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Review Paper

Navigating the Future of Nutraceuticals and Herbal Products: Insights into Bioavailability and Pharmacokinetics

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ABSTRACT:
The global market for herbal and nutraceutical products has experienced significant growth, fueled by an increasing consumer preference for natural remedies over synthetic pharmaceuticals. Despite their promising therapeutic benefits, many herbal compounds exhibit limited bioavailability due to poor lipid solubility and suboptimal molecular size, which directly influences their pharmacokinetic profiles. Recent advancements in formulation techniques, including nanoemulsions, liposomes, and microencapsulation, demonstrate the potential to enhance both the bioavailability and overall pharmacokinetics of these bioactive compounds. Additionally, innovative bioenhancers derived from various herbal substances can significantly improve the absorption, distribution, and metabolism of nutraceutical formulations. Studies on bioactive collagen peptides and polyphenol-based products underscore the necessity for thorough investigations into their pharmacokinetics, extraction methods, and formulation strategies. The COVID-19 pandemic has further accelerated the demand for nutraceuticals, highlighting a critical need for robust scientific validation. As the market continues to expand, addressing the challenges of pharmacokinetics and ensuring rigorous testing methodologies are essential for developing effective and safe herbal and nutraceutical products. This paper reviews current trends in pharmacokinetics and bioavailability research, emphasizing the importance of ongoing studies in shaping the future landscape of herbal and nutraceutical applications.

Keywords: Nutraceuticals, Herbal Products, Bioavailability, Pharmacokinetics, Clinical Trials.

INTRODUCTION:

Overview of Nutraceuticals and Herbal Ingredients:

Nutraceuticals, a combination of nutrition and pharmaceuticals, are products that promote health beyond basic nutrition. Nutraceuticals are specifically designed formulations intended to address specific dietary needs and promote preventive healthcare. As defined by the FSSAI, nutraceuticals support physiological well-being and maintain good health (1). They are food-derived substances that offer potential health benefits, including disease prevention and treatment. Advances in nutritional science have expanded our understanding of the role of nutrition in human health, shifting the focus from nutrient deficiencies to the prevention and management of chronic diseases (1). Herbal products, closely related, focuses on medicinal plant use, ranging from traditional practices to standardized extracts. Nutraceuticals often combine probiotics, prebiotics, and food for specific medical purposes, with herbal products playing a central role. Together, these categories support health, longevity, and disease prevention (2).

Nutraceuticals and herbal products offer potential benefits in promoting overall health & wellbeing, healthy aging, preventing chronic diseases, increasing lifespan, and supporting bodily functions (3). Studies suggest that nutraceuticals have positive effects on cardiovascular health, immunity, and could potentially reduce the risk of infections and cancer.

Conducting pharmacokinetic (PK) and bioavailability (BA) studies is crucial today due to the rapidly evolving nutraceutical and herbal product landscape, not just for establishing safety and efficacy but also for fostering scientific credibility and regulatory compliance. Unlike pharmaceuticals, these products are often marketed without the same regulatory

oversight, which can lead to variability in product quality, effectiveness, and consumer outcomes. Robust PK and BA studies provide a scientific foundation by elucidating how bioactive compounds are absorbed, distributed, metabolized, and excreted, ensuring that claims of efficacy are supported by measurable biological effects. Furthermore, such studies help optimize formulations to enhance absorption, reduce variability between individuals, and mitigate potential drug interactions. As consumers seek natural alternatives for health, ensuring that nutraceuticals and herbal products have well-characterized PK and BA profiles is essential for gaining scientific credibility, consumer trust, and regulatory acceptance. Although herbal and nutraceutical medicine is increasingly embraced as a healthcare alternative, its assessment requires rigorous clinical trial methodologies to uncover potential risks and validate efficacy (2). Despite their generally favorable safety profiles, there is a pressing need for intensified clinical and preclinical research to comprehensively understand their profile (4).

