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A study on Dual-Layer Flavor system for Dietary Supplement: Concepts, Technologies and Applications

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Abstract

Dual-layer flavor systems have emerged as a promising approach to improve the sensory appeal and functional performance of dietary supplements. Many vitamins, minerals, and probiotics exhibit bitter or undesirable tastes that can reduce consumer compliance and limit product effectiveness. By encapsulating bioactive ingredients in a core layer and applying an outer coating, dual-layer systems enable controlled flavor release, protection against environmental stressors, and enhanced stability during storage and gastrointestinal transit. This review explores the concepts, design principles, materials, and technologies used in dual-layer flavor systems, including conventional methods such as spray drying and freeze-drying, as well as advanced techniques like electrospinning, nanoemulsions, and layer-by-layer assembly. Applications in functional foods and nutraceuticals are discussed, along with the challenges of scalability, industrial feasibility, and long-term stability. The study highlights current research gaps and provides insights into future directions for the development of consumer- friendly, effective, and commercially viable dietary supplements.

Keywords

Dual-layer flavor system, Dietary supplements, Encapsulation technology, Controlled release, Functional foods

1. Introduction

Modern nutrition relies heavily on dietary supplements which give consumers convenient methods to support health, wellness, and specific dietary needs. Flavor is one of the major determinants of consumer acceptance and compliance. Many vitamins, minerals, and botanicals have a bitter or otherwise undesirable, taste which can negatively impact their palatability and compliance with supplementation. One of the key challenges in the development of supplements is the improvement of flavor without compromising the stability and functionality of such bioactives of quality (Siegrist & Hartmann, 2020).

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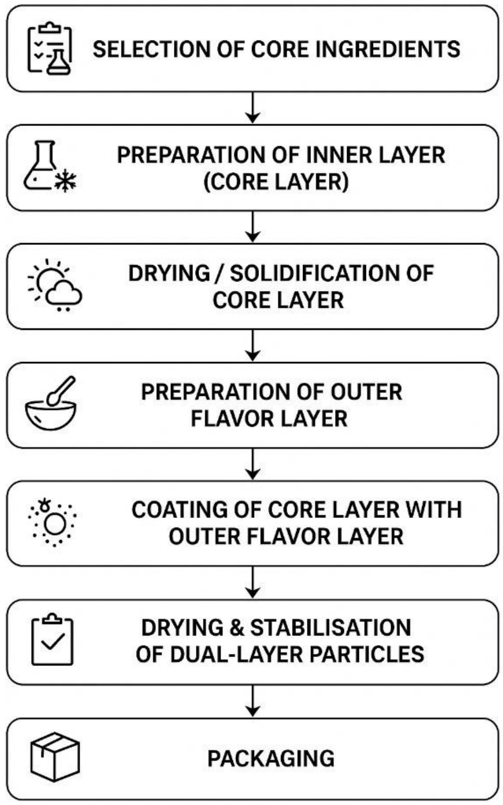

Fig: Flow chart of Dual layer flavor system

Source: Own processing

Recent times have been witnessing the launch of functional foods and nutraceuticals. However, this requires a shift in rationale both concerning sensory world appeal, nutrition, and introduction of technology. (Alongi & Anese, 2021; Granato et al., 2020). Dual layer flavor systems have emerged as a potential solution to tackle these challenges. These systems can mask off-flavors, enhance stability in storage and processing, and improve the sensory experience of the consumer with a layer that contains the active bioactive and a coating layer that controls flavor release. The ingredient's controlled release can be regulated through environmental factors (pH, temperature, and/or enzymes) to allow for the delivery of flavor and bioactives (Granato et al., 2020). There is growing demand for functional food products.

While there are advantages, studies on the dual-layer flavor systems in the case of dietary supplements are limited. This is especially in terms of substrate selection, layering and scale- up techniques. Bridging the aforementioned gaps is important for the translation of laboratory findings into commercialisable products that meet performance efficacy and consumer acceptance criteria (Siegrist & Hartmann, 2020; Alongi & Anese, 2021). This review provides a detailed overview of the notion, technologies, materials, and applications of dual-layer flavor systems in food supplements along with present trends, challenges, and future perspectives.

