RESEARCH PAPER

Lipid And Polymeric Nanocarriers For Controlled Release Of Nutritional Bioactive Molecules

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Abstract
The review provides a comprehensive overview of lipid and polymeric nanocarriers as advanced delivery systems for the controlled release of nutritional bioactive molecules. Bioactive compounds such as vitamins, polyphenols, carotenoids, and omega-3 fatty acids offer significant health benefits; however, their practical application is often limited by poor solubility, instability, and low bioavailability. Nanocarrier-based systems have emerged as effective solutions to overcome these challenges by enhancing encapsulation efficiency, protecting bioactives from degradation, and enabling controlled and targeted release. Lipid-based nanocarriers, including solid lipid nanoparticles, nanostructured lipid carriers, liposomes, and nanoemulsions, provide excellent biocompatibility and are particularly suitable for lipophilic compounds. In contrast, polymeric nanocarriers offer tunable release kinetics and structural versatility, allowing precise control over delivery profiles. This review further examines key factors influencing controlled release, such as particle size, surface charge, carrier composition, and environmental conditions. Additionally, recent advancements, including stimuli-responsive systems, hybrid nanocarriers, and artificial intelligence-driven formulation design, are discussed. Despite their potential, challenges related to scalability, safety, regulatory approval, and integration into food systems remain. Overall, nanocarrier technologies represent a promising approach for improving the functionality and efficacy of bioactive compounds, paving the way for next-generation functional foods and nutraceuticals.
Keywords: Nanocarriers, Controlled release, Nutritional bioactives, Lipid nanoparticles, Polymeric nanoparticles
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1. Introduction

The growing emphasis on preventive healthcare within the international society has heightened the attention on the functional foods and the nutraceuticals since it is perceived to have the capacity to enhance health and reduce the prevalence of the chronic ailments [1]. They are fortified with bioactive compounds like vitamins, polyphenols, carotenoids and essential fatty acids which have physiological effects that go beyond mere nutrition [2]. Nutraceuticals, found at the border between food and medicine also provide more therapeutically-relevant forms of such bioactives in concentrated form and constitute a shift to diet-based health interventions and sustainable nutrition approaches [3]. However, their potentials are good and the difficulty lies mainly in the fact that these compounds are rather unstable and inefficient in natural physicochemical processes in terms of delivery.

The main dilemma of the application of nutritional bioactive molecules is their low solubility, poor stability, and low bioavailability. Many bioactives and lipophilics are insoluble in aqueous solution, so it decreases their incorporation into the food system and their uptake in the gastrointestinal tract [4]. Besides, the compounds are highly susceptible to the destruction due to the environmental factors such as heat, light, oxygen, and pH variation during processing, storage and digestion [5]. There are also other barriers like enzymatic activity and the difference in pH levels that can also occur in the gastro intestinal tract and can result in a drastic reduction in the percentage of bioactives that do enter the systemic circulation [6]. These constraints, therefore, require the formulation of novel delivery methods to maintain bioactive activity.

To that extent, the nanocarrier-based delivery systems have emerged as new methods of enhancing the stability and bioavailability of nutritional bioactives (Figure 1). Nanocarriers are nanosized constructs that are able to accept bioactive molecules and safeguard them against degradation, and release them under certain conditions [7]. The peculiar features of such properties are high surface area, adaptable structure and efficient interaction with biological systems and thus make good performers of delivery [8]. Compared to the

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conventional systems, nanocarriers have a high encapsulation capacity, potential of delivery of selected targeting and high protection of environmental stresses and are, therefore, very desirable in the use of functional food and nutraceuticals [9, 10].

