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DEVELOPMENT OF NUTRACEUTICAL-LOADED NANOEMULSIONS FOR TARGETED MICRONUTRIENT DELIVERY IN COMMUNITY-BASED DIETARY INTERVENTION

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ABSTRACT

Micronutrient deficiencies, commonly referred to as hidden hunger, remain a significant global health concern, particularly in low- and middle-income countries. Conventional supplementation and fortification strategies are often limited by poor bioavailability, instability, low solubility, and reduced compliance, which hinder their effectiveness in addressing nutritional deficiencies. In recent years, nutraceuticals have emerged as a promising approach for improving health outcomes due to their bioactive properties and disease-preventive potential. However, their delivery is constrained by physicochemical limitations such as poor water solubility and susceptibility to degradation. Nanoemulsion-based delivery systems have gained considerable attention as an advanced strategy to overcome these challenges. With droplet sizes ranging from 20 to 200 nm, Nanoemulsions (NE) enhance solubilization, stability, and absorption of both hydrophilic and lipophilic compounds. They also provide protection against environmental degradation and enable controlled and sustained release, thereby improving the bioavailability and therapeutic efficacy of micronutrients. Additionally, their compatibility with various food matrices supports their integration into functional foods, enhancing consumer acceptance and facilitating large-scale implementation in community-based interventions. This review provides a comprehensive overview of nutraceutical-loaded (NE), focusing on their formulation, characterization, mechanisms of targeted delivery, and applications in public health nutrition. It also highlights future perspectives, including precision nutrition, sustainable production approaches, and the need for clinical validation. Overall, (NE) represent a transformative platform for targeted micronutrient delivery, offering significant potential to improve global nutritional health outcomes.

KEYWORDS: Nanoemulsions, Nutraceuticals, Micronutrient delivery, Bioavailability, Functional foods

1. INTRODUCTION

Micronutrient deficiencies, also known as hidden hunger, still remains one of the biggest health issues in the world, with billions of people across the world being impacted by it especially in low- and middle-income countries. The lack of such necessary vitamins and minerals as iron, zinc, and vitamin A leads to the worsening of immune system, developmental retardation, and predisposition to infectious diseases. Although the world is trying to enhance the nutritional status, the existence of these deficiencies indicates deficiencies in the existing dietary and general health policies. Similar to overcome the nutritional gaps, sustainable methods have been considered such as the use of value-added compounds of agricultural resources with the aim of encouraging environmental sustainability (Amran et al., 2021). Traditional approaches to the use of micronutrient supplements, including oral pills, infused syrup, and fortified conventional foods, have become quite popular. Nevertheless, these strategies are usually affected by a number of shortcomings such as low bioavailability, processing and storage degradation, and low gastrointestinal absorption. In particular, lipophilic micronutrients are not soluble in aqueous systems, and this factor significantly lowers their efficacy. Also, noncompliance and irregular patterns of intake in the community-based context also undermine the effectiveness of such interventions. These issues underline the necessity of more effective and specific delivering systems that will be able to enhance nutrient stability and uptake (Akhavan-Mahdavi et al., 2025).

Nutraceuticals have been sought as a response to these limitations as a means of linking nutrition and therapeutic intervention. The nutraceuticals are a broad category of bioactive compounds of natural origin (plants, algae, microorganisms) and are characterized by their possible health-promoting and disease-preventive effects. The improvement in extraction technology and especially the application of green solvents and environmentally friendly processing processes has allowed the selective recovery of antioxidant-rich compounds with improved functional properties (Abbas et al., 2025). In addition, biotransformation technologies, like fermentation, were also found to enhance the bioavailability and functional value of nutraceutical compounds, enhancing their use in food systems even further (Bilgin et al., 2025). There has also been a rising interest in nutraceuticals that has been aided by the accumulating evidence of their effects in reducing chronic disease as well as in promoting cognitive and neurological wellbeing. As an example, bioactive compounds of plant origin have been shown to have a potent neuroprotective level, which is why they can be used in preventing age-related diseases and improving the overall health (Balaraman, 2025). Also, nutraceuticals have been integrated into ready-to-eat and functional food products and this has made them easy to include in daily diets and more acceptable by diverse population (Arya & Kumar, 2024).