Historical context and traditional uses, particularly in India:

India's deep-rooted tradition of using nutraceuticals and herbal products, since times immemorial, is primarily shaped by Ayurveda. Ancient Ayurvedic texts, like the *Charaka Samhita* and *Sushruta Samhita*, detail the extensive use of herbs like turmeric, ashwagandha, and neem for health and wellness. While regional practices have enriched this tradition, the historical context underscores India's enduring belief in the therapeutic value of natural substances. India is famous for its ancient medicinal systems, Ayurveda, Siddha, and Unani. Around 60% of people worldwide use alternative or traditional medicines. These practices are popular in both developing and developed countries where modern medicines dominate. Traditional medicines often use herbs, minerals, and natural substances. India has a long history of using plants for medicine, which remains a crucial part of its healthcare system (5). Traditional medicine is often preferred due to its lower cost, alignment with patient beliefs, concerns about synthetic drug side effects, desire for personalized care, and greater accessibility. It is primarily used for health promotion and chronic conditions, but its usage surges when conventional treatments fail, such as in advanced cancer or emerging infectious diseases. While traditional medicines are generally perceived as natural and safe, this is not always the case. Interactions with prescription drugs, over-the-counter medications, or other herbs can significantly increase the risk of adverse effects (4).

Significance of Pharmacokinetics and Bioavailability:

PK studies are a critical yet often neglected aspect of traditional medicine. Unlike modern pharmaceuticals, most Ayurvedic, nutraceuticals, herbal formulations lack data on absorption, distribution, metabolism, and excretion (ADME) profiles, leading to limited understanding of how these products interact with conventional drugs. This gap poses risks, as the active compounds in these formulations are often not standardized, unknown or present in low concentrations, making their detection and study difficult. Herb-drug interactions, particularly involving cytochrome P450 enzymes, can lead to significant clinical effects, including treatment failures or adverse reactions. To ensure the safe integration of nutraceutical, herbal and ayurvedic treatments into modern healthcare, a deeper understanding of their PK profiles is essential, along with bioactivity-guided methods to identify relevant marker compounds for quality control and efficacy (6).

Bioavailability (BA) in Nutraceuticals refers to the proportion of a bioactive compound that, after ingestion, becomes available for absorption in the gastrointestinal tract and is distributed to target tissues. Unlike pharmaceutical bioavailability, which often focuses on the amount of a drug absorbed into the systemic circulation, oral bioavailability in nutraceuticals encompasses all stages from ingestion to excretion. This includes the release of the bioactive compound from the food matrix, its absorption through the GIT, metabolism, and eventual distribution to organs and tissues. Understanding oral bioavailability is essential to assess how much of a nutraceutical is effectively utilized by the body after consumption (7).

BA is a crucial factor in determining the efficacy of both drugs and nutraceuticals. It refers to the proportion of a substance that enters the bloodstream when it is introduced into the body and is made available for use or storage. The key to the bio-efficiency of food bioactive substances is oral bioavailability, which assesses the connection between food and health benefits (8).

Bioavailability is a fundamental aspect of pharmacokinetics, the study of drug movement within the body. Pharmacokinetics is often summarized using the acronym ABCD, representing administration, bioavailability, clearance, and distribution (9). Together, bioavailability and clearance are key factors in determining the steady-state concentration of an active ingredient or formulation. Steady-state concentration is the point at which the rate of input equals the rate of elimination, resulting in a constant active ingredient level in the body (10).

The route of administration (ROA) and dosage can significantly affect the rate and extent of bioavailability. Higher doses may be necessary for drugs or formulations with low bioavailability to achieve effective concentrations. Each ROA has

unique capabilities in achieving specific plasma drug concentrations. Changing the ROA often requires adjusting the dosage. For instance, oral formulation must pass through the gastrointestinal system, encountering intestinal absorption and hepatic first-pass metabolism (11).

Bioavailability is a complex process influenced by interrelated factors, including bioaccessibility, absorption, metabolism, and bioactivity. Each step in this process can affect the overall bioavailability of a compound. In vivo, ex vivo, and in vitro methods can be used to study these individual processes and their combined impact on bioavailability (12).

