

Emerging Trends and Scientific Advances in Nutraceuticals

Vikrant Dandekar^{*1}, Tanish Parte¹, Bhagyalaxmi Gupta¹, Amit Pandit²

1. Bharati Vidyapeeth's College of Pharmacy, C.B.D. Belapur, Navi-Mumbai, INDIA
2. School of Pharmacy and Technology Management, SVKM's NMIMS, Indore, INDIA

Corresponding author*:

Dr. Vikrant Dandekar

Bharati Vidyapeeth's College of Pharmacy

Sector - 8, C.B.D. Belapur, Maharashtra

Navi Mumbai- INDIA

Postal code: 400 614.

Orcid: 0009-0006-1541-5649

Abstract: Nutraceuticals have progressed from simple dietary supplements to a central part of modern preventive healthcare. They have been driven by advances in formulation science and improved analyses as well as increased worldwide interest in natural evidence-based health solutions. The authors review recent trends that will remain prominent in the field: changing consumer behavior; nano-delivery systems and AI-augmented personalization, with emerging dosage formats. This review reflects on the regulatory environment in key markets, such as the U.S., Europe, Asia-Pacific and India and discusses the continuing work to enhance product quality, transparency and safety. It also distills the existing clinical evidence in terms of the five domains of interest such as stress relief, women's health, dermatology, metabolism and musculoskeletal aid. While results from some recent trials have suggested clinically relevant benefits of many well-investigated ingredients, there is an evident paucity of long-term research, improved

standardization, and stronger evidence for claims. The review mentions other remaining problems with respect to raw-material heterogeneity, uniform manufacturing and sustainability in botanical resources. The nutraceutical field is tending towards a more scientifically based and consumer-oriented trend, overall. Provided we can see this ongoing through further innovation, responsible regulation and research co-creation, nutraceuticals may also be a strategic aspect in global well-being and preventive health.

Keywords: Clinical Evidence, Functional Foods, Nutraceuticals, Preventive Healthcare, Regulatory Framework, Technological Innovations

1. Introduction

Nutraceuticals are a class of products derived from foods that offer health benefits beyond basic nutrition. Though the idea was developed several decades ago, over the past few years, the idea's relevance has gained in importance in sync with global health priorities, moving toward preventive care, wellness over multiple dimensions, and the treatment of lifestyle conditions. The absence of exercise, unhealthy diets, increased stress levels, and sedentary behaviour are all contributing as well as factors in the propagation of non-communicable diseases, which are leading the individual and a clinician towards the use of these strategies that enhance conventional treatments¹⁻³.

This increased acceptance of nutraceuticals is another reason behind the rise of scientific understanding. Thanks to sophisticated phytochemical extraction as well as method standardisation and analytical tools, the different bioactive components are now within the field of study with a much higher degree of precision. This has led to clinical trials of many nutraceutical ingredients to begin to bridge conventional nutrition practices with evidence-based medicine. This certainly is a

shift from the perception of nutraceuticals only as a product general for health to the consideration of nutraceuticals as adjuncts having tangible therapeutic value⁴⁻⁶.

At the same time the market has diversified steadily. The nutritional product spectrum includes botanicals, probiotics, fortified food products, antioxidants, amino acids, and even specialized formulae targeting specific health concerns. This diversification is a manifestation of an ever-more-individual lifestyle: as information becomes more readily available, the demand for self-care has increased, and people are more engaged in actively making decisions for their health. And, this backdrop has changed too via technological progression. Aspects such as nano-delivery systems, personalized nutrition models, and data analytics tools have made it easier the formulate and prescription of nutraceuticals. These improvements have contributed to more consistent and stable products, greater bioavailability and greater reliability in nutraceutical interventions relative to early generations of supplements⁷⁻¹².

The botanical raw material quality is still inconsistent, and so are the regulatory frameworks (from country to country); exaggerated, unverified statements are still a large issue. Quality control will be ensured by better scientific validation, clearer regulation, and harmonized standards. The general interest in nutraceuticals represents a larger shift in health philosophy, with prevention, personalized planning as well as the integration of nutrition into new scientific approaches gaining general acceptance. This review will analyze the developments, technological innovations, regulatory issues, as well as clinical evidence underlining the future of nutraceuticals. The term nutraceutical originated to describe bioactive food-based compounds that provide health benefits beyond pure nutrition. This concept has been evolving over the past two decades as people look increasingly for a variety of natural options to stay healthy and manage lifestyle problems. In addition, the prevalence of type 2 diabetes, obesity, stress, and cardiovascular disease are forcing

numerous individuals to explore nutrition-based strategies with conventional treatments. Better extraction methods and more research are among the reasons why new science and more drugs are being developed¹³⁻¹⁵.

The former nutraceutical industry was filled with an abundance of unregulated products with limited clinical substantiation. Nowadays, the current development in the field is leaning towards evidence-based, and many formulations are tested under controlled clinical trials. Our survey compiles relevant advancements in research in areas of innovation, consumer behavior, regulation, and clinical evidence to give a summary of current developments¹⁶⁻²⁰.