1.1 Importance

- ❖ Flavor is a critical determinant of consumer acceptance and compliance in dietary supplements; many bioactives have bitter or unpleasant tastes.
- ❖ Dual-layer flavor systems improve sensory appeal while protecting sensitive bioactives like vitamins, minerals, and probiotics.
- ❖ They allow controlled release of flavors and active ingredients, responding to environmental triggers such as pH, temperature, or enzymes.
- ❖ These systems enhance product stability, shelf life, and functional efficacy, bridging the gap between laboratory innovation and commercially viable supplements.
- ❖ They are particularly relevant in modern functional foods and nutraceuticals, where taste, efficacy, and stability must all be optimized simultaneously.

1.2 Objectives

To explore the concepts, technologies, materials, and applications of dual-layer flavor systems in dietary supplements, focusing on enhancing flavor masking, bioactive protection, and controlled release for improved consumer acceptance and functional efficacy.

1. To review the current literature on dual-layer flavor systems and their applications in dietary supplements.
2. To analyze the design principles, materials, and formulation strategies for inner (core) and outer (coating) layers.
3. To evaluate encapsulation technologies, including conventional and advanced methods (e.g., electrospinning, nanoemulsions, layer-by-layer assembly), for flavor and bioactive delivery.
4. To assess the functional and sensory performance of dual-layer flavor systems under simulated gastrointestinal and storage conditions.

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2. Review of literature

Author(s)	Year	Aim	Objective	Scope	Key Findings
Alongi, M., & Anese, M.	2021	Explore holistic approaches in functional food development	Analyze strategies for functional food design	Functional foods and nutraceuticals	Emphasized integrative approaches considering health benefits, sustainability, and processing impacts
Castro Coelho, S., Nogueiro Estevinho, B., & Rocha, F.	2021	Review emerging electrohydrodynamic techniques for encapsulation	Summarize electrospinning and electrospraying applications in food	Food industry encapsulation	Highlighted potential of electrohydrodynamic methods for protecting bioactives and improving stability
Fijan, S., ter Haar, J. A., & Varga, L.	2021	Examine probiotics and health benefits	Discuss role of probiotic microorganisms	Human health	Demonstrated that probiotics have significant health benefits and highlighted mechanisms of action
Galanakis, C. M.	2021	Study functionality of food components	Assess emerging technologies in food processing	Food engineering & technology	Found that advanced technologies enhance bioactive functionality and product quality
García-Moreno, P. J., Mendes, A. C., Jacobsen, C., & Chronakis, I. S.	2018	Discuss nano/microencapsulation via electrohydrodynamic processing	Analyze biopolymer usage for encapsulation	Food applications	Nano/microencapsulation improves stability and controlled release of bioactive ingredients
Granato, D., Barba, F. J., Kovačević, D. B., Lorenzo, J. M., Cruz, A. G., & Putnik, P.	2020	Review functional food product development	Discuss trends, efficacy testing, and safety	Global functional food industry	Provided comprehensive overview of functional food development trends, highlighting technological and regulatory challenges
Green, A.,	2020	Assess	Evaluate	Food	Found trade-offs