The Nutraceutical Bioavailability Classification Scheme (NuBACS) categorizes the key factors limiting the oral availability of nutraceuticals in food matrices into three main classes: bioaccessibility, absorption, and transformation within the gastrointestinal tract (GIT). Each class has specific subclasses based on physicochemical or physiological mechanisms that affect bioavailability (figure 2). Understanding these mechanisms can help in designing more effective delivery systems or food matrices to enhance the bioavailability of nutraceuticals. Examples of nutraceuticals classified according to the NuBACS system include quercetin, resveratrol, β-carotene, curcumin etc. For instance, quercetin and resveratrol may face limitations in bioavailability due to poor solubilization and metabolism, while β-carotene and curcumin often exhibit challenges related to low absorption and chemical degradation (14).

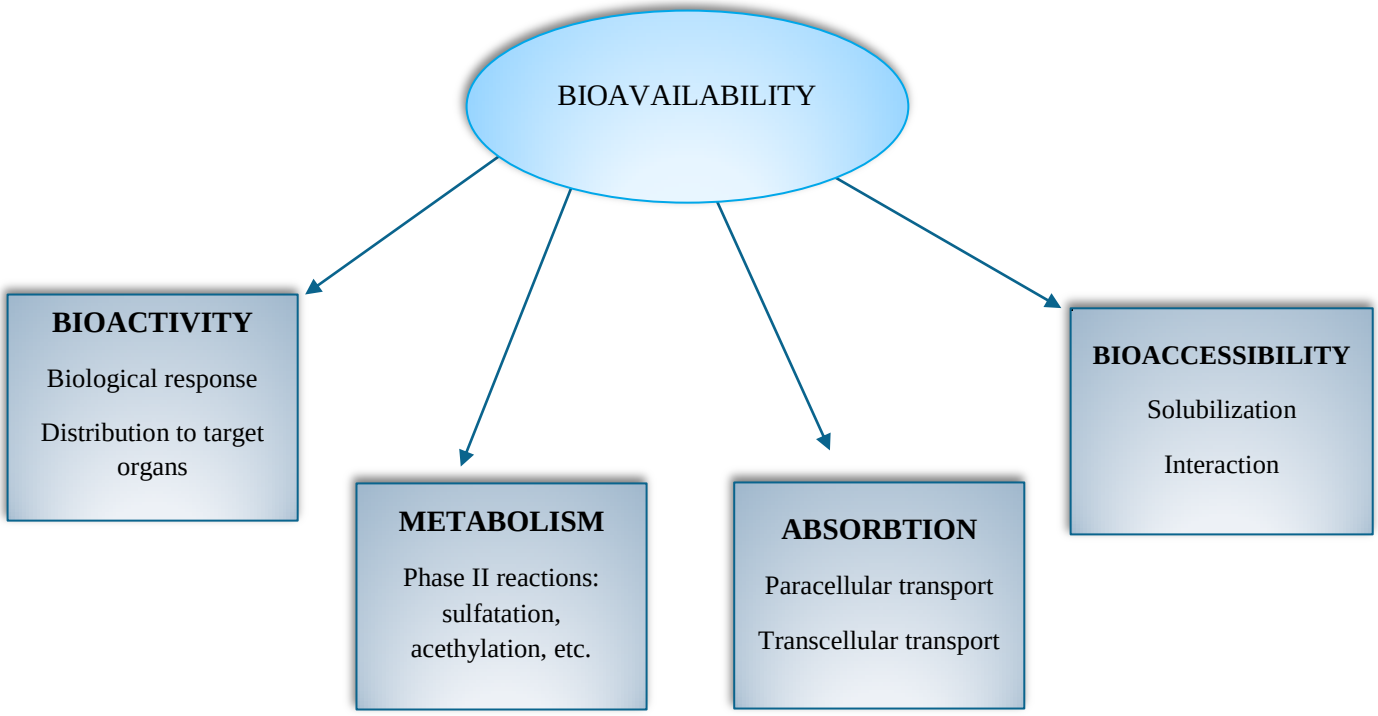

Figure 1: Bioavailability concept (13).