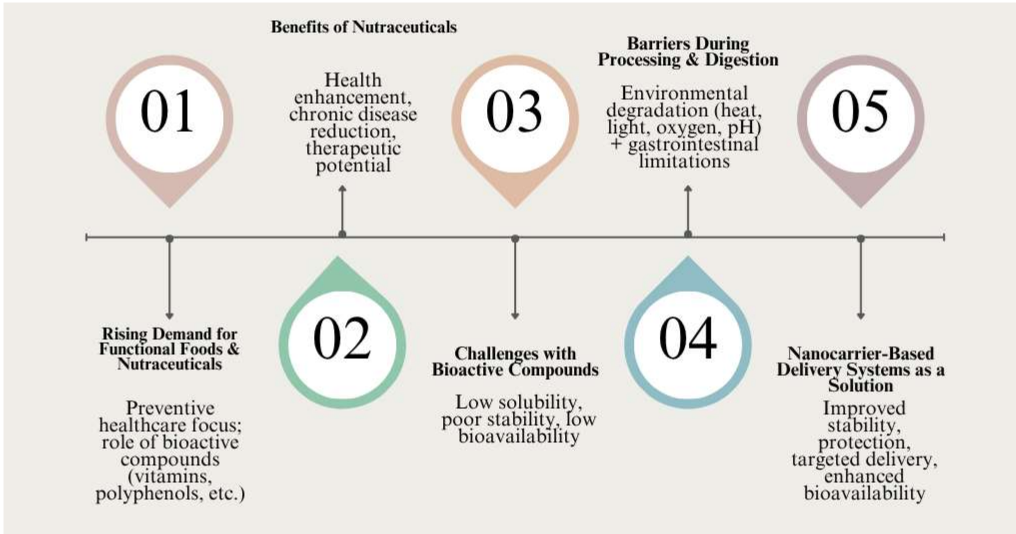

Figure 1: Nanocarrier-Based Strategies to Enhance Nutraceutical Bioavailability

This flowchart outlines the progression from increasing demand for nutraceuticals to inherent challenges in bioactive delivery, highlighting environmental and physiological barriers, and emphasizing nanocarrier systems as advanced solutions for improving stability, protection, and bioavailability of functional compounds.

4. Nutritional Bioactive Molecules: Characteristics and Delivery Challenges

The nutritional bioactive molecules are diverse and they have a great number of compounds, which are vitamins, polyphenols, carotenoids, omega-3 fatty acids, bioactive proteins and peptides which help in promoting health and disease prevention as shown in table 1. These materials are very different with regard to chemical framework and functionality [11]. Vitamins are classified into lipophilic or hydrophilic, and influence absorption and stability whilst polyphenols and carotenoids are high-antioxidant, but are easily destroyed [12]. In the same vein, the omega-3 fatty acids are so easily oxidized and enzymes are able to easily degrade proteins and peptides [13].

These bioactives are most often affected by their physicochemical properties in determining the efficiency of their delivery. The low solubility especially in lipophilic compounds restricts its dispersion and absorption [14]. Stability problems also reduce their use due to thermal processing, oxidation and enzymatic reactions. In addition, their movement across biological membranes and their bioavailability in general are affected by the molecular size and polarity [15].

Besides, the gastrointestinal tract has other obstacles, including varying PH, enzymes destruction, and reduced absorption through the intestinal epithelium. All these factors adversely affect the effective use of bioactive compounds that is why it is necessary to propose new delivery systems that will enhance their stability and bioavailability [16].

Table 1. Characteristics and Delivery Challenges of Major Nutritional Bioactive Molecules

Delivery Barrier	Bioactives Commonly Affected	Effect on Bioactive Delivery	References
Low aqueous solubility	Carotenoids, omega-3 fatty acids, fat-soluble vitamins, polyphenols	Limits dispersion in gastrointestinal fluids and reduces absorption	[11], [14]
Oxidative degradation	Polyphenols, carotenoids, omega-3 fatty acids	Causes loss of biological activity and reduces product stability	[12], [13]
Thermal and processing instability	Vitamins, carotenoids, polyphenols, peptides	Leads to degradation during food processing, drying, or storage	[11], [13]
Enzymatic degradation	Bioactive proteins and peptides	Causes premature breakdown before intestinal absorption	[12], [16]
Variable gastrointestinal pH	Vitamins, polyphenols, proteins, peptides	Alters stability, release behavior, and molecular integrity	[14], [16]
Poor epithelial permeability	Peptides, proteins, polar compounds, large molecules	Limits transport across the intestinal barrier and reduces bioavailability	[15], [16]
Biological barrier interactions	Encapsulated bioactives and nanoparticle systems	Particle size, polarity, and surface properties influence absorption and biological fate	[15], [16]