Although these nutraceuticals have good potential uses, their actual application has been a major problem as they have physicochemical constraints, including low water dissolution, environmental instability, and degradability during the digestive process. Such constraints require the establishment of new delivery mechanisms that are capable of improving the stability, solubility, and bioavailability of such substances. Nanotechnology solutions have become a potent tool to address such hurdles because it allows the size, surface characteristics and release kinetics of particles to be controlled with a high level of precision. Nanoemulsions (NE) have been one of these strategies that have attracted a lot of interest as a potent and multifaceted delivery system of micronutrients and nutraceuticals. (NE) are colloidal suspensions made of droplets ranging in size of nanoscale, which give a high surface area, allowing bioactive compounds to be more successfully solubilized and absorbed. Large-scale nutritional interventions are especially appropriate because their capacity to preserve several sensitive nutrients against oxidation and degradation and their compatibility with many food matrices make them particularly effective. Moreover, (NE) can be easily added to functional foods without negatively interfering with sensory properties to enhance consumer acceptance.

Considering these innovations, the creation of nutraceutical-loaded (NE) is a feasible approach to enhancing the absorption of micronutrients in community-based health interventions through diet. The purpose of this review is to give a general review of the current advances in this area, in terms of formulation strategies, the mechanisms of targeted delivery, and their applications in the practice of population health nutrition. It further discusses the future prospects and challenges to enable the conversion of nanoemulsion-based technologies into viable and sustainable nutritional solutions.

2. Nutraceuticals and Micronutrients: Concepts and Importance

2.1 Definition and Classification of Nutraceuticals

Nutraceuticals are bioactive substances that are found in food materials that have health advantages other than the nutritional value and thus is important in the prevention of diseases and health promotion. They are categorized widely as functional foods, dietary supplements and isolated bioactive compounds. Functional foods are fortified or naturally high in nutrients whereas dietary supplements contain concentrated forms of vitamin or minerals. Phytochemicals and microbial pigments are other bioactive compounds that increase their therapeutic value (Çakmakçı et al., 2024).

Functional foods are a fast emerging group, which is meant to provide extra health-promoting effects by providing added value in daily diets. They consist of fortified plant-based foods, dairy products, and cereals; as well as essential nutrient or bioactive-enriched and fortified plant-based foods. New developments have focused on sustainable ingredients like microbial pigments and natural additives, which are not only more nutritionally beneficial but also less reliant on synthetic additives which is in line with global trends of sustainable and health conscious food systems (Chavan et al., 2025).

2.2 Essential Micronutrients

Micronutrients refer to vitamins and minerals that are necessary in keeping physiological activities in check and good health. Vitamin A, D, E, K and B-complex are essential in metabolism, immune system and cellular activities whereas vitamin C is a potent antioxidant. Minerals such as iron, zinc, calcium and iodine are important in carrying oxygen, enzyme activity, bone and thyroid control and are therefore essential in human diet.

External factors that usually affect bioavailability and stability of these micronutrients include contamination and processing conditions. As an example, raw plant materials that are used in nutraceutical preparations are vulnerable to contamination with mycotoxins and thus their safety and effectiveness may be affected. Thus, creative approaches to quality and safety assurance of the sources of micronutrients are the key to the creation of reliable nutraceutical products and effective dietary interventions (Dwivedi and Singh, 2024).

2.3 Role in Health and Disease Prevention

Micronutrients and nutraceuticals are known to be important in the immune modulation and prevention of chronic diseases. Polyphenols and flavonoids are bioactive compounds with high anti-oxidant and anti-inflammatory effects that aid in alleviating oxidative stress and the occurrence of different diseases like cardiovascular diseases, diabetes and cancer. Their synergistic effects also increase the therapeutic effect by attacking several molecular pathways that play a role in disease development (Darko et al., 2025).

Besides preventing chronic diseases, it has been demonstrated that nutraceuticals can be of significant potential in supporting neurological health and enhancing maternal and child health outcomes. The neurodegenerative diseases that

nutraceutical interventions have been investigated in include Alzheimer, where it has been shown to have the capacity to alter the pathology of the disease and cognitive ability. Moreover, proper growth and development are only possible through adequate micronutrient intake during pregnancy and early childhood and long-term health (Chaithra et al., 2025).