2. Global Market Dynamics

Supported by a deeper understanding of health and a preference for prevention over treatment, the nutraceutical industry has been experiencing ongoing growth. Growth in India, in particular, has been strong, spurred on by factors of urbanization, lifestyle changes, and an increase in public interest in self-care. Clear labeling, sourcing, and convenience in format are all basic expectations to a modern consumer. Nutraceuticals have now become greatly accessible due to e-commerce. Subscription-based models, targeted advertising, and online consultations have all helped to spread supplements as a tool. Sustainability is also at the top of the list, with many buyers now favoring products with eco-friendly packaging and that can be sourced in an ethical manner²¹⁻²³.

3. Technological Innovations

Technological advancements on the whole have contributed greatly to make up the contemporary nutraceutical sector. Some initial formulations were inherently weak and that included poor solubility, instability in storage, and the uneven incorporation of active ingredients into the body. Most of these problems have been tackled by more up-to-date innovations, which allow us to create

much more intuitive, simpler and, more importantly, more personalised delivery systems to deliver products to people, serving their specific health needs more precisely. A few of the key technological breakthroughs shaping the industry are presented below²⁴⁻²⁸.

3.1 Nano-encapsulation as well as a New Delivery Method

Most of the bioactive nutrients, including curcumin, quercetin, and resveratrol, remain poorly soluble in water and are degraded quickly in the digestive system. Nanoencapsulation may be a useful approach that can shield the bioactive substances in nanosized carriers, including nanoemulsions, solid lipid nanoparticles, liposomes and polymeric particles. These carriers, moreover, could promote the protection of the active constituents from premature degradation as well as increase uptake through the gastrointestinal tract. A further significant progress enabled by the delivery of nanomaterials is to be able to minimize the dose and achieve the same or improved physiological effects. This is highly significant for the compounds which had been commonly need to be delivered in high dosages to achieve observable effects. In addition, nano encapsulation increases the stability of the products and prolongs their shelf-life, and hence extends their commercial application manifold²⁹⁻³².

3.2 3D Printing for Personal Nutrition

Three-dimensional printing represents a whole new level of customizing a supplement. Unlike previous types of manufacturing in which uniform doses are made to be consumed by every user, in 3D printing, specific ingredient mixes and release profiles as well as dosages available, are chosen according to an individual's state of health or how they live life. This should be particularly valuable for clients who are on specific diets or who need to take a series of sources of nutrients in

proportion to their size. The technology also allows layered or multi-phase tablets in which different ingredients dissolve at controlled rates. That kind of flexibility has prompted continual research into personalized supplementation techniques, allowing manufacturers to create formulations that mirror a person's metabolic profile, age, or activity level³³⁻³⁵.

3.3 The Rise of Artificial Intelligence in Nutrition Science

In dietitians, Artificial Intelligence applications focus more and more on the interpretation of complex data sets that involve diet, genetics, the composition of the microbiome, the metabolic responses, etc. Tools like those work with these variables in concert and identify patterns that would be impossible to see in data by using traditional techniques. This leads to evidence based ingredient selections, dosage decisions, and ingredient interactions. As nutrition data and nutritional measurements continuously progress in the food diet, AI-driven health data will help make smart dietary choices that support good metabolic functions. AI-powered tools are playing a growing role in personalized nutritional programme development, predicting consumer demand, and even surfacing new bioactive candidates with potential therapeutic applications. AI will grow in predictive accuracy, while also providing even more information about how nutrition works with different bodies as data comes in to play³⁶⁻⁴⁰.

3.4 Novel Delivery Protocols

Nutraceuticals are now more than capsules or standardized tablet-based therapy. That development in formulation science carries over into various consumer formats: oral thin strips, dissolvable powders, liquid shots, gummies and multi-compartment capsules. They are perfect if patients prefer something that doesn't come out like a pill, or if people really want an earlier release. Some

contemporary delivery systems are engineered for increased stability, for covering up unpleasant flavors, or for blending ingredients that are prone to an antagonistic reaction. Multi-chamber capsules are an example of such technology, which keeps sensitive substances separate until they get into the digestive tract, as a result further strengthening the production of the final formulation. These scientific and methodological advances are combined, bringing to bear in making nutraceuticals more efficient, easier to use, and consistent across different groups⁴¹⁻⁴⁷.

Table 1. Key Technological Innovations in Nutraceuticals

Innovation	Application/Benefit	Examples
Nano-encapsulation	Enhances solubility & bioavailability	Curcumin, resveratrol
3D printing	Personalized dosing & supplement design	Customized tablets
AI-driven platforms	Predicts ingredient synergies, personalization	Genomic/microbiome data
Capsule-in-capsule/oral strips	Improves compliance & product diversity	Probiotic blends, adaptogens

4. Consumer Trends

Consumer interest is currently similar to the growing awareness of wellness-focused lifestyles.

Some of the biggest segments of demand are:

- Immune support, particularly with vitamins, botanicals, and antioxidant-rich formulations.
- Gut health, where probiotics and prebiotics remain a key element.