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Nemecek, T., Chaudhary, A., & Mathys, A.		sustainability of agri-food production	nutritional, health, and environmental aspects	production systems	between health benefits, nutrition, and environmental sustainability in agri-food systems
Kaistha, S. D., & Deshpande, N.	2021	Explore probiotics and engineered biotherapeutics in wound healing	Review mechanisms and applications	Chronic wounds	Showed probiotics and engineered products improve wound healing outcomes and reduce infections
Kohut, M., Lohne, O., Leker, J., & Bröring, S.	2021	Examine market convergence in probiotics start-ups	Analyze commercialization trends	Start-up perspective	Start-ups in probiotics converge toward hybrid products combining health, nutrition, and biotech innovation
Luo, X., Song, H., Yang, J., Han, B., Feng, Y., Leng, Y., & Chen, Z.	2020	Test encapsulation of E. coli Nissle 1917	Develop layer-by-layer chitosan-alginate matrix for GI delivery	IBD treatment	Layer-by-layer encapsulation improved probiotic survival and therapeutic potential in gastrointestinal conditions
Mendes, A. C., Sevilla Moreno, J., Hanif, M., Douglas, T. E. L., Chen, M., & Chronakis, I. S.	2018	Study electrospun chitosan/phospholipid nanofibers	Analyze morphology, mechanics, and mucoadhesion	Food & pharmaceutical applications	Hybrid nanofibers showed good mechanical strength and mucoadhesive properties, useful for delivery systems
Mendes, A. C., Stephansen, K., & Chronakis, I. S.	2017	Explore electrospinning of food proteins and polysaccharides	Review process and applications	Food engineering	Electrospinning can produce nanofibers that enhance bioactive delivery and stability
Niamah, A. K., et al.	2021	Review electrohydrodynamic encapsulation	Summarize trends, challenges, and	Probiotics encapsulation	Identified electrospinning/electrospraying as promising

		of probiotics	prospects		methods for probiotic stability and controlled release
Pérez-Masiá, R., et al.	2015	Encapsulate folic acid in hydrocolloids	Evaluate nanospray drying/electrospraying	Nutraceutical applications	Successfully improved stability and bioavailability of folic acid via encapsulation
Shang, F., et al.	2020	Investigate probiotics' effect on colon cancer	Study in vitro and in vivo inhibitory effects	Colon cancer therapy	Certain probiotics inhibited colon cancer cell growth and modulated gut microbiota
Siegrist, M., & Hartmann, C.	2020	Study consumer acceptance of novel food technologies	Assess perception and willingness to adopt	Food technology	Acceptance depends on risk perception, trust, and information about benefits
Singh, R., Yadav, K., & Yadav, D.	2019	Study basics of flavors in nutraceuticals	Discuss flavor industry significance	Functional foods and nutraceuticals	Highlighted importance of flavors for consumer acceptance and product development
Soares, J. M. D., et al.	2020	Investigate Lactobacillus paracasei encapsulation	Use electrospun fibers of Eudragit® L100	Probiotic delivery	Electrospinning improved survival and release of probiotics under simulated GI conditions
Yilmaz, M. T., Taylan, O., Karakas, C. Y., & Dertli, E.	2020	Test probiotic encapsulation in alginate nanofibers	Monitor survival under GI conditions	Kefir and functional foods	Alginate electrospun fibers protected probiotics and maintained viability
Zupančič, Š., et al.	2019	Evaluate effects of electrospinning on probiotics	Assess viability of lactic acid bacteria in PEO nanofibers	Probiotic encapsulation	Electrospinning preserved viability of several lactic acid bacteria species

2.1 Research Gap

Dual-layer flavor systems are gaining popularity in the supplement industry due to their capacity to mask unpleasant flavors, protect vulnerable bioactives, and achieve a targeted release profile. Research thus far has already shown some benefits of incorporating probiotics, however, it has often only looked at one aspect flavor retention or probiotic viability or nutrient

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stability. Lack of understanding on how combinations of encapsulating materials and the layering techniques/processing parameters can enhance both sensory characteristics and functional efficacy of dietary supplements. In addition, there is, poor knowledge about the interactions between the layers, and their impact on the release kinetics of active compounds under real gastrointestinal conditions.

Besides, little attention has been given to their scalability, industrial feasibility and long-term stability during storage. A limitation of most studies includes being conducted at lab scale raising questions about cost-effectiveness, reproducibility, and consumer acceptability. It is imperative to tackle the gaps in coherent commercial dual-layer systems so that one helps in retaining the bioactive functionality while not compromising on the taste or consistency of the product. It's important to study formulation, processing and functional evaluation together to take this emerging technology to the next stage.