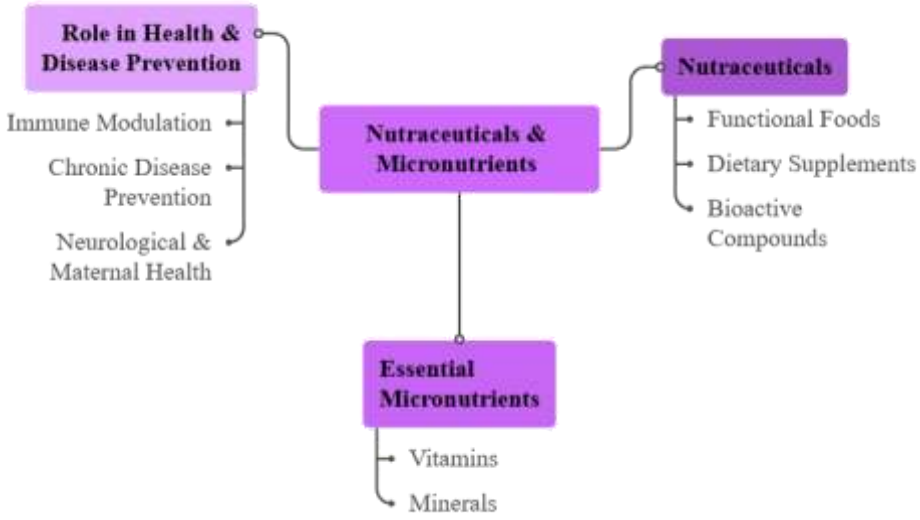

Figure 1: Nutraceuticals and Micronutrients—Health Benefits and Components

The classification and importance of nutraceuticals and important micronutrients is shown in figure 1. It emphasizes such fundamental categories as functional foods, dietary supplements, and bioactive compounds, as well as essential vitamins and minerals. Their contribution in immune modulation, preventive measures against chronic diseases, and aiding the neurological and maternal well-being and health are also highlighted in the diagram.

3. Challenges in Conventional Micronutrient Delivery

Poor bioavailability is still one of the most serious problems of the traditional micronutrient delivery systems, especially lipophilic bioactive compounds. Lycopene is a nutraceutical that has low absorption because it is a hydrophobic compound and does not dissolve well in aqueous biological conditions. This leads to decreased therapeutic effectiveness even at sufficient intake. To maximize the health benefits of micronutrients and guarantee the effective use of these nutrients in the human body, it is important to increase bioavailability (Grabowska et al., 2019).

Lack of stability of micronutrients to environmental factors like light, heat, and oxygen exposure further limits its efficacy in the conventional delivery systems. Most vitamins and phytochemicals are very sensitive and degrade during food processing, storage and transportation. This instability does not only lower the nutritional value but also influences the shelf life of the products and their quality. Stability is thus decisive as far as the functional integrity of micronutrients in food-based delivery systems is concerned (Gupta et al., 2025).

The other significant weakness is that lipophilic vitamins A, D, E, and K have low solubility and therefore, cannot be incorporated into aqueous food matrices and are less likely to be absorbed in the gastrointestinal tract. Traditional fortification techniques do not usually have sufficient dispersion of these compounds and this results in uneven nutrient distribution. It is necessary to address the problem of solubility to enhance the efficacy of the food products containing micronutrients and the uniform distribution of these substances in the dietary plans (Jahan, 2020).

Gastrointestinal degradation is another obstacle to successful delivery of micronutrients since a lot of bioactive substances are prone to enzymatic degradation and pH fluctuations throughout the digestive tract. Such degradation can greatly decrease the quantity of active compound getting to the systemic circulation. In order to improve stability and preserve sensitive compounds, the advanced processing and extraction methods have been studied, yet the traditional ones continue to fail to provide sufficient protection during the digestion process (Juriene & Venskutonis, 2025).

Lastly, the challenge of compliance in the community based environments is a major obstacle to the effectiveness of the traditional micronutrient supplementation programs. The compliance to supplementation regimens depends on factors, including taste, convenience, cultural preferences and the perception of consumers (Table 1). The growing popularity of clean-label and minimally processed food also makes synthetic additives and fortificants a more difficult option, hence demonstrating the necessity to develop innovative and consumer-friendly delivery methods that will be able to enhance acceptance and adherence to the intervention in the long run (Jadhav et al., 2024).