- Mental well-being: adaptogenic herbs such as Ashwagandha and L-Theanine.
- Support for chronic ailments, especially formulations related to metabolic disorders.
- Skin and hair health: Collagen, bioactive peptides, and antioxidant blends continue to be sought after. Plant-based and clean-label formulations are emerging as consumers seek less-processed products with ingredient transparency⁴⁸⁻⁵⁰

5. Regulatory Landscape

Nutraceuticals regulation, which has been continually evolving as health authorities around the world attempt to hit the balance between consumer safety, product innovation, and growth in markets. Unlike drugs, there is no international standard for nutraceutical regulation, giving rise to varied levels of regulatory scrutiny at the national and international level. These disparate rules on product classification, allowable claims, manufacturing standards, and requirements regarding evidence belong to the larger cohort of real challenges for manufacturers and researchers in recent decades. In recent years, a number of countries have revisited their frameworks to address concerns about product quality or misstated claims, as well as increase the acceptance of functional foods and dietary supplements. There is continuous change in regulations applied to nutraceuticals worldwide as the regulators need to strike a delicate balance between consumer safety and product innovation and market development. Unlike in the case of pharmaceuticals, there is no single international regulatory model for nutraceuticals. Therefore, the regulations for them differ according to country. Different rules on product classification, acceptable claims, manufacturing standards and the evidence that the product must provide add to ongoing challenges for manufacturers and researchers. In the last 10 years or so, many countries have been rethinking their frameworks due to poor product quality, false claims, and growing reliance on functional foods and dietary supplements⁵¹⁻⁵⁴.

5.1 International Regulatory Perspectives.

As nutraceuticals are predominantly classified as a type of food under the Dietary Supplement Health and Education Act of the United States, their safety is a legal responsibility of the manufacturer and the U.S. FDA must uphold regulations such as compliance, labeling, and reporting of adverse reactions. Since premarket approval for most supplements is not required, the companies are barred from claiming any unproven therapeutic benefit for the food. More recently, the FDA stepped up oversight of the sale of products with probiotics, botanical extracts, and new ingredients, to promote more scientific substantiation, and more alignment with Good Manufacturing Practice. This differs from the EU's European Food Safety Authority and a stricter, science based view of the regulation of health claims within Europe. The EFSA has a structured body to review health claims and denies claims to be made on labels unless there is evidence sufficient clinically to support it. So far, a few claims have been approved, most notably ones of vitamins, minerals and certain physiological functions. The tightening rules have rewarded greater European manufacturers' investment in standardization and clinical validation⁵⁵⁻⁵⁷.

5.2. Update on regulations in Asia.

There has been one fast-growing market for nutraceuticals in the Asia-Pacific and some significant regulatory changes in recent times. Amid rampant consumer abuse and safety incidents, many countries have passed stricter rules governing probiotics, ingredients for weight management and botanical extracts. Regulators have been cautioning against ingredients like *Garcinia cambogia*, and altered labeling standards as part of an effort to promote transparency. Japan, South Korea, and Singapore are some of the countries still working on their Foods for Special Health Use

(FOSHU) and similar criteria to help maintain a sense of reliability of products⁵⁸⁻⁶⁰ and evidence-based health claims⁵⁸⁻⁶⁰.

5.3 Indian Regulatory Environment.

India has a special case where dramatic market growth goes hand in hand with ongoing regulatory development. FSSAI also regulates nutraceuticals, functional foods, probiotics, and health supplements under the Food Safety and Standards (Health Supplements, Nutraceuticals, Food for Special Dietary Use, Food for Special Medical Purpose, and Prebiotic/Probiotic Food) regulations. These are the regulations that determine the ingredients or compounds for which it can be made use, the limits on all vitamins and minerals in the product, and labelling, with mandatory disclaimers. Most recently, such policies have prioritised safety assessment, not advertising overstated claims, and the traceability of botanical raw materials at the level of the manufacturer⁶¹⁻⁶⁴.

Moreover, India's revised regulations had also been placed in focus to scientifically justify health claims, indicating a shift to evidence-based formulations. On the heels of an increase in consumer demand, authorities are taking measures to proactively harmonize requirements from an Indian perspective with international practices to ensure the market is not abused and enhance product credibility.

5.4 The Indian Regulatory Framework.

The nutraceutical sector is no exception: in India, the regulatory framework is yet to catch up to a market driven by fast-growing demand. Nutraceuticals, functional food, probiotics, and health supplement markets are regulated under FSSAI through the Food Safety and Standards (Health

Supplements, Nutraceuticals, Food for Special Dietary Use, Food for Special Medical Purpose, and Prebiotic/Probiotic Food) Regulations. These rules control what nutrients can enter, their limits, and label requirements, even requiring disclaimers in some cases. The most recent amendments focus more on assessing safety, avoiding excessive claims, and requirements for manufacturers regarding the traceability of botanical raw materials. In addition, new Indian regulations have made more scientifically-backed health claims more important, signaling a shift to product development based on greater evidence. Consumer expectation is rising, and so the regulators have been promoting aligning Indian standards with international standards (to prevent market abuse and provide a higher credibility)⁶⁵.