5. Lipid-Based Nanocarriers

Lipid nanocarriers have been of immense interest as an efficient form of delivery of nutritional biologic compounds due to their biocompatibility in addition to the ability to enhance solubility and stability. Such systems are divided into solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), liposomes and nanoemulsions [17]. SLNs are hard lipid cores that increase structural integrity compared to NLCs that mix solid lipids with liquid lipids to increase the loading capacity and reduce crystallinity-related limitations [18]. Liposomes are vesicles made of phospholipid bi-layers and capable of trapping both hydrophilic and lipophilic molecules and nanoemulsions are fine oil-water dispersions that are more effective in enhancing bioavailability of lipophilic bioactives [19].

Nanoparticle carriers based on lipids can be prepared using several techniques, including; high-pressure homogenization, microemulsion, solvent evaporation, and ultrasonication as shown in table 2. One of the methods that have frequently been used in the manufacture of stable and uniform nanoparticles, in particular in the food sector, is high-pressure homogenization [20]. Thermodynamically stable systems are provided by microemulsion methods, whereas solvent evaporation and ultrasonication can be used to control particle size and encapsulation efficiency [21].

The diffusion mechanisms, the degradation of lipid matrices, and the environmental factors like pH and enzymatic activity mainly control the controlled release of lipid nanocarriers. Diffusion-controlled release allows slow release of the encapsulated compounds; however, degradation of lipids offers a slow release over time [22]. External stimuli also exist in the gastrointestinal environment and are also associated with release behavior to facilitate certain delivery.

The lipid-based nanocarriers possess several advantages including high biocompatibility as well as high solubility of lipophilic molecules and oxidative resistance to degradation [23]. They however possess their own weaknesses such as physical instability, incapability to load drugs with certain systems and large-scale production issues. However, despite these constraints, lipid nanocarriers have demonstrated a potential to serve as a system of nutritional bioactives (vitamins, carotenoids, polyphenols) delivery to increase their stability, bioavailability, and functionality in food systems [24].

Table 2. Comparison of Lipid-Based Nanocarriers for Nutritional Bioactive Delivery

Nanocarrier	Structure	Key Advantages	Main Limitations	References
SLNs (Solid Lipid Nanoparticles)	Solid lipid core stabilized by surfactants	Good stability, protection against oxidation, controlled release	Low loading capacity; possible drug expulsion during storage	[17], [19]
NLCs (Nanostructured Lipid Carriers)	Blend of solid and liquid lipids	Higher loading capacity and encapsulation efficiency than SLNs	More complex formulation	[17], [18]
Liposomes	Phospholipid bilayer vesicles	Encapsulate both hydrophilic and lipophilic compounds	Prone to leakage and physical instability	[19], [24]
Nanoemulsions	Fine oil–water dispersions	Improved solubility and bioavailability of lipophilic bioactives	Limited long-term stability	[19], [24]

6. Polymeric Nanocarriers

Polymeric nanocarrier is an extremely diverse form of delivery systems that were extensively studied in order to trap and release bioactive nutritional compounds. These systems can be loosely classified as natural and synthetic polymer-based carriers. The natural polymers that are biodegradable, biocompatible, and low-toxic, among others, and can be utilized in the food and nutraceutical sectors should be used (chitosan, alginate, gelatin and others) [25]. Synthetic polymers, such as poly (lactic-co-glycolic acid) (PLGA), polyethylene glycol (PEG) and polycaprolactone (PCL), in their turn, provide a higher level of control over the physicochemical characteristics and degradation rates and can be modified to a desired profile of delivery [26].