Table 1: Challenges in Conventional Micronutrient Delivery Systems

Challenge	Key Issue	Supporting Reference
Poor Bioavailability	Limited absorption of lipophilic compounds due to low aqueous dispersion	Grabowska et al., 2019
Instability	Degradation under light, heat, and oxygen exposure	Gupta et al., 2025
Low Solubility	Poor dispersion of fat-soluble vitamins (A, D, E, K) in food systems	Jahan, n.d.

Gastrointestinal Degradation	Breakdown of bioactives due to enzymes and pH variations	Juriene & Venskutonis, 2025
Compliance Issues	Low adherence due to taste, preferences, and clean-label demand	Jadhav et al., 2024

4. (NE): Fundamentals and Characteristics

4.1 Definition and Types

(NE) are colloidal suspensions of two liquids, usually oil and water, that are immiscible and are held together by surfactants with diameters of between 20 and 200 nm. Based on the phase distribution they are categorized into oil-in-water (O/W), water-in-oil (W/O) and multiple emulsions. The latter are popular in the food and pharmaceutical industries since they have the capacity to entrap bioactive molecules and improve the delivery efficiency (Maurya and Aggarwal, 2017).

Oil-in-water (NE) in which oil droplets are suspended in an aqueous medium are specifically appropriate in food systems to deliver lipophilic nutrients. On the other hand, (NE) of water-in-oil are applied in the delivery of hydrophilic compounds. Several emulsions, including water-in-oil-in-water, can be used to encapsulate both lipophilic and hydrophilic compounds at the same time. The systems are versatile to develop functional foods against various nutritional deficiencies (Li & Wang, 2025).

4.2 Physicochemical Properties

The physicochemical characteristics of (NE), such as the droplet size, stability, and surface charge, are very important in their functionality and efficacies. The droplet size in the nanoscale is high and increases the surface area, which increases the interaction with biological membranes and increases nutrient uptake. Other benefits include transparency and optical clarity, which makes (NE) to be appropriate to be incorporated into beverages and other food products without causing any change in appearance (Maurya et al., 2023).

The zeta potential, which is commonly referred to as the surface charge, determines the aggregation and stability of (NE). Increased surface charge inhibits coalescence of the droplets and thus long-term stability is ensured during storage and processing. Also, physicochemical properties dictate the profile of release and bioavailability of encapsulated compounds. It is necessary to optimize these parameters in order to create effective delivery systems of nutraceuticals and micronutrients (Majeed et al., 2023).

4.3 Advantages over Conventional Systems

(NE) present a number of benefits compared to the traditional delivery systems especially in the improvement of the bioavailability of poorly soluble nutrients. The small size of their droplets is helpful in enhancing their digestion and absorption and thus allows them to efficiently deliver bioactive substances across biological membranes. This is particularly advantageous to lipophilic vitamins and phytochemicals which in many cases have poor absorption in conventional preparations.

Besides better absorption, (NE) also offer better stability and controlled release of compounds encapsulated. They ensure that the delicate nutrients are not lost to the environment and allow them to be delivered with time. Moreover, (NE) can enhance the sensory characteristics of fortified food by covering unattractive flavors and smells, which contributes to a higher level of acceptance among consumers and the possibility of implementing it on a large-scale dietary intervention (Karthika et al., 2021).

