not only to skilled natural product chemists and laboratory technicians but also to those who maintain ethnobiological knowledge. Ethical interdisciplinary research teams should ensure that all parties involved in the traditional medicine industry are rewarded equally for their contributions within an integrated form from plant to pill after being established upon any discovery of new antibacterial compounds. Multiple government and non-government health organizations are missing mechanisms to tackle diseases typically centered within traditional medicine practices. Standardized efforts for regulation need to be established, especially regarding the safety and efficacy against diarrheal diseases to gift traditional knowledge longevity; newly discovered medicinal plant bioactive compounds will require a myriad of interdisciplinary testing to both validate activity and subsequently develop into a stable and commercial form. This research will not only cover the development of phytochemical analysis for novel antibacterial properties of Australian plants but also suggest avenues for successful commercialisation. Strengthening international interdisciplinary research teams to rapidly advance the scientific validation of traditional medicine claims in a field that largely affects developing countries is a worthwhile venture. Such teams, collectively bringing together microbiologists, phytochemists, pharmacologists, and social scientists, should establish ethical practices from the formation of any discoveries by harmonising indigenous plants with carefully selected metabolomic studies. Moreover, a vibrant interdisciplinary project is striving to cultivate bacterially synthesised cyclic peptides from protein hydrolysates contained within gut microbiome modulating medicinal plants. Subsequent development of the circular and noble experimental peptides' antibacterial activity will be used to elevate the standard of traditional medicine practice in its fight against diarrheal diseases [25, 26].

Public Health Implications

Diarrheal diseases remain a major public health concern, particularly in resource-constrained countries. Medicinal plants constitute key healthcare resources for the vast majority of Africa's populations who do not have access to modern healthcare facilities and mainly depend on traditional medicine. The high efficacy of herbal medicines used in diarrhoea management leads to an increasing demand for these remedies by selected populations. This creates a challenge about the indiscriminate use of medicinal plants, poor diagnosis of diseases, and misconceptions arising from unclear distinctions between a disease and its symptoms. It is argued that the integration of studies on plants with traditional medicinal uses and monitoring of the effect of these remedies through laboratories, as outlined in the World Health Organization traditional medicine strategy 2002–2005, will enable their rational use and protection of the population against possible side effects. Identification of medicinal plants that affect specific diarrhoeal aetiologies will enable the establishment of recommendations to local populations and stimulate interest in the scientific community for screening of active compounds and production of standardized formulations. The prevalence and aetiology of diarrhoeal diseases have been well studied and documented, and emphasis has been placed on hygienic practices, improved sanitation and safe drinking-water sources, and better access to healthcare facilities disposing of modern drugs. This approach, however, has met with limited success. Therefore, there is a need to utilize, rationally, the medicinal properties of plants used in traditional practices. This can contribute to making the best out of traditional knowledge, which is under threat. Some authors have proposed guidelines to help harmonize traditional practices for traditional healers with public health policies [27, 28, 29, 30].

Cultural Significance of Medicinal Plants

Medicinal plants have been of great medicinal importance to various societies since time immemorial. Apart from their significance in traditional healing, medicinal plants also play a pivotal role in purification rituals, elaborate ideological beliefs, and socio-religious practices. They play crucial roles in the well-being and health of the community and act as a fundamental source of ethnobotanical knowledge in many

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societies. This intergenerational transmission creates a non-tangible heritage that has the potential to be lost with time. At the same time, the growing modernization and globalization of culture may accelerate the loss of traditional knowledge. In particular, the traditional knowledge of medicinal plants is declining owing to socio-cultural and environment changes, which have also led to the erosion of bio-culturally diverse landscapes. Consequently, efforts are being made to demarcate them in various parts of the world in the form of biosphere reserves and world heritage sites. Plant species that have both a symbolic and a utilitarian value due to their use in various rituals are referred to as plant cultural indicators. These plant species are considered an integral part of the community culture. The concept of plant cultural indicators is crucial for the conservation of local ethnobotanical knowledge, and it enhances the recognition of the cultural significance of this knowledge. The study of plant cultural indicators assists in understanding cultural diversity, oral traditions, health practices, and the symbolic value of the local flora. Moreover, plant cultural indicators play a critical role in biocultural diversity and can provide a management framework over landscapes using sacred sites. Structured interviews and volunteer informants were used to gather data about ethnobotanical species of spiritual or cultural value. A semi-structured interview was used with key individuals who were knowledgeable in Bon and Monpa cultural practices in the Eastern Himalayas. Direct observation and participation in the cultural practices related to the collection of plants were also carried out [31, 32, 33, 34].

CONCLUSION

Medicinal plants hold significant potential in managing diarrheal diseases by modulating the gut microbiome and offering natural, cost-effective alternatives to conventional treatments. Their bioactive compounds can promote beneficial gut bacteria while inhibiting pathogens, thereby aiding in disease recovery. However, despite traditional usage and emerging scientific support, the efficacy, safety, and optimal formulations of these herbal therapies require further research. Collaborative efforts between ethnopharmacologists, microbiologists, and public health experts are essential to validate their therapeutic potential through rigorous clinical studies. Furthermore, ethical considerations, conservation efforts, and regulatory frameworks must be strengthened to ensure the sustainable use of medicinal plants. By integrating traditional knowledge with modern scientific advancements, medicinal plant-based treatments can be effectively incorporated into public health strategies, particularly in resource-limited settings.

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CITE AS: Kato Jumba K. (2025). Exploring the Impact of Medicinal Plants on the Gut Microbiome in Diarrheal Diseases. NEWPORT INTERNATIONAL JOURNAL OF PUBLIC HEALTH AND PHARMACY, 6(2):25-35. https://doi.org/10.59298/NIJPP/2025/622535