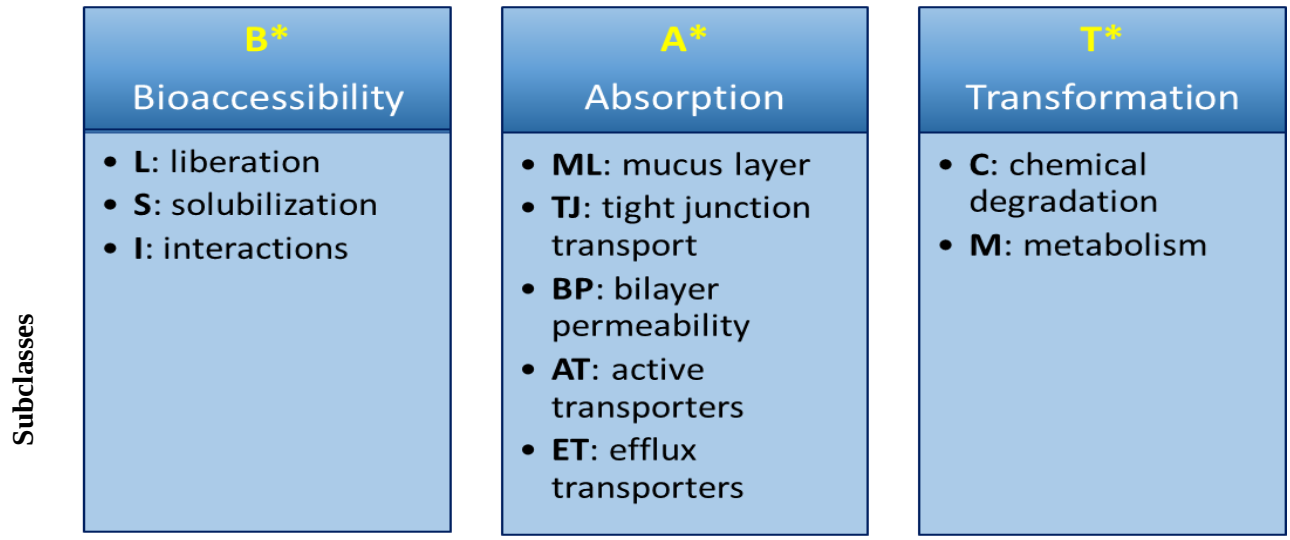

Figure 2: Nutraceutical bioavailability classification scheme (14)

The Role of Bioavailability in Optimizing Nutraceutical and Herbal Product Effectiveness:

While clinical testing on animals or in vitro is mandatory for pharmaceutical compounds, traditional methods for verifying the effects of foods in disease prevention and treatment have been less rigorous in the nutrition industry. As consumer awareness of health-related issues increases, there is a growing need for scientifically validated testing of food composition, including herbal and neutraceutical products, to ensure its effectiveness in maintaining health and preventing diseases (15).

An essential phase in the development of functional foods involves evaluating the BA of nutraceuticals incorporated in food fortification, which is crucial for identifying potential challenges and exploring technological solutions (16). Oral BA is a critical parameter for determining the correlation between dietary intake and associated health benefits (8). In recent years, numerous research groups have concentrated on elucidating the underlying processes and mechanisms governing the BA of nutraceuticals, to enhance the bioefficacy of functional foods while mitigating potential toxicity risks (17, 18). McClements, Li, and Xiao (2015) proposed the Nutraceutical Bioavailability Classification Scheme (NuBAC), a framework similar to the Biopharmaceutical Classification System (BCS), to categorize the factors influencing nutraceutical oral bioavailability (19). Direct measurement of BA involves in vivo pharmacokinetic studies (20).