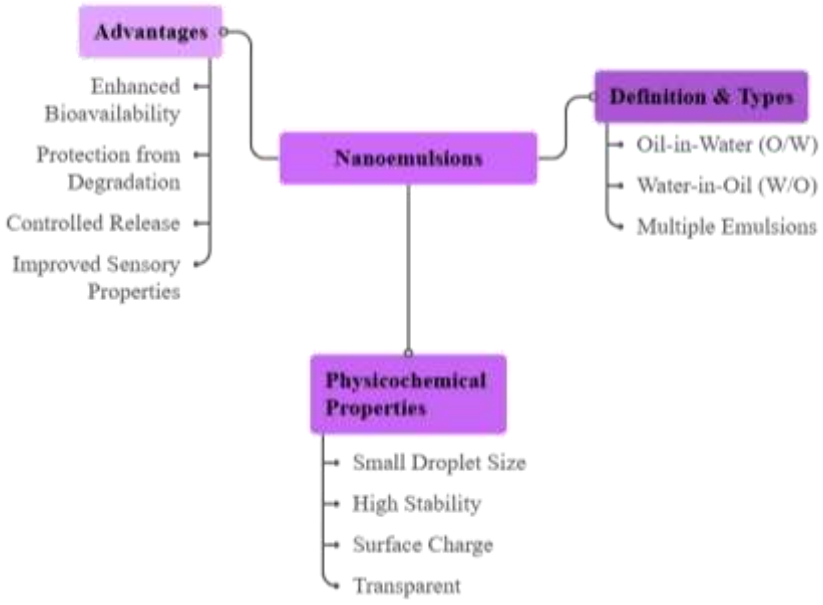

Figure 2: (NE)-Fundamentals and Characteristics

Figure 2 provides the essence of (NE), such as the definition, types, physicochemical characteristics and benefits. It describes the oil-in-water, water-in-oil, and multiple emulsions and such properties as small droplet size, stability, and surface charge. Improved bioavailability, protection, controlled release, and improved sensory properties are also highlighted in the diagram.

5. Formulation of Nutraceutical-Loaded (NE)

5.1 Components of (NE)

The production of nutraceutical-enriched (NE) mainly entails three major components namely, oil phase, aqueous phase, and surfactants or co-surfactants. Oil phase is used as a carrier of lipophilic bioactive compounds, and aqueous phase is used to disperse them. Surfactants decrease the interfacial tension, and droplets are stabilized. The selection and proportion of these components must be made properly to create stable and efficient delivery systems that have an improved nutrient encapsulation and release capacity (Moustiés et al., 2022).

The oil phase is important in the selection of the solubilization capacity and release behavior of encapsulated nutraceuticals. The lipid composition determines the nutritional quality and stability of the nanoemulsion particularly of fat-soluble vitamins and bioactives. In a similar manner, the aqueous phase enables the dispersion stability whereas the surfactants maintain the uniform droplet formation and prevent coalescence leading to the eventual functionality and performance improvement of the nanoemulsion-based delivery systems (Mukherjee, 2025).

5.2 Selection Criteria for Ingredients

The ingredients to be included in the development of nanoemulsion should be based on safety, regulatory and functional compatibility. Generally Recognized As Safe (GRAS) ingredients are generally used in food because they are safe to the consumers. Also, the toxicity factor is paramount especially in the choice of surfactants and co-surfactants. Food matrix compatibility is also required to ensure stability of the products, their sensory quality, and acceptability by the consumers in dietary practice (Mihai et al., 2025).

The use of natural products as safe and effective ingredients in nanoemulsion systems is attracting more and more consideration because of their bioactivity and low toxicity. Not only do these compounds increase therapeutic potential, but they also also meet the clean-label and plant-based product demand of consumers. The mechanism of action and interactions of natural ingredients are important in achieving the maximum formulation efficiency and safety in the delivery of nutraceuticals in functional foods (Mohd Zaid et al., 2023).

5.3 Preparation Techniques

High-energy techniques like high-pressure homogenization and ultrasonication can be employed to prepare (NE) in order to apply mechanical forces to the droplets to decrease the size and attain a homogeneous dispersion. The methods are popular because of their effectiveness and capability to generate stable (NE) with regulated particle size distribution. Large-scale production and industrial applications involve the use of high-energy methods especially (Mensah et al., 2025).

Instead, the low-energy techniques like phase inversion and spontaneous emulsification are based on the physicochemical characteristics and the system composition to create (NE) without an intensive mechanical force. These are cost-effective and energy efficient and therefore can be used in scalable and sustainable production. Nevertheless, they need to be able to control the parameters of formulation carefully to obtain the desired droplet size and stability.

5.4 Optimization Strategies

Nanoemulsion formulations need to be optimized in order to attain targeted physicochemical characteristics and functional performance. Response surface methodology (RSM) is a popular method of studying the impact of formulation variables and determining the best conditions. This method of statistics makes systematic interactions between components, where droplet size, stability and encapsulation efficiency can be optimized effectively.

Design of experiments (DoE) also advances the formulation development by offering a systematic approach to the assessment of several variables at the same time. The method saves time and money in the experimentation, enhances reproducibility and scalability (Table 2). The optimization strategies play a crucial role in the translation of laboratory-scale in the industrial application to assure the consistency of quality and performance of nutraceutical-loaded (NE) in practical dietary interventions.