3. Design Principles and Materials for Dual-Layer Flavor Systems

No.	Layer / Component	Key Materials	Main Functions	Release / Protection Mechanism	References
1	Inner layer (core)	Vitamins, minerals, probiotics, flavor compounds	Encapsulation of bioactives, flavor delivery	Protects from environmental stresses; controlled release (pH, enzymes, temperature)	Green et al., 2020; Kohut et al., 2021; Kaistha & Deshpande, 2021
2	Outer layer (coating)	Polymers (proteins, polysaccharides), lipids, gums	Taste masking, controlled release, barrier against moisture, light, oxygen	Responds to digestive conditions; protects from oxidation and moisture	Green et al., 2020
3	Polymers / Proteins	Gelatin, whey protein, alginate, pectin	Mechanical stability, enzymatic responsiveness, biocompatibility	Enzyme-triggered release	Green et al., 2020
4	Lipids	Vegetable oils, waxes, fatty acids	Barrier against moisture, oxygen, and light	Moisture/oxygen barrier; temperature-responsive	Green et al., 2020
5	Gums / Hydrocolloids	Guar gum, xanthan gum, gum arabic	Stabilization, viscosity control, taste masking	Delayed release via swelling or pH response	Green et al., 2020

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6	Emulsifiers	Lecithin, mono- and diglycerides	Improve coating uniformity,	Helps protect hydrophilic and	Green et al., 2020

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			encapsulation efficiency	lipophilic actives	
7	Controlled-release triggers	pH-sensitive polymers, enzyme-sensitive matrices, temperature-sensitive lipids	Targeted release in the digestive tract	Stomach → intestine release for probiotics or bioactives	Kohut et al., 2021; Kaistha & Deshpande, 2021
8	Composite / multi-layer combinations	Protein-lipid, polymer-lipid, polysaccharide-lipid	Synergistic protection, enhanced sensory profile	Sequential release and multi-step protection	Green et al., 2020
9	Flavor stabilizers	Antioxidants (vitamin E, ascorbic acid), chelating agents	Maintain flavor stability, prevent degradation	Prevents oxidation and off-flavors	Green et al., 2020

4. Encapsulation Technologies and Processing Approaches

Technologies to encapsulate nutrients have led to the creation of dual-layer flavor systems which can protect sensitive bioactive materials in food supplements and control flavor release. Flavors and functional ingredients have been incorporated into microencapsulation using conventional methods such as coacervation, spray drying and freeze-drying. This has provided stability, more shelf life, and masking of unwanted flavor (Singh, Yadav, & Yadav, 2019). In Ganlaki's 2021 review we see that newer nano- and microencapsulation methods like liposomal encapsulation, nanoemulsions, and electrohydrodynamic processing have become important for greater bioactive delivery and targeted controlled release.

The layer by layer assembly works effectively on dual-layer formulations as layer after layer, protective layers can be deposited on the core. This method is versatile. It can be for delivery of active components. This could be for probiotics delivery that is responsive to pH levels. Alternatively, it can be for enzyme-triggered flavor release. It makes sure that both bioactive substances and flavors are protected from contact with the surrounding environment up to the time of consumption (Fijan, ter Haar, & Varga, 2021). For example, probiotics in multilayer matrices survive stressing gastrointestinal conditions making them more viable and effective in gut health (Shang et al., 2020).

The technology chosen for the encapsulation of bioactives is dependent on the specific nature of the bioactive and the flavor. Many things can affect the choice of suitable techniques and materials like solubility, thermal sensitivity and 15 more. Using modern technology with traditional processes to develop simple and