In recent years, many people have chosen foods high in nutraceuticals, which help prevent or treat chronic illnesses. Oral bioavailability is a crucial stage in nutraceutical bioefficiency, influenced by endogenous and exogenous factors such as food matrices, solubilization, absorption, and chemical transformations. So, it is important to determine the bioavailability of nutraceuticals (21, 22).

Nutraceuticals and herbal products, like pharmaceutical drugs, can be eliminated from the body through either first-order or zero-order kinetics. Zero-order kinetics involve a constant rate of elimination regardless of plasma concentration, which can lead to saturation and potential toxicity. In contrast, first-order kinetics eliminate a constant fraction of the drug, with the elimination rate increasing proportionally to plasma concentration (10). Understanding the elimination kinetics of nutraceuticals and herbal products is crucial for optimizing their use. For active ingredients that follow first-order kinetics, frequent dosing can lead to accumulation in the system, potentially causing unintended supratherapeutic effects and adverse side effects (23).

To enhance the predictive accuracy of nutraceutical oral bioavailability, researchers are diligently developing in vitro and in vivo models as surrogate endpoints for human pharmacokinetic studies. However, substantial advancements are imperative to refine the correlation between these models and human data. Furthermore, establishing precise scaling factors that account for interspecies differences in pharmacokinetics is crucial for achieving reliable predictions (24).

The importance of conducting PK and BA studies in herbal and nutraceutical products cannot be overstated, especially as the consumer market for these products grows. Understanding PK and BA is not only vital for ensuring that formulations are safe and effective but also for meeting consumer expectations in a competitive marketplace.

Challenges in Bioavailability:

Nutraceuticals like β-carotene, curcumin, and vitamins A, D, E, and K present significant challenges when added to food products because of their chemical instability, which can occur during food processing and storage due to factors like light, oxygen, and heat, or within the gastrointestinal tract due to factors like pH and/or enzyme degradation, as well as their low water solubility and low bioavailability (25).

Inter-individual variability in nutraceutical bioavailability is significantly influenced by dietary factors, genetic predispositions, and the composition and activity of the gut microbiome. Many bioactive food compounds, such as polyphenols, exhibit low oral bioavailability, typically ranging from 0.3% to 43%. Consequently, circulating plasma concentrations of their metabolites are often insufficient for therapeutic efficacy (26). This limited bioavailability poses a significant challenge in utilizing bioactive food compounds as functional ingredients. To fully harness the potential health benefits of these compounds, a comprehensive understanding of their absorption mechanisms is essential for developing strategies to enhance their bioavailability (27).

Nutraceuticals are food types and dietary ingredients that provide both nutritional value and medical benefits. The majority of organic substances, including flavonoids and tannins, dissolve readily in water but have trouble being absorbed because they can't get pass the lipid membrane surrounding the cell. Their very big size causes bioavailability and adequacy loss (25). A number of physicochemical and physiological processes, such as release from food matrices, solubility in gastrointestinal fluids, interaction with gastrointestinal components, chemical breakdown or metabolism, and epithelium cell permeability, may restrict the oral bioavailability of a health-promoting dietary component (28).

Nutraceuticals and herbal ingredients face several challenges regarding BA, such as chemical instability during processing, low water solubility, and poor

absorption. Inter-individual variability, influenced by genetic predispositions and gut microbiome composition, further complicates the issue. Understanding and improving these factors is essential for optimizing therapeutic outcomes and delivering consistent, high-quality products.

Regulatory and Quality Control Issues:

In the pharmaceutical industry, clinical testing on animals or in vitro is required to validate the effects of compounds. Historically, nutrition lacked similar methods to verify the impact of foods on disease prevention or treatment. However, recent years have seen scientific testing of food compositions increase, driven by growing awareness of health issues and the role of food in maintaining health and preventing diseases (1).