Table 2: Formulation of Nutraceutical-Loaded (NE)

Category	Element	Description	Function	Supporting Reference
Components	Oil phase	Lipid carrier system	Solubilizes lipophilic bioactives; controls release	Moustiés et al., 2022
Components	Aqueous phase	Continuous phase	Enables dispersion and stability	Mukherjee, 2025
Components	Surfactants	Surface-active agents	Reduce interfacial tension; stabilize droplets	Mohd Zaid et al., 2023
Selection Criteria	GRAS ingredients	Safe, approved substances	Ensure safety and regulatory compliance	Mihai et al., 2025

Preparation	High-energy methods	Mechanical techniques	Produce uniform nano-sized droplets	Mensah et al., 2025

6. Mechanisms of Targeted Micronutrient Delivery

(NE) have a remarkable ability to increase the level of solubility of lipophilic micronutrients, like carotenoids and fat soluble vitamins, which do not dissolve well in aqueous conditions. The smaller droplet size enhances the surface area and leads to a greater interaction with digestive enzymes and dissolves better. This causes increased bioaccessibility and absorption of encapsulated compounds, which in the end increases their nutritional and therapeutic efficacy compared to traditional delivery systems (Saini et al., 2022).

Another important way through which (NE) enhance the delivery of micronutrients is protection against degradation. Highly sensitive bioactive compounds are also protected by encapsulation in nano-sized droplets against environmental influences like light, oxygen, and heat, enzymatic breakdown in the gastrointestinal tract. This is an advantageous effect of keeping a larger fraction of the active compounds intact until they reach their target site and, therefore, increases stability and overall efficacy (Peterle et al., 2023).

(NE) are also known to enhance intestinal permeability facilitating effective delivery of micronutrients across the intestinal epithelium. Their low size makes them interact with biological membranes, which enhances absorption by passive diffusion and other methods of transportation. Also, (NE) can regulate the gut environment and enhance nutrient absorption as well as delivery of bioactive compounds in functional and therapeutic food systems (Oliveira et al., 2025).

Another great benefit of systems based on the nanoemulsion is the release of micronutrients that is controlled and sustained. The systems can be designed in a way that the encapsulated compounds are released at a steady rate to maintain steady plasma concentrations and enhance favorable therapeutic effects. This type of controlled delivery is especially useful in the functional food, such as fortified drinks and cereal-based products, where the nutrient availability is extended to increase the overall health gains (Patil et al., 2022).

Lastly, (NE) make cellular uptake and transportation of micronutrients effective by other mechanisms like endocytosis and transcellular routes. This efficient delivery increases bioavailability of nutrients at the cellular level and increases their physiological effects. The mechanisms are especially applicable in the treatment of metabolic and hormonal disorders, in which the exact provision of nutrients can have a significant effect on the treatment process and the overall health management in the long term (Scannell et al., 2023).