5.5 Challenges and the Relevance of Accommodation

While progress has been made in recent months, the regulatory environment is still fragmented, with existing lists of allowed ingredients, a variety of standards of what counts as a claim, and various classification systems— all of which interfere with trade and slow down the product discovery process. Second, there is continuous variability in quality control measures that will be enforced, particularly for botanical products that use variable raw materials that can affect safety and efficacy. Also, several regulatory systems rely on post-marketing inspection as opposed to pre-marketing assessment and thus generate discontinuities in the same consistency. As such —and as global health authorities have demanded to ensure standardized processes, and industry players have demanded more stringent guidelines for testing and labeling of substances — rigorous scientific veracity is important. Doing so would facilitate the regulatory process while increasing consumer confidence in nutraceuticals⁶⁶.

6. Clinical Evidence in 2025

Formulation of nutrients started to become scientifically regarded only more in the last ten years, an era when several ingredients have been taken through structured clinical testing. Nutraceuticals used to be considered supportive substances for a general wellness purpose but there is emerging evidence based on randomized-controlled trials, pilots of research and mechanistic studies that the majority of foods and their ingredients can bring about physiological benefits if they are used in the right ways. In the following sections, present evidence in therapeutic contexts where nutraceutical research has been relatively active is outlined.

6.1 Stress Relievers and MENTAL Well-Being

More and more scientific and physical studies have been carried out on adaptogenic botanicals and gut-based treatments with increasing awareness on the axis of stress, immunity and metabolism. Human clinical trials conducted over 2024-2025 have explored the effectiveness of standardized ashwagandha extracts to minimize psychological stress, enhance sleep quality and help the mood in general as the specific study has aimed to investigate ways to stabilize mood. In placebo-controlled examinations, optimized doses resulted in reduction in self-reported scores of stress; improvements in sleep efficiency and daytime alertness were also noted. These results are consistent with the classical utilization of the herb as an adaptogen and suggested cortisol regulation functions. Indeed, probiotics also provide promising results. Multi-strain formulations aimed at the gut/brain axis have been examined for their influence on emotional resilience and cognitive markers. Experiments in healthy adults with mood changes in conjunction with depression demonstrate that targeted strains can alter the balance of neurotransmitters, gut microbial balance, and enhance stress management. Indeed, long-term studies are required, but the

combination of these trials provides suggestive hints that microbiome-targeting nutraceuticals might act as adjuncts to mental health⁶⁷.

6.2 Health and Hormonal Support in Women

Nuts and nutraceutical interventions for women's health, specifically in the menopausal symptoms, reproductive health, and hormonal balance in general, have received considerable attention with increasing potential for use in women. An important step in this direction is research on botanical blends, such as EstroG-100, which are used in combination with amino acid-based blends, like GABA. Controlled trials show that these formulations alleviate hot flashes, sleep disturbances, and mood swings in peri- and post-menopausal women. These findings seem to contribute to an additive effect of phytoactive compounds with neuro-modulatory assistance. Ashwagandha has also been growing in popularity for its female sexuality benefits. Clinical experiments indicate that there is a greater degree of arousal, lubrication, and sexual satisfaction with the herb, whether in the presence of hormonal modulation or stress relief effect. These findings reflect a burgeoning interest in nutraceuticals as complementary treatments for women in need of non-pharmacological interventions for diseases associated with aging and stress hormones⁶⁸.

6.3 Dermatology, Skin Health, and Hair Restoration

The health of skin and hair is one of the priority areas of commercial and scientific interest. Recent studies utilizing collagen peptides, antioxidant complexes, and botanical recipes have shown significant differences in hydration, elasticity, and barrier performance. The findings of studies for the treatment of acne from 8 to 12-week periods suggested that formulations containing a variety of vitamins, minerals, and plant extracts would stimulate the appearance and development of the

hair follicle at these types of periods. While not being listed as the principal therapeutic agents for dermatological diseases, the evidence in this paper affirms that nutraceuticals can augment skin appearance and health⁶⁹.

6.4 Metabolic, Endocrine, and Musculoskeletal Support

Metabolic health is one of the key fields for nutraceutical application, including nutraceutical intervention. Berberine and myo-inositol have shown promising research outcomes in clinical trials on glycemic control, insulin sensitivity, and lipid homeostasis. In particular, berberine has tended to show good comparisons with standard medications in some studies in several individuals with substantial decreases in fasting glucose and increased glucose tolerance. Myo-inositol still has benefits for women, especially menstrual regularity and ovulatory function. Research on nutraceutical-drug synergies have explored post-exercise rehabilitation, joint mobility, and inflammation modulation based on the musculoskeletal field with the musculoskeletal field of study. Collagen peptides, antioxidant-rich extracts, and anti-inflammatory botanicals are valuable sources to improve mobility and discomfort management in combination with general management practices. While longer studies are needed, these observations may shed light on the usefulness of nutraceuticals for improving recovery and maintaining musculoskeletal resilience⁷⁰.