Nutraceutical regulation is complex due to varying definitions across countries and a lack of unified quality standards. Harmonizing regulations globally would not only benefit the industry but also ensure consumer safety. As the food trade market expands, international regulations are crucial to safeguard consumer health and promote industry growth (44). The development of herbal bio-enhancers presents novel regulatory challenges. Given the distinct physicochemical and pharmacokinetic properties of nanotechnology-based drug products compared to conventional formulations, there is a growing need for regulatory frameworks that address the unique characteristics of these innovative therapies (28).

Standardizing herbal drugs involves ensuring consistent composition through comprehensive controls, including analytical methods for identifying, marking, and assessing active principles. There is no universal legal framework for medicinal plants, leading to varying definitions and regulatory approaches across countries regarding licensing, manufacturing, and trading.

Global and Indian Regulations Affecting Bioavailability Research:

In 2006, the Indian government enacted the Food Safety and Standards Act (FSSAI) to consolidate and streamline regulations for nutraceuticals, foods, and dietary supplements. Herbal drug products are a significant component of India's recognized health systems. Regulation of herbal medicines falls under several frameworks, including the IMCC (Central Council of Indian Medicine) Act, various research councils (ICMR and CSIR), the Department of AYUSH (Ayurveda, Yoga & Naturopathy, Unani, Siddha, and Homoeopathy), and the Drugs and Cosmetics Act of 1940 (Amendment) (30).

The regulatory landscape for nutraceuticals varies significantly across countries, posing challenges for researchers and manufacturers seeking to conduct bioavailability studies. Global health authorities, such as the World Health Organization (WHO), have established guidelines and recommendations to promote the safety and efficacy of nutraceuticals. However, the implementation of these guidelines often varies, leading to disparities in regulatory standards. In India, the Food Safety and Standards Authority of India (FSSAI) plays a crucial role in regulating nutraceuticals. While the FSSAI has made strides in establishing regulations for the industry, the enforcement of these regulations can be challenging, particularly for small-scale manufacturers. Additionally, the lack of clear guidelines for bioavailability studies in India can hinder research efforts. To address these challenges, there is a growing need for harmonization of global regulations and the development of standardized protocols for bioavailability assessment of nutraceuticals.

Current Trends in Nutraceuticals and Herbal Bioavailability:

The global utilization of herbal and nutraceuticals has witnessed a surge in recent years owing to their purported therapeutic benefits and reduced incidence of adverse reactions compared to conventional pharmaceuticals. Despite promising in vitro efficacy, numerous herbal entities and extracts exhibit limited or negligible in vivo activity due to their inadequate lipid solubility or suboptimal molecular size. These factors contribute to poor absorption and subsequent bioavailability, hindering their therapeutic potential (28). In recent years, there has been a growing focus on developing reliable in vitro and ex vivo models to simulate the biological barriers encountered in preclinical testing (22). This effort aims to streamline development and research processes and enhance the reproducibility of results (29).

Peptides derived from collagen, often used in nutraceutical formulations, offer potential benefits in cosmetic applications due to their enhanced bioavailability and solubility. A controlled study of VERISOL®, a bioactive collagen peptide (BCP), has demonstrated its efficacy in cosmetic applications. This evidence supports the clinical validation of collagen peptides as effective ingredients in cosmetic formulations (30). Polyphenols, plant-based micronutrients, are a diverse group of compounds with potential cosmetic applications. Their bioavailability varies significantly among different polyphenol families, with the most abundant polyphenols often exhibiting the highest concentrations of active metabolites in target tissues. Extraction methods can significantly influence the composition and proportion of polyphenols in cosmetic formulations. To optimize the efficacy of polyphenol-based cosmetic products, it is essential to study their bioavailability and identify extraction techniques that maximize the delivery of active metabolites to target tissues (31). Formulation development is crucial for enhancing the bioavailability of nutraceutical and herbal products. Advanced delivery systems, such as nanoemulsions,

liposomes, and microencapsulation, can protect bioactive compounds from degradation, enhance their solubility, and improve their absorption. The development of these formulations should be guided by PK studies that explore how different formulations affect the bioavailability of compounds.