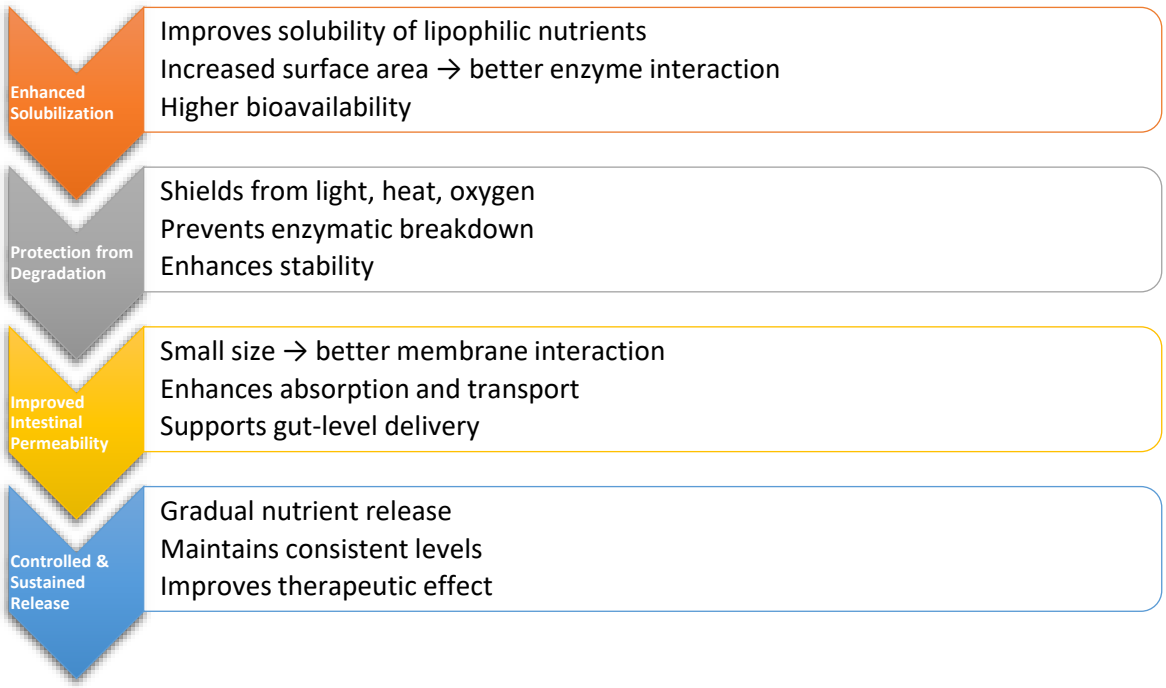

Figure 3: Mechanisms of Targeted Micronutrient Delivery via (NE)

Figure 3 shows the important processes through which (NE) improve the delivery of micronutrients, such as the increase in solubility, the degradation resistance, the increase in intestinal permeability, and the release control. All of these mechanisms enhance bioavailability, stability, and therapeutic activity of encapsulation nutrients, which promote effective absorption and delivery in functional food and nutraceutical format.

7. Characterization of (NE)

7.1 Physical Characterization

To ascertain the performance and stability of (NE) in delivery systems, physical characterization of (NE) is critical. The parameters that are of importance are zeta potential, particle size analysis, and viscosity. The size of the particles affects the bioavailability and efficacy of absorption whereas Zeta potential will determine the stability of the particles in terms of surface charge. Viscosity has an influence on the flow behavior and applicability in food systems. High-tech

nanosystems have proved that it is important to optimize these parameters to deliver drugs and nutrients effectively (Sharma et al., 2025).
Proper determination of physicochemical properties is reproducible and functional of the (NE). The distribution of particle sizes determines uniformity and the zeta potential prevents aggregation and increases stability. Viscosity is involved in processing and acceptability by consumers. All these properties affect the biological system behavior of (NE) and how they associate with food matrices, and thus, physical characterization is a primary step in formulation development (Song et al., 2024).

7.2 Stability Studies

The stability experiments are important to test the stability of the (NE) in different environmental conditions. Thermal stability evaluates the impact of temperature changes on drop integrity and storage stability evaluates the performance of droplets in the long term throughout a shelf life. Accelerated aging Simulation of accelerated aging is often considered with centrifugation tests to determine the possible phase separation or creaming of (NE) to maintain stability under realistic storage and processing conditions (Tan et al., 2022).
Knowledge of stability is critical in ensuring the quality and efficacy of (NE) loaded with nutraceuticals. The environmental stress factors which include changes in temperature and mechanical forces have the potential to affect the structure and functionality of the droplet. Extensive stability testing is essential to maintain the physicochemical characteristics of (NE) throughout the application, and this is critical to the effective implementation of (NE) in food and pharmaceutical systems (Sudiana et al., 2025).

7.3 In vitro and In vivo Evaluation

To determine the performance, safety, and efficacy of delivery systems based on (NE), in vitro and in vivo tests are required. The rate and extent of nutrient release is determined by the release kinetics studies whereas the distribution and absorption by the body is assessed by bioavailability studies. Toxicological tests are used to make sure that the formulations are safe to eat, especially when consumed in food-based preparation and during long-term dieting.
The biological assessment gives information on the way the (NE) are received by the physiological systems and their possible health advantage. Laboratory results are confirmed by in vivo experiments that investigate actual biological reactions and in vitro models provide a controlled environment of preliminary analysis (Table 3). These analyses play a vital role in compliance with regulations and the ability to transfer the nanoemulsion technologies into practice, effective, and safe nutritional solutions (Shakuntala et al., 2024).