Many various approaches exist to the preparation of polymeric nanocarriers and each approach has an influence on the particle size, encapsulation efficiency and release behavior. The main reason why nanoprecipitation is a popular technique is that the technique is simple and can be utilized to form homogenous nanoparticles [27]. In emulsion-solvent evaporation technique, stable particles with controlled morphology can be obtained, namely, the ionic gelation technique can be used with natural polymers, such as chitosan. Large-scale production and better stability of encapsulated compounds are also done by spray drying [28, 29].

Various processes determine the controlled release of bioactives by polymeric nanocarriers and they include polymer degradation, diffusion through the polymer matrix, stimulus responsive release. The polymers can be degraded in a hydrolytic or enzymatic degradation to enable slow release or diffusion can be employed to regulate slow diffusion of the encapsulated molecules. The complex systems are capable of responding to environmental cues, e.g. pH or temperature and transport to a location of interest.

Among others, the advantages of polymers Nanocarriers include the possibility to control the kinetics of release, structural flexibility, and delivery targeted. The drawbacks such as the fact that some of the synthetic polymers could be toxic, regulation, and the cost of manufacture should however be eliminated. Despite these restrictions, polymer-based systems have also proved to have a great potential in encapsulation of sensitive bioactives such as proteins and antioxidants in order to enhance their stability and bioavailability.

7. Comparative Analysis: Lipid vs Polymeric Nanocarriers

In order to understand the suitability of lipid-based and polymeric nanocarriers regarding their ability to deliver nutritional bioactive compounds, both types of nanocarriers should be compared. The two systems have different physicochemical properties that affect their functioning [30]. Hydrophobic Lipid nanocarriers are usually amphiphilic and have a hydrophobic core, which enables the incorporation of lipophilic compounds, whereas polymeric nanocarriers can assume a broader range of structures and can also be tuned in terms of surface properties such as charge and functionality [31]. Polymeric systems also allow regulating the architecture of particles with high degree of precision, which can enhance the interaction with the biological environment compared to lipid-based ones [32].

Lipid nanocarriers are more likely to release faster due to the diffusion and rearrangement of the lipid matrix than polymeric nanocarriers, which can be more regulated and sustained due to polymer degradation and diffusion of the matrices [33]. This makes polymeric systems particularly useful in areas where a long delivery time is required, whereas lipid carriers are more useful in rapid enhancement of bioavailability.

The two systems also differ greatly in terms of stability and shelf life. Lipid nanocarriers have higher chances of being physically unstable including aggregation and lipid oxidation that limits their storage capacity. Polymeric nanocarriers, on the contrary, tend to be more structurally stable and less vulnerable to the environmental factors including temperature and pH changes [34].

The biocompatibility and safety viewpoint, which is the use of food-grade lipids, is what makes lipid-based systems safe, in general. Polymeric nanocarriers (e.g. natural polymer based) are biocompatible as well; despite the fact that some synthetic polymers may cause toxicity and regulatory risks to increase.

With regard to industrial feasibility, lipid nanocarriers may be easier to scale-up in utilizing the existing food processing technologies, whereas polymeric systems may be linked with complex fabrication technologies and high cost of production. The two systems could also be affected by food contact with food matrices in terms of bioavailability and functionality [35]. In general, the selection of lipid and polymeric nanocarriers is determined by the purpose, the release profile demanded and the needs of the formulation as shown in table 3.