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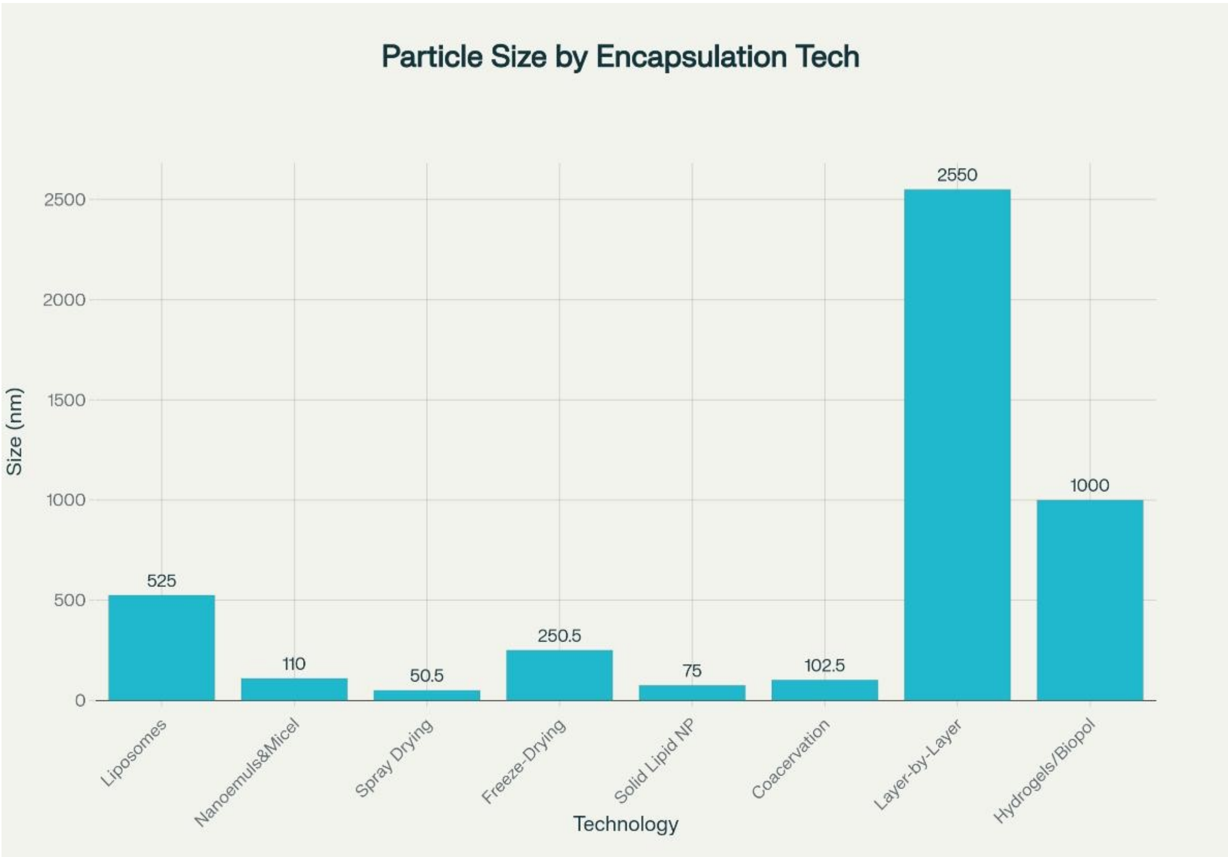
double-layered systems. They will help in improving stability, sensory and functional performance. Such systems can prove effective for developing contemporary food supplements (Galanakis, 2021; Singh et al., 2019).

Table: Encapsulation Technologies and Processing Approaches

Source: Own processing

Technology	Particle Size Range	Encapsulation Efficiency (%)	Key Advantages	Key Limitations	Typical Applications
Liposomes	50 nm - 1 µm	70 - 90	Biocompatible, enhances absorption	Stability issues, high production cost	Vitamin C, curcumin, glutathione
Nanoemulsions & Micelles	20 - 200 nm	80 - 95	Fast absorption, high stability	Requires surfactants/emulsifiers	Vitamin D, CoQ10, botanical extracts
Spray Drying	1 - 100 µm	60 - 90	Extended shelf life, taste masking	High processing temperatures	Probiotics, omega-3 oils, iron
Freeze-Drying	1 - 500 µm	70 - 95	Suitable for heat-sensitive compounds	Expensive, slower process	Probiotics, enzymes, heat-sensitive nutrients
Solid Lipid Nanoparticles	50 - 100 nm	80 - 95	Sustained release, good physical stability	Complex production methods	Polyphenols, carotenoids, fat-soluble vitamins
Coacervation	5 - 200 µm	70 - 90	High payload capacity, good stability	Process complexity	Flavors, vitamins, various bioactives
Layer-by-Layer Assembly	100 nm - 5 µm	80 - 95	Controlled release, multi-responsive systems	Process complexity	Probiotics, enzyme-triggered release
Hydrogels/Biopolymer Systems	Variable, 1 µm - mm scale	60 - 85	Biodegradable, targeted delivery	Moisture sensitive, swelling issues	Probiotics, enzymes, minerals