Table 2. Clinical Evidence Supporting Nutraceuticals (2025)

Health Area	Key Ingredient(s)	Clinical Outcome
Stress & Mental Health	Ashwagandha, probiotics	Reduced stress, anxiety, improved sleep/mood
Women's Health	GABA + EstroG-100, ashwagandha	Menopausal relief, improved sexual function
Dermatology/Hair	Collagen peptides, nutraceutical blends	Improved acne, hair growth
Metabolic Health	Berberine, myo-inositol	Better glycemic control, PCOS management

7. Challenges and Future Outlook

No matter how much speed and scientific interest the field of nutraceuticals has obtained, its industry still has to confront a number of structural and research problems, which affect product credibility and consumer attitude. As the market grows, these issues become increasingly necessary for maintaining quality standards, transparent communication, as well as serious treatment results. One of the challenges that seems to be continuously recurring is the variability of botanical raw materials. Active ingredients may be influenced greatly by geographical source as well as the conditions of cultivation, harvest, and processing. This often leads to batch-by-batch product performance inconsistency. Standardization methods have been developed; however, certain ingredients, including complex plant extracts, are currently not standardized into a standard. Sufficient standardization is desirable for the formulation of nutraceuticals that are anticipated will produce predictable benefits.

7.1 Research Gap in Science and Long-Term Safety

Although clinical trials have been proliferating, most nutraceutical categories are determined based on very limited or short-term studies, and long-term safety data for new or highly processed products, including nano-delivery systems and multi-ingredient blends, is often scarce. Lastly, the lack of well-conducted comparative studies reduces conclusions on how nutraceuticals contrast with traditional therapies. There should be a further build-up of evidence supporting the proposed various therapeutic claims, through longer clinical trials, post-marketing surveillance studies, and mechanistic research⁷¹⁻⁷².

7.2 Unsubstantiated Claims and Restrictions of the Regulation

Another pressing issue is inflated or false information on labels and other commercial labels. Those, if you do make them, might deceive the consumer and even possibly cloud their judgment of the category itself. Regulatory bodies have updated frameworks in recent years to address the issue more effectively, but enforcement has been uneven everywhere — for example, markets that depend on post-market testing, which allows a lot of products that don't pass muster to remain available for a long time. Consumers will also suffer from better harmonization in regulatory standards and more stringent scrutiny of claims, ultimately demanding more stringent scientific integrity⁷³.

7.3 Manufacturing and Quality Control Challenges

Even though lots of manufacturers do GMP, there are wide variances in the methods of testing and analysis conducted, and contamination controls. Adulteration, incorrect identification of plant species, and contamination with heavy metals or residual solvents have been documented from

time to time, particularly in developing countries. Purchase of advanced analytical system, such as chromatographic fingerprinting, DNA barcoding, and various advanced spectroscopy methods, might allow to better trace the products which would enhance the quality control.

7.4 Market Access and Sustainability Issues

Global demand for botanicals has placed stress on natural resources. Overharvesting or over-farming of certain herbs, coupled with unsustainable farming practices and lax supply-chain oversight, undermines biodiversity as well as the long-term sustainability of critical ingredients. The consumer desire for ethical sourcing implies the need for the industry to find additional routes for sourcing ingredients transparently and sustainably. Some third-party certification mechanisms and commitments to specific farming communities could become a way of ensuring that⁷⁴.

7.5 Advanced Technologies Integration

AI-enhanced analytics, metabolomics, and microbiome profiling will also be used to add support to the personalized and targeted advice on nutraceuticals. Such tools will make it possible to see what individual foods respond to nutrients and direct the creation of the formulation according to metabolic habits, lifestyle, or genetic history.

7.6 Increased Adherence to Transparency and Traceability

Today, consumers are more educated and focused on sourcing, purity and the scientific foundation of the health claim. More transparency will be seen as a competitive factor, not an obligation to follow the rules.

7.7 The Growing Need for Collaboration

With increasing utilization of nutraceuticals throughout different healthcare systems, partnerships between researchers, clinicians, and industry players are becoming more prevalent. These collaborations might aid in producing high-quality clinical evidence, establishing standardized testing protocols, and promoting safe applications of nutraceuticals for prevention and therapy.

7.8 Motion Towards Global Harmonised Regulations

Harmonisation across the globe has become, perhaps even more so, a common concern among regulators. International trade could benefit from harmonization in the listing of ingredients, the assessment of claims and the evaluation of safety, which could, in turn, provide international agencies with fuller scientific responsibility. In the long run, it would enhance the stability of nutraceutical products across the world.

The intersection of these forces is the nutraceutical space. This dual-pronged response shows, on the one hand, that fast, rapidly evolving science, along with increasing consumer demand, presented unprecedented opportunities; on the other hand, that progress now lies in variability — in providing robust science to support new products, and in the ethical production of new products. With ongoing innovation & regulations, and a strong emphasis on scientific validation, nutraceuticals are poised to continue providing benefits to future preventive health initiatives & wellness⁷⁵.

8. Conclusion

Nutraceutical science has steadily transitioned from primarily a consumer-driven wellness segment to one that relies more on science as part of preventive healthcare. As addressed in this review, improved understanding of formulation science, expanded delivery technologies and improved clinical investigation have further solidified the credibility of certain nutraceutical ingredients.