Table 3. Comparative Evaluation of Lipid-Based and Polymeric Nanocarriers for Nutraceutical Delivery

Parameter	Lipid Nanocarriers	Polymeric Nanocarriers
Physicochemical nature	Amphiphilic with a hydrophobic core; suitable for lipophilic compounds	Structurally diverse; surface charge and functionality can be tailored [30,31]
Structural flexibility	Comparatively less tunable	High architectural precision; better control of biological interactions [32]
Release behavior	Faster release due to diffusion and lipid matrix rearrangement	More controlled and sustained release through polymer degradation and matrix diffusion [33]
Stability and shelf life	More prone to aggregation and lipid oxidation	More structurally stable; less sensitive to temperature and pH changes [34]
Biocompatibility and safety	Generally safe due to use of food-grade lipids	Often biocompatible, especially natural polymers; some synthetic polymers may raise toxicity and regulatory concerns [35]
Industrial feasibility	Easier scale-up using existing food-processing technologies	More complex fabrication and higher production cost [35]

8. Factors Influencing Controlled Release

It is a complex phenomenon, and the release characteristics of the nanocarrier systems of bioactive compounds are achieved because of the interaction of a variety of physicochemical and environmental factors to characterize a combination of release kinetics, stability and bioavailability. Among them, the size of the particles and the surface charge is the most significant one that influences the dynamics of diffusion and interaction with the biological interfaces [36]. Smaller particles of nanoscale have higher ratios of surfaces-to-volume which enhance the rate of diffusion and bioaccessibility. Moreover, surface charge also has a tremendous influence on colloidal stability, aggregation properties and mucoadhesion, which adjusts residence time in the gastrointestinal tract and cellular uptake efficiency [37].

Structural and functional performance of nanocarriers is also determined by the composition of the carrier. The choice of lipid/polymeric materials determines the density of the matrix, crystallinity and degradation behaviour that, respectively, determine the encapsulation efficiency and the release profile of bioactives [38]. A good example is the retarded diffusion in highly crystallized matrices and the amorphous structures can be discharged faster. Artificial intelligence and machine learning techniques have composed most of the new developments to simplify the formulation parameters to be able to possess predictive control over the release kinetics and the system performance [39].

Environmental factors e.g. pH, temperature, enzymatic activity are the essential factors that mediate or regulate release mechanisms. Changes in the gastrointestinal pH may lead to structural changes caused by nanocarriers, and enzyme reaction may facilitate the breakage of the matrix to achieve site-specific release [40]. Carrier integrity and release stability can also be influenced by thermal conditions at processing and storage.

Additionally, the functionality of the nanocarriers is greatly influenced by the contact of nanocarriers with the food matrix. The components that can be complexed with the nanocarriers include proteins, lipids and polysaccharides and that alters the properties of physicochemicals, release kinetics and bioavailability. The interactions can either increase or reduce the effectiveness of the delivery process and the need of applying system specific design strategy in the usage of the functional foods [41].

9. Functional and Health Applications

With the introduction of nutritional science to the nanocarrier based systems of delivery, the functional and health uses of bioactive compounds have greatly increased in various areas of application such as functional foods, dietary supplements, clinical nutrition, and personalized nutrition. Lipid and polymeric nanocarriers are increasingly being incorporated in functional foods and beverages in order to enhance the stability, solubility, and bioavailability of the bioactives that are sensitive e.g. polyphenols, carotenoids, vitamins. These systems allow the addition of other unstable in food matrices without any influence on their sensory properties and nutritional value hence enhancing the efficacy of products and consumer acceptance [24].

Related to dietary supplements, nanocarriers offer a platform to the controlled and extended delivery of bioactive compounds that will result in an enhanced rate of absorption and an augmented physiological effect. Carriers made of polymers like PLGA or PEG have been extensively studied to entrap drugs as a mechanism of increasing bioavailability, and therapeutic properties [26]. Besides this, the polymer-based systems that are natural can be taken as oral supplements since they are biodegradable and safe.

The next notable area of use is in clinical nutrition where nanocarriers are applied in the delivery of bioactive compounds in the prevention and treatment of diseases. With the help of the more advanced fabrication methods such as nanoprecipitation, emulsion-solvent evaporation, it is possible to develop certain delivery systems capable of releasing bioactives in a localized location inside the body [27]. The measures can be particularly implemented when managing chronic health conditions and improving patient-centred nutritional therapy.