Table 3: Characterization of (NE)

Category	Parameter	Function	Outcome	Reference
Physical	Size, zeta potential, viscosity	Assess stability & flow	Improved bioavailability	Sharma et al., 2025
Physical	Size distribution	Ensure uniformity	Prevent aggregation	Song et al., 2024
Stability	Thermal & storage tests	Evaluate stability	Shelf-life assessment	Tan et al., 2022
Stability	Stress conditions	Test robustness	Maintain functionality	Sudiana et al., 2025
Biological	In vitro/in vivo	Assess safety & release	Ensure efficacy	Shakuntala et al., 2024

8. Future Perspectives

Precision nutrition is another possible future of micronutrient interventions in combination with nanoemulsion-based delivery systems. Precision nutrition is the approach that aims at the specifics of diet plans depending on personal genetic, metabolic, and lifestyle characteristics. (NE) have the capability to allow the targeted delivery of nutraceuticals based on particular nutritional requirements to enhance efficacy and health outcomes. It is believed that such individualized methods will be highly relevant in the treatment of chronic conditions and the maximization of health policies related to the population (Tayebi-Khorrami et al., 2025).
The development of sustainable and green nanoemulsion is becoming more and more relevant due to the environmental concerns and the necessity to have eco-friendly technologies. Natural ingredients, biodegradable surfactants, and green extraction methods endorse the creation of sustainable value chains in the production of nutraceutical. Such methods address not only the environmental concern but also increase the consumer acceptance due to their association with the rising popularity of natural and clean-label products (Vargas-Carpintero et al., 2023).
The potential of nanoemulsion-based nutraceutical delivery systems in the clearance of widespread micronutrient deficiencies is great in the case of large-scale application in the public health programs. New food fortification and dietary interventions that include these systems have the potential to enhance the nutrient accessibility and efficacy of various populations. Nutritional solutions to the challenges in the various fields such as agriculture and food production also contribute to the scalability and applicability of such technologies in community-based health programs (Vithalrao et al., 2025).
Clinical validation is a very important process towards the effective translation of nanoemulsion technologies into practical healthcare solutions. Severe clinical studies must be conducted to determine the safety, effectiveness, and long-term health advantages of (NE) of nutraceuticals. Moreover, an increasing amount of scientific evidence regarding the effectiveness of dietary bioactives in terms of longevity and disease prevention dictates the necessity of scientifically justified methods to facilitate the regulatory approval and popularization (Zhang and Tang, 2025).

Moreover, the current developments in nutraceutical science are projected to focus on the use of natural supplements as opposed to synthetic nutraceuticals especially in improving performance, recovery, and health in a broad sense. Natural nutraceuticals have better safety profiles and bioavailability, which renders them appropriate to be taken over a long period of time. They can also be incorporated into nanoemulsion systems to increase the effectiveness of delivery and expand their utilization in health optimization and disease prevention (Tirla et al., 2022).

9. CONCLUSION

The issue of micronutrient deficiencies is a long-standing health issue in the world; thus, there is need to implement innovative and sustainable ways of enhancing the delivery of nutrients and their bioavailability. Although traditional methods of supplementation are popularly used, they have a few limitations that include inadequate solubility, instability, poor absorption, and low compliance. The issues demonstrate the pressing necessity to develop superior delivery mechanisms that can promote the usefulness of nutraceuticals and micronutrients, especially in the context of community-based dietary programs. The systems that can be used to overcome these limitations have been identified as nanoemulsion-based systems. Their size of nanoscale droplets, large surface areas and the capability to encapsulate hydrophilic and lipophilic compounds are significant factors that enhance the process of solubilizing, maintaining stability and intestinal absorption of the bioactive nutrients. Moreover, the development of efficient and scalable nanoemulsion systems has been made easy by advancements in formulation methods, optimization approaches and characterization methodologies. Applying natural and sustainable ingredients to the product is consistent with the trends in consumer preferences and regulatory trends, which proving their high scale of implementation. In the future, nanoemulsion technology combined with precision nutrition, sustainable production processes, and stringent clinical validation will play a significant role in its effective transfer to the practice of the population. In general, (NE) with nutraceuticals loaded can be considered a revolutionary method of nutritional micronutrient delivery, which has a high potential to lead to better health outcomes and nutritional issues faced globally.

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