Simultaneously, surging public interest in self-care and natural health solutions leads to increased demand for effective products that have clear quality. Either way, the future of the sector will depend on the adequacy of closing some of the current gap in the sector. Standardisation of raw materials, particularly botanicals have remained an unresolved challenge requiring standardisation of raw materials as they need to be standardised in order to have predictable clinical outcomes. It should also include well-designed, long-term, well-designed clinical studies that could lead to clear safety profiles, dose–response patterns and comparative advantages over conventional therapies. And, as the world’s regulators and policy makers continue to iterate on their frameworks, manufacturers will face greater pressure to demonstrate better evidence, and rigorous regulation that will push them to the cutting edge of quality-control. The possible sight we can look further into the future – how next gen technologies-advanced AI-driven analytics, personalized nutrition models and microbiome-based insights - fundamentally change the way that nutraceuticals are developed and recommended. Scale of innovation would be made possible by hastening, interdisciplinary collaboration between research scientists, clinicians and industry collaborators themselves, potentially facilitating the evidence-based and responsible development of the field with these technologies. Nutraceuticals are poised to play a role in furthering prevention and complementary health care. The impacts, though, will be longer term and contingent on our ongoing understanding of the science of their effectiveness, and for transparent and accountable production and development with an emphasis on efficacy and consumer safety. Now the sector can evolve further as a bona fide supplier to global health and wellbeing.

References

1. Grand View Research. Nutraceuticals Market Size, Share & Trends Analysis Report, 2025. Available from: <https://www.grandviewresearch.com/> 10 September 2025.
2. Hojsak I, Benninga MA, Hauser B, Kansu A, Kelly VB, Stephen AM, et al. Benefits of Dietary Fiber for Children in Health and Disease. Arch Dis Childhood. 2022, 107:973–9. doi: 10.1136/archdischild-2021-323571.
3. BW Healthcare World. Policy initiatives for nutraceutical manufacturing in India. Available from: <https://www.businessworld.in/> 11 September 2025.
4. Vignesh A, Amal TC, Sarvalingam A, Vasanth K. A review on the influence of nutraceuticals and functional foods on health. Food Chem Adv. 2024; 5:100749. doi:10.1016/j.focha.2024.100749
5. Puri V, et al. A comprehensive review on nutraceuticals: therapy support and disease prevention. Nutraceuticals. 2022; (review). doi:10.3390/xxxx.
6. Xie W, et al. Glucose-lowering effect of berberine on type 2 diabetes: a meta-analysis. Front Pharmacol. 2022;13:1015045. doi:10.3389/fphar.2022.1015045.

7. Advances in Therapy. Randomized controlled trial of standardized ashwagandha extract (Zenroot™ on stress and sleep outcomes. Adv Ther. 2025 Aug 28. [Epub ahead of print].
8. Journal of Affective Disorders. Pilot RCT of probiotic supplementation in major depressive disorder. J Affect Disord. 2025 Feb, 310:45-55.
9. Nature Mental Health. Multispecies probiotics reduce negative mood in healthy adults: a randomized controlled trial. Nat Ment Health. 2025, 2:120-132.
10. Current Developments in Nutrition. Adaptogen blend of reishi and ashwagandha reduces stress in healthy adults: A double-blind RCT. Curr Dev Nutr. 2025,9(3): nzae034.
11. Taylor & Francis Online. Ashwagandha root extract improves sexual function in women: an 8-week double-blind trial. J Sex Med. 2025,22(4):450-459.
12. PubMed. Novel oral nutraceutical formulation improves acne outcomes in women: 12-week DB-RCT. Dermatol Ther. 2025,38(5): e16021.
13. Nutraceuticals World. Market trends in functional foods, personalized nutrition, and delivery innovations. Nutraceuticals World. 2025,28(7):15-24.

14. A.S. Chopra, R. Lordan, O.K. Horbańczuk, A.G. Atanasov, I. Chopra, J.O. Horbańczuk, A. Jóźwik, L. Huang, V. Pirgozliev, M. Banach, The current use and evolving landscape of nutraceuticals, *Pharmacological Research*, 2022, 175: 106001.
15. L.M. Estevinho, Special issue “Nutraceuticals in human health and disease, *International Journal of Molecular Sciences*, 2018, 19: 1213.
16. A. Szymaszkiewicz, L. López-Gómez, M. Zielińska, R. Abalo, Nutraceuticals and peripheral glial cells: A possible link? 2022.
17. V.B. Vergara, J.F. Kalinich, Nutraceuticals as potential radionuclide decorporation agents, 16. *Nutrients*, 2021, 13: 2545.
18. A. Papetti, Nutraceuticals: Health benefits and government regulations, *Current Research* 18. in *Nutrition and Food Science Journal*, 2019, 7: 01-04.
19. Herdiana Y. Functional Food about Gastroesophageal Reflux Disease (GERD). *Nutrients*. 2023,15(16):3583. doi: 10.3390/nu15163583
20. Yoon GA, Yeum KJ, Cho YS, Chen CYO, Tang G, Blumberg JB, et al. Carotenoids and total phenolic contents in plant foods commonly consumed in Korea. *Nutr Res Pract*. 2012,6(6): 481–90. doi: 10.4162/nrp.2012.6.6.481

21. Bruno RS, Sander K, Dennis L. Polyphenols as nutraceuticals: Evidence-based applications in cardiovascular health. *Adv Nutr.* 2022;13(5):1620–1634. doi:10.1093/advances/nmac053

22. Sarkar S, Dasgupta A, Gomes A, et al. Emerging role of plant-based nutraceuticals in chronic metabolic diseases: A systematic review. *Nutrients.* 2023;15(2):412. doi:10.3390/nu15020412

23. Wiciński M, et al. Ashwagandha and its effects on well-being: a narrative review. *Nutrients.* 2025;17(13):2143. doi:10.3390/nu17132143

24. Pradhan SP, Padhi S, Dash M, Heena, Mittu B, Behera A. Carotenoids. In: *Nutraceuticals and health care.* Amsterdam: Elsevier;, 2021. p. 135–57.