Innovative Delivery Systems:

Nutraceuticals require encapsulation to protect them from adverse external factors, enhance their solubility in water-based environments, mask off-flavors, allow controlled release, and preserve their bioactive properties until they reach their target site. Consequently, micro- and nano-scale delivery systems have gained significant interest globally. Recent advancements and strategies in these delivery systems have notably improved the bioavailability and efficacy of nutraceuticals (32).

Nanotechnological strategies like polymeric nanoparticles, solid lipid nanoparticles (SLNs), liquid crystal systems, precursors for liquid crystals (PSLCs), liposomes, and microemulsions enable diverse substances to be used in a single formulation and can alter their properties and behavior in biological environments. These advancements have transformed drug delivery by enhancing the effectiveness of active components and allowing the reintroduction of previously discarded components (33). Nanotechnology addresses the issue of low bioavailability in nutraceuticals by enhancing their water solubility and membrane permeability. This is achieved by reducing their size to the nanonutraceuticals and modifying their surface properties (33).

Nanotechnology has significantly improved the bioavailability of various nutrients. For vitamin A, encapsulation in nano-materials enhances its stability and absorption compared to free vitamin A. Vitamin B12 uptake is notably increased with protein-lipid composite nanoparticles, which are over 20 times more effective than traditional forms. Zein nanoparticles also boost the bioavailability of folic acid by about twofold, while iron encapsulated in solid lipid nanoparticles shows over fourfold increased bioavailability. Despite these advancements, further in vivo studies and clinical trials are needed to confirm the efficacy of these nano-based delivery systems for all these nutrients (34).

Micro/nanoencapsulation techniques have gained significant interest for their ability to enhance the bioaccessibility, bioavailability, stability, and durability of bioactive compounds. Proteins, polysaccharides, and other carriers are commonly used for their protective, stabilizing, and delivery properties. This has led to the development of nutraceutical capsules containing a variety of bioactive compounds, such as phenolic compounds, essential oils, carotenoids, vitamins, and polyunsaturated fatty acids (PUFAs) (35). Lipid formulations, such as nanocapsules and micronized carriers, offer potential for improving the controlled release, solubility, and bioavailability of phenolic compounds. For example, β-Car nanocapsules (>300 nm) have demonstrated exceptional physical stability during storage, making them suitable for incorporation into functional foods and beverages. This suggests their potential as nutraceutical delivery systems. Further research is needed to explore the specific benefits of lipid formulations in enhancing the bioavailability of phenolic compounds and their applications in various food and nutraceutical products (36, 37).

Bioavailability of the nutraceuticals can be improved by using bioenhancer. A 'bioenhancer' is a substance that improves the bioavailability and efficacy of a drug when used together without having significant pharmacological activity on its own at the doses applied. Various herbal compounds, such as quercetin, genistein, naringin, sinomenine, piperine, glycyrrhizin, and nitrile glycoside, have shown potential in boosting bioavailability (38).

Donatella Paolino et. al. investigated two microencapsulated Curcumin formulations using polymethacrylate polymers (Eudragit® Retard) through in vitro, ex vivo, and in vivo methods, analyzed with laser confocal microscopy. Curcumin permeation through CaCo-2 monolayers and its mucoadhesion were assessed using human intestinal cells and rat intestinal mucosa. Oral administration to rats showed a sevenfold increase in bioavailability, reduced Tmax, and a five-fold increase in plasma concentration compared to the unencapsulated drug. These findings highlight the potential for enhancing Curcumin's oral absorption and bioavailability (39).

In the modern food industry, edible nanoemulsions are increasingly used to encapsulate and deliver lipophilic ingredients like vitamins, polyphenols, aromas, pigments, proteins, and preservatives. These nano-sized droplets offer advantages over traditional emulsions, including enhanced stability, improved antibacterial properties, better taste, and longer shelf-life. They also improve the wettability and solubility of poorly water-soluble compounds, potentially enhancing the pharmacokinetic and pharmacodynamic properties of nutraceuticals (40).