Besides, the emergence of personalized nutrition has given new possibilities to the application of nanocarriers. Optimization of nanocarriers through information on single metabolisms and physicochemical interactions can be used to maximize the nutrient delivery and efficacy [30]. The versatility of the polymeric and hybrid nanocarriers design, including more advanced designs, such as Janus nanoparticles, also makes the creation of personalized delivery systems in accordance with specific health requirements possible [32]. Altogether, the nanocarrier-based systems are changing the future of functional and therapeutic nutrition as shown in table 4.

Table 4. Applications of Nanocarrier-Based Delivery Systems in Nutrition

Application Area	Role of Nanocarriers	Key Benefits	References
Functional Foods & Beverages	Encapsulation of polyphenols, carotenoids, and vitamins	Improved stability, solubility, bioavailability, and sensory acceptance	[24]
Dietary Supplements	Controlled and sustained delivery of bioactives using polymeric carriers (e.g., PLGA, PEG)	Enhanced absorption and physiological efficacy	[26]
Clinical Nutrition	Targeted delivery of bioactives using advanced fabrication methods	Improved disease prevention, treatment, and patient-centered nutrition therapy	[27]
Personalized Nutrition	Customized nanocarriers based on individual metabolic needs	Optimized nutrient delivery and health outcomes	[30], [32]

10. Safety, Toxicity, and Regulatory Aspects

Strict attention to the safety and toxicity of nanocarriers and other regulatory issues should be considered in use of nanocarriers in food and nutraceutical systems to be subject to suitability as a food item. The toxicological factor remains also of first concern as the size of those systems is nanoscale and the surface reactivity is high, which may lead to the biological interactions which are not the same as the conventional materials. Some of the factors that can influence the cytotoxicity, bioaccumulation, and potential long-term health effects include particle size, surface charge, composition, and degradation products. Although natural polymers such as chitosan, alginate, and gelatin can be regarded as safe due to their biodegradability and biocompatibility, natural polymers will be toxic depending on their composition and degradation properties [25]. Moreover, lipid-based systems are considered to be safer, as they have food-grade materials, but their stability and interactions with biologic systems ought to be considered.

Government bodies like the U.S. Food and Drug Administration (FDA) and European Food Safety Authority (EFSA) at the regulatory level regulate nanotechnology in food systems by ensuring that it is completely characterised, analysed in terms of safety and risk before it is approved. Some of the parameters that are highlighted in regulatory frameworks are physicochemical properties, manufacturing processes, exposure levels, and possible toxicity. However, the rapid delivery nature of nanotechnology is likely to outrun the regulatory standardisation and this presents a challenge in the establishment of standardised guidelines in the nanocarrier-based systems [20]. Additionally, lack of consistency in the preparation process that can involve microemulsion and high-pressure homogenization processes can influence consistency and safety of products, and this is the reason why high-quality control is required [21].

The other important factor that contributes towards successful commercialization of nanocarrier-based food products is consumer acceptance. Some of the factors that dictate the perception of the population on nanotechnology in food are the safety issues, transparency, and perceived benefits. It has been shown that, acceptance would be improved more in the event that effective communication of clear health benefits and safety guarantees are put across. Therefore, the problem of safety, regulations, and consumer-related issues must be taken into account to allow the universal application of nanocarriers in the functional foods and nutraceutical sector.

11. Recent Advances and Emerging Trends

Recent advancements in the nanocarrier based delivery systems have significantly enhanced the efficacy, specificity and sustainability of bioactive compounds delivery because of the use of nanocarrier based delivery systems. The other innovation that has been suggested among them is the stimuli-responsive nanocarrier, which regulates release upon a certain physiological stimulus, such as pH, temperature, or enzymes activity. They are especially useful in negotiation of complex biological systems such as gastrointestinal tract where the pH gradient and enzymatic conditions can be utilized to offer sites specifically [16]. These smart systems can possess the capability of developing the accurate spatiotemporal release of the physicochemical properties, which are manipulated to enhance bioavailability and therapeutic results [14].