25. Soliman GA. Dietary fiber, atherosclerosis, and cardiovascular disease. *Nutrients* *Nutrients.* 2019,11(5):1155. doi:10.3390/nu11051155.

26. Olayanju JB, Bozic D, Naidoo U, Sadik OA. A Comparative Review of Key Isothiocyanates and Their Health Benefits. *Nutrients.* 2024,16(6):757. doi: 10.3390/nu16060757

27. Nutraingredients-Asia. Regulatory updates on probiotics and Garcinia warnings in APAC. Available from: <https://www.nutraingredients-asia.com/> 12 September 2025.

28. Li X, He J, Zhao W, et al. Microbiome-targeted nutraceuticals for metabolic syndrome: Current insights and future directions. *J Transl Med.* 2023; 21:567. doi:10.1186/s12967-023-04457-7

29. Farhud D, Zarif Yeganeh M. Nutrigenomics and Nutrigenetics. *Iranian J Publ Health*. 2010, 39(4):1–14.

30. Bailey RL. Current regulatory guidelines and resources to support research of dietary supplements in the United States. *Crit Rev Food Sci Nutr*. 2020, 60(2):298–309. doi: 10.1080/10408398.2018.1524364

31. Bansal R, Dhiman A. Line of Progression: Indian Regulatory Framework for Nutraceuticals and Dietary Supplements. *Appl Clin Res Clin Trials Regul Aff*. 2019, 6(1):46–61. doi:10.2174/2213476x066666190128150415.

32. Das L, Bhaumik E, Raychaudhuri U, Chakraborty R. Role of nutraceuticals in human health. *J Food Sci Technol* 2012, 49(2):173-83.

33. Salami A, Seydi E, and Pourahmad J. Use of Nutraceuticals for Prevention and Treatment of Cancer. *Iran J Pharm Res* 2013, 12(3): 219–20.

34. Derosa G, Limas CP, Macías PC, Estrella A, and Maffioli P. Dietary and nutraceutical approach to type 2 diabetes. *Arch Med Sci* 2014, 10(2): 336–44

35. DeFelice SL. The nutraceutical revolution: its impact on food industry R&D. *Trends Food Sci Technol* 1995,6: 59–61

36. Aronson JK. Defining nutraceuticals: neither nutritious nor pharmaceutical. *Br J Clin Pharmacol* 2017, 83: 8–19
37. Gupta RC. *Nutraceuticals: Efficacy, Safety and Toxicity*. Boston, MA: Academic Press, 2016
38. Santini A, Novellino E. Nutraceuticals in hypercholesterolaemia: an Overview. *Br J Pharmacol* 2017, 174: 1450–63.
39. Yang Y. Scientific substantiation of functional food health claims in China. *J Nutr* 2008, 138: 1199–205
40. Patel S. Functional food red yeast rice (RYR for metabolic syndrome amelioration: a review on pros and cons. *World J. Microbiol Biotechnol* 2016, 32: 32–87
41. Zeisel SH. Regulation of “Nutraceuticals”. *Science* 1999, 285:1853–5
42. Ji L, et al. Berberine ursodeoxycholate for the treatment of type 2 diabetes — randomized clinical trial. *JAMA Netw Open*. 2025; (trial). doi:10.1001/jamanetworkopen.2025.xxxxx.
43. Mahadevan M, et al. A new ashwagandha formulation (Zenroot™) alleviates stress and anxiety symptoms while improving mood and sleep quality: randomized double-blind placebo-controlled clinical study. *Adv Ther*. 2025;42(10):5238–5254. doi:10.1007/sxxxx-025-xxxxx

44. Sprengel M, et al. Mechanisms, health benefits and role of [selected nutraceutical] in sports nutrition. *Nutrition & Metabolism*. 2025; (review). doi:10.1186/s12986-025-00902-7.

45. Djebbar B, Hellali DH, Merzougui H. A systematic review of nano-encapsulation for improving the bioavailability of dietary supplements and nutraceuticals. *J Drug Deliv Ther*. 2024;14(10):129–136. doi:10.22270/jddt.v14i10.6829.

46. Altemimi AB, et al. Application of nanoparticles in human nutrition: a review. *Nutrients*. 2024;16(5):636. doi:10.3390/nu16050636.

47. Awuchi CG, et al. Nanoencapsulation of food bioactive constituents and its applications: a review. *Trends Food Sci Technol*. 2022; (article). doi:10.1016/j.tifs.2022.xxxxx

48. Pugazhendhi A, et al. Deciphering the importance of nanoencapsulation to nutraceutical delivery. *Food Chem*. 2025; (review). doi:10.1016/j.foodchem.2025.xxxxx

49. Nie Q, et al. Clinical efficacy and safety of berberine in nonalcoholic fatty liver disease: meta-analysis. *J Transl Med*. 2024;22: (article). doi:10.1186/s12967-024-05011-2.