Consumer Demand and Market Trends:

Growing concerns over the negative effects of synthetic drugs, including steroids, antibiotics, and painkillers, have increased the demand for medicinal herbs both domestically and internationally. According to a Market Research Report by Fortune Business Insights, the global herbal medicine market is expected to expand from $165.66 billion in 2017 to $347.50 billion by 2029, with a compound annual growth rate of 11.16% during the forecast period (41). The COVID pandemic has further boosted the demand for nutraceuticals, leading to a blossoming market for nutraceuticals. Due to the increase in consumer

demand, even during the COVID pandemic, the global nutraceutical market has grown significantly, with the market size increasing from USD 320 billion in 2020 to USD 352.92 billion in 2021 (36). The global nutraceutical market is projected to grow significantly from 2023 to 2031, driven by various factors. The market value is estimated to increase from USD 420.14 billion in 2023 to USD 868.38 billion by 2031, with a compound annual growth rate of 9.50% (42).

The market for nutraceuticals and herbal products has witnessed remarkable growth in recent years, driven by a confluence of factors. Increasing consumer awareness of the potential health benefits of natural ingredients, coupled with a growing distrust of synthetic pharmaceuticals, has fuelled demand for plant-based supplements. Additionally, changing lifestyles, aging populations, and rising disposable incomes have contributed to the expansion of this market. As consumers seek natural alternatives for various health concerns, including chronic diseases, weight management, and stress reduction, the demand for nutraceuticals and herbal products continues to soar. This growing market presents both opportunities and challenges for manufacturers and researchers, emphasizing the need for rigorous scientific investigation to ensure the quality, safety, and efficacy of these products (43).

Trends in Consumer Preferences Towards Plant-Based and Natural Supplements:

In recent years, there has been a significant shift in consumer preferences towards plant-based and natural products, including supplements. Driven by increasing awareness of the potential health benefits of natural ingredients and concerns about the safety and efficacy of synthetic compounds, consumers are increasingly seeking out nutraceuticals and herbal remedies as alternatives to traditional pharmaceuticals. This growing trend has led to a surge in demand for plant-based supplements, such as vitamins, minerals, and botanical extracts (1).

The nutraceutical and herbal product market is experiencing significant growth, driven by several key factors. The global consumer market for nutraceuticals and herbal products is particularly influenced by the increasing geriatric population, the prevalence of chronic diseases, and the integration of traditional medicine into modern healthcare practices. The rising popularity of these products can be attributed to their perceived nutritional and medicinal benefits, shifting consumer lifestyles towards healthier options, and the growing trend of veganism. Innovation in nutraceutical product development and increased venture investment in the sector further contribute to market expansion and rise in consumer preferences. (43, 44).

CONCLUSION:

In conclusion, the expanding field of nutraceuticals and herbal products offers significant opportunities but faces challenges, particularly regarding the complexities of bioavailability and pharmacokinetics. As consumer demand for natural health alternatives rises, it becomes increasingly important to conduct robust scientific research to validate the efficacy and safety of these products. While innovations in delivery systems and extraction techniques are essential for improving the absorption and therapeutic potential of bioactive compounds, it is equally critical to address the limitations in current pharmacokinetic and bioavailability data.

Given the growing consumer awareness and interest in personalized health solutions, expanding research in PK and BA studies will benefit research community, healthcare professionals and consumers. The development of bio-enhancers and advanced encapsulation technologies is key to overcoming bioavailability barriers, but these innovations must be supported by comprehensive pharmacokinetic, bioavailability and clinical trials to translate preclinical findings into practical applications.

A deeper understanding of the mechanisms governing bioavailability, combined with more extensive PK data, will not only improve product development but also enhance consumer trust by ensuring that herbal and nutraceutical products meet high standards of quality, efficacy, and safety. This integrative approach will serve research, healthcare professionals and consumer communities by driving scientific advancements and delivering better, more reliable health products to the market.

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