The other trend which is interesting is the one of hybrid nanocarriers especially lipid-polymer carriers which is a combination of the benefits of lipid-based and polymer carriers. The hybrid systems are more robust structure wise; they have high encapsulation efficiency and tuning release profiles. The case in point is that polymer matrix lipid cores can contribute to overcoming the disadvantage of lipid oxidation and polymer rigidity, which results in the development of high-quality and effective delivery systems [23]. The further evolution of lipid nanoparticles is nanostructured lipid carriers (NLCs) that have greater loading capacity and reduced crystallinity and improves the delivery of sensitive bioactives [18].

At the same time, green nanoencapsulation strategies to boost sustainability and safety are under the limelight. Such methods as high-pressure homogenization and solvent-free applications gain their popularity due to the opportunities to reduce the employment of toxic solvents as well as to save the energy and maintain the quality of the products [20]. These green practices go hand-in-hand with augmented requirement of clean-label and sustainable foods technologies.

Moreover, the introduction of artificial intelligence (AI) and machine learning (ML) into the design of formulation is a radical innovation in the sphere. The predictive models can be optimized AI-based and be used to forecast the nanocarrier characteristics, including the particle size, encapsulation efficiency and release kinetics, and thereby accelerate the development process and reduce the expenses of the experiments. All of these changes are transforming the environment of the nanocarrier systems that is opening the door of the more efficient, sustainable and personalized delivery systems.

12. Challenges and Future Perspectives

Although the nanocarrier-based systems of delivering food and nutraceutical processes have made a huge breakthrough, there are a number of challenges that continue to limit the widespread application of the systems. Another important limitation is scalability due to the fact that most of the fabrication techniques that have been developed at the laboratory level are difficult to scale to an industrial scale due to their high cost, processing is hard at an industrial scale, and are not reproducible and batch consistent. Moreover, the lack of standardized characterization procedures of characterizing parameters such as particle size, surface charge, encapsulation efficiency, and release kinetics creates discrepancies among studies and makes it hard to accept regulations and regulate quality. The second important issue is long term safety, as there has been little research done on long-term exposure, bioaccumulation and possible toxicological impact of nanocarriers although there is a general acceptance of the biocompatibility of most lipid and natural polymer systems. In addition, nanocarriers are not easily formulated when applied in disease food matrices as interactions with proteins, lipids and carbohydrates can alter stability, release and sensory characteristics of the end product. The solutions to these questions are in the creation of scalable and cost-efficient production, standardization of the evaluation procedure, and long-term research on safety, interdisciplinary action to simplify the functionality of nanocarriers to be implemented in food systems into practice.

13. Conclusion

The review illustrates the significance of lipid and polymeric nanocarrier to the improvement of the delivery efficacy of the nutritional bioactive molecules in overcoming the long-standing issue of inadequate bioavailability, instability, and inadequate solubility. Systems based on lipids such as SLNs, NLCs, liposomes and nanoemulsions are highly biocompatible and are specifically used in the encapsulation of lipophilic compounds, but polymeric nanocarriers are highly flexible in their structure and provide high level of control in the release kinetics. This comparative analysis sheds light to some extent on the fact that carrier system used should be founded on the release profile needed and physicochemical characteristics of bioactives. The factors that significantly influence the controlled release behavior and the performance are also the radius of particles, the surface properties, composition of carriers and the environmental factors. The new technologies in the field are also being extended by the development of stimuli-responsive systems and hybrid nanocarriers and a more intensive method of formulation based on AI that creates effective and specific solutions of delivery. Nonetheless, the issue of scalability and standardization, safety review and its integration in food systems are to be resolved to make commercialization of it widespread. Overall, nanocarrier based delivery mechanisms have a considerable potential in development of the new generation of functional foods and nutraceuticals that are more stable, targeted, and health-promoting, which would result in the advances of precision nutrition and sustainable healthcare.

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