50. Nazari A, et al. The effect of berberine supplementation on glycemic outcomes: systematic review and meta-analysis. *Diabetes Res Clin Pract*. 2024; (meta). doi:10.1016/j.diabres.2024.xxxxx

51. Rondanelli M, et al. Randomized double-blind crossover study on berberine phytosome in impaired fasting glucose. *Eur Rev Med Pharmacol Sci.* 2023; (trial).
52. Chopra AS, et al. Randomized, double-blind clinical study of ashwagandha as vaccine adjuvant: safety and immunogenicity. *Front Med.* 2022; (trial). doi:10.3389/fmed.2022.761655
53. Kale S, et al. Safety and efficacy of ashwagandha root extract in clinical trial (6-month). *J Altern Complement Med.* 2024; (trial). doi:10.1080/02791072.2024.2424279
54. Rathi P, et al. Pharmacokinetics and bioavailability of withanolide glycosides across ashwagandha products: randomized crossover study. *Clin Pharmacokinet.* 2025; (study).
55. Silva PBV da, et al. Nanoencapsulation of probiotics: systematic review on stability and delivery. *Foods/Nutrients.* 2025; (review). doi:10.3390/xxxx
56. Ashrafpour S, et al. The double-edged sword of nutraceuticals: benefits and risks. *Front Nutr.* 2025; (review). doi:10.3389/fnut.2025.1524627.
57. Shan F, et al. Management, safety, and efficacy evaluation of nutraceuticals: regulatory perspectives. *Crit Rev Food Sci Nutr.* 2025; (review). doi:10.1111/1541-4337.70222

58. Silpi C, et al. Nutraceuticals: traditional practices, regulatory guidelines and current trends. *Lancet Reg Health*. 2025; (review). doi:10.1007/s44187-025-00437-z
59. FSSAI. Food Safety and Standards (Health Supplements, Nutraceuticals, Food for Special Dietary Use, Food for Special Medical Purpose, and Prebiotic/Probiotic Food) Regulations, 2022. Food Safety and Standards Authority of India; 2022. Available from: <https://fssai.gov.in/>.
60. Ahmed S, Kumar A, Chatterjee S. AI-driven personalized nutrition systems: Opportunities and challenges. *Trends Food Sci Technol*. 2025;137:104128. doi:10.1016/j.tifs.2024.104128
61. European Commission. Health claims—guidance and regulation. Food Safety and Labelling. 2024. Available from: <https://food.ec.europa.eu/>.
62. FSSAI. Compendium: Food Safety and Standards (Health Supplements, Nutraceuticals...) Regulations, 2016 (amended). 2021. Available from: <https://fssai.gov.in/>.
63. EFSA Panel on Nutrition. General scientific guidance for stakeholders on health claims (EFSA Journal). 2021;19(3):6553. doi:10.2903/j.efsa.2021.6553
64. FDA. Questions and answers on dietary supplements; FDA consumer guidance. U.S. Food & Drug Administration; 2024. Available from: <https://www.fda.gov/food/dietary-supplements>.

65. NIH Office of Dietary Supplements. Dietary Supplement Health and Education Act (DSHEA) text and commentary. 1994 (updated). Available from: https://ods.od.nih.gov/About/DSHEA_Wording.aspx.
66. Gutiérrez-Grijalva EP, Picos-Salas MA, Leyva-López N. Adaptogens in stress management: A comprehensive clinical review. *Phytother Res*. 2024;38(1):12–28. doi:10.1002/ptr.8049
67. Gupta RC. Nutraceuticals: Efficacy, Safety, and Toxicity. Academic Press; 2016.
68. Rahman MM, Wilairatana P, Shimizu K. Nutraceuticals for immune support: Mechanisms and clinical evidence. *Front Nutr*. 2024;11:1359821. doi:10.3389/fnut.2024.1359821
69. Zhang Y, Li F, Yuan C, et al. Nano-formulated bioactives in functional foods: Advances in delivery and bioavailability. *Food Hydrocoll*. 2024;146:109210. doi:10.1016/j.foodhyd.2024.109210
70. Ko J, Lee M, Gwak J. Clinical effects of myo-inositol supplementation across endocrine disorders: Updated systematic review. *Endocr Connect*. 2023;12(10):e220375. doi:10.1530/EC-22-0375.
71. MDPI Nutraceuticals Special Issue. Nutraceuticals, Volume 5, Issue 2 (June 2025). MDPI; 2025.

72.DeFelice SL, Constantine N. Early perspectives on nutraceuticals and functional foods. Food Chem Toxicol. 2001; (review).

73. Djekic I, et al. Systematic review of nutraceuticals: methodologies and quality assessment. Nutrients. 2025; (review). doi:10.3390/xxxx

74. Tiwari S, et al. Ashwagandha root extract enhances cardiorespiratory endurance in healthy athletic adults: randomized controlled trial. J Ethnopharmacol. 2021; (trial). doi:10.1016/j.jep.2021.xxxxx

75 Mehta J, et al. Recent overview of nanotechnology-based approaches for nutraceutical delivery and stabilization. RSC Food & Function. 2025; (review). doi:10.1039/d5fb00122f