Graph: Particle Size by Encapsulation tech



The first graph reveals the particle size distribution across various encapsulation technologies, highlighting how size influences application suitability. Technologies such as Layer-by-Layer Assembly and Hydrogels/Biopolymer Systems generate larger particles ranging from micrometers up to millimeters, making them well-suited for encapsulating bulk bioactive compounds or enabling prolonged release in food matrices. Conversely, Liposomes and Solid Lipid Nanoparticles produce nanoparticles in the nanometer range, optimizing these methods for enhanced bioavailability and cellular uptake. Spray Drying and Freeze-Drying create intermediate particle sizes, balancing payload capacity with protection of sensitive ingredients. Particle size is a critical factor affecting stability, bioavailability, and the controlled release of encapsulated nutrients or flavors.

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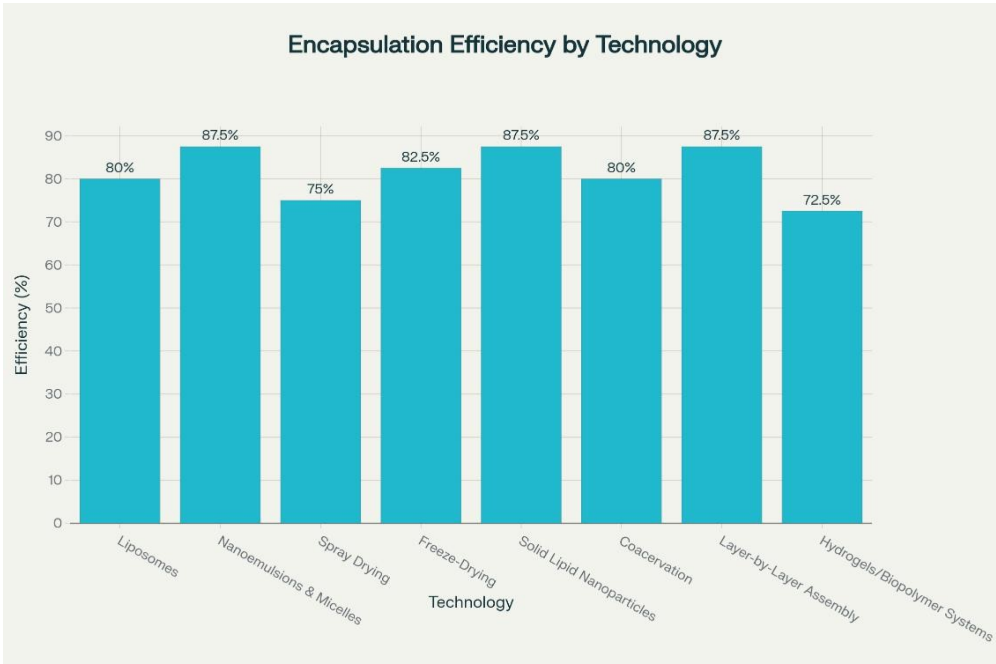
Graph: Encapsulation Efficiency by tech



This graph focuses on encapsulation efficiency, which quantifies how well each technique retains the active ingredient during processing. Methods like Nanoemulsions, Solid Lipid Nanoparticles, and Layer-by-Layer Assembly show encapsulation efficiencies above 80%, indicating strong protection and effective delivery of bioactives. Spray Drying, though slightly less efficient, offers advantages in scalability and cost. On the other hand, simpler technologies such as Hydrogels have moderate efficiency levels around 70%, highlighting trade-offs between ease of production and encapsulation protection. Higher encapsulation efficiency correlates with improved shelf life, stability, and sensory quality of food supplements.

Together, these two perspectives illustrate the inherent trade-offs in encapsulation technology selection. Smaller particle sizes generally enhance delivery efficiency but may entail increased complexity and cost, while larger particles facilitate easier production and sustained release. The choice of technology thus depends on the specific functional goals, such as bioactive protection, release profile, and sensory attributes desired in food supplement formulations. This understanding aids in optimizing formulation strategies for targeted nutrient and flavor delivery in diverse food applications.

5. Evaluation and Applications in Dietary Supplements

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The effectiveness of dual-layer flavor systems in dietary supplements is dependent on their design and encapsulation, as well as their evaluation under relevant conditions. Particle size, morphology, and encapsulation efficacy are special sections that will help in the physical assessment of the parties Techniques like electrospinning and electrospraying now allow the use of nanoscale and microscale carriers, improving bioactive and flavor protection and allowing for more precise release profiles (Castro Coelho, Nogueiro Estevinho, & Rocha, 2021).

To assess whether the encapsulated ingredient can withstand and be released in the gastrointestinal tract, we apply various simulated conditions. Commonly studied ingredients include probiotics and sensitive vitamins. Research has demonstrated that electrospun alginate or Eudragit® L100 fibers containing probiotics have more significant viability during their passage through a simulated gastric and intestinal environment, therefore, they can enhance their functional efficiency. (Yilmaz, Taylan, Karakas, & Dertli, 2020; Soares, Abreu, Costa, Melo, & Oliveira, 2020) Nanospray-dried vitamin and bioactive (folic acid) encapsulation has been found to better stability and controlled release in nutraceuticals (Pérez-Masiá et al., 2015).

You can use a two-layer system for tablets, capsules, powders and/or functional drinks in terms of application. They are especially effective when used to improve flavor while also acting as delivery systems for functional ingredients, for example, probiotics, vitamins, or plant extracts. When sensory demand and functional expectation is simultaneously met, the acceptability, compliance and effectiveness of dietary supplements is increased. By using advanced encapsulation technologies and targeted evaluation approaches, next generation functional supplements with efficacious and organoleptic qualities can be developed (Castro Coelho et al. 2021; Yilmaz et al. 2020).

6. Challenges, Opportunities, and Future Perspectives

Although researchers have made great improvements in dual-layer flavor systems for nutritional supplements, there are still many hurdles to commercialisation at scale. Improvements to encapsulation processes, especially the electrohydrodynamic ones – such as spinning and spraying – are still a major challenge. Although they are capable of providing control over the particle size, morphology and release kinetics, adjustments of specific material properties and processing parameters are required to ensure reproducibility, scalability and cost-effectivity (García-Moreno et al., 2018; Mendes et al., 2017).

Choosing materials is difficult. The biopolymers used in encapsulation must be compatible with the active bioactives and flavor compounds and must have good mechanical and chemical stability and offer controlled-release under physiological conditions. Besides maintain the electrospun or layered system's mucoadhesive and mechanical properties without making them sensory less appealing is quite a challenge for complex formulations such as probiotics and other sensitive nutraceuticals (Mendes et al., 2018).

But these challenges provide valuable opportunities. Smart encapsulation systems, being responsive to stimuli, hold promise for promoting the delivery of bioactives. pH- or enzyme-triggered release systems are two such innovations. According to consumers, clean-label products that do not contain toxic or harmful chemicals as well as eco-friendly products, Perkins products are the best candidates for the development of sustainable, biodegradable, and food-grade polymers. Also, new analysis procedures for electrohydrodynamic processing offer exciting opportunities for the design of multilayer nanofibers and microcapsules, as well as controlled flavor release and improved functionality (Niamah et al., 2021).

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