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Microencapsulated bioactive compounds for fortification of dairy products: A review

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Abstract
Bioactive compounds are naturally derived chemical compounds having distinct biological activities and pronounced effects on human health. Dairy products offer a great way to incorporate these substances and create functional food items which are able to cater to the needs of consumers. Dairy fortification has been getting a lot of attention, especially in functional dairy foods like probiotic yogurts, butter, cheese, ice cream, and other fermented milk goods. Microencapsulation, a technique by which tiny particles of target chemical are enclosed in a coating, is an efficient way to fortify milk and associated byproducts. In addition to providing a protective barrier for volatile substances, encapsulation also extends controlled release, improved stability, and enhanced bioavailability of bioactive compounds. Though varied, the technique involves three main stages creating a wall around the substance, avoiding inadvertent leakage, and guaranteeing product purity. The present literature attempts to consolidate microencapsulation methods *viz* extrusion, coacervation, spray drying, emulsion, etc. along with the bioactive compounds predominantly used with dairy products. The review also evaluates the difficulties that microencapsulation faces in the dairy business, including the necessity for regulatory compliance, quality control testing, and sterile processing. However, the future of Microencapsulation in the dairy business is bright, particularly with regard to improving the nutritive content of products and developing new types of packaging.

Keywords: Microencapsulation, bioactive compounds, dairy fortification, stability, bioavailability, future trends

1. Introduction

Consumer interest in adopting a variety of natural, healthful meals has increased recently. Due to this change in consumer behavior, the food industry has been forced to allocate resources into food development that may have health advantages in order to meet the requirements and desires of this new demographic. Dairy products stand out among the food items that have attained widespread appeal around the world for their practical qualities. As a result, adding bioactive ingredients to dairy products can boost output dramatically and open new business options. Microencapsulation is a suitable candidate for incorporating molecules of interest into food systems [1]. Agricultural products, home and personal care products, culinary products, textiles, and even building insulation are just a few of the many areas where microcapsule technology is being applied. While bioactive compounds offer a variety of potential health benefits, their stability and efficacy are regularly impacted by different environmental factors. When subjected to various physical forces, many of these compounds may lose their efficacy or even become inert. The tough conditions of the digestive system, such as acidic stomach conditions and the presence of gastric secretions that can destroy them before they are absorbed into the body, must also be overcome by these compounds. Therefore, optimizing the potential health advantages of these chemicals and ensuring their continued efficacy depends on developing ways to conserve and preserve them. The use of microencapsulation makes it easier to create value-added goods that support well-being and health and satisfy the demands of consumers who care about their health.

2. Current Standing of Fairy Fortification

In recent times, a burgeoning demand for low-calorie, low-fat diets with little to no saturated fat is being put forth by people inhabiting in both industrialized and developing countries. This trend can be linked to a number of causes, including an increase in public awareness of the harmful consequences of a diet heavy in fat, the prevalence of lifestyle disorders like obesity, and the growing influence of fitness culture [2, 3, 4].

Food producers are thus under increased pressure to provide goods that satisfy this demand for better dietary alternatives. In response, several businesses have started investigating fresh approaches to food fortification and creating functional meals that have a variety of health advantages. There is now active interest to fortify foods with vitamins, minerals, and probiotics among others

2.1 Milk

Milk is a priceless and indispensable liquid that has enormous long-term advantages for individuals of all ages and society, which have been a significant part of the human diet from prehistoric times In addition to offering the body's essential nutrients, milk is a substantial source of bioactive substances such as lactoferrin, lacto peroxidase, lysozyme, immunoglobulins, and growth factors, which provide numerous health benefits. Commercial cow milk is rich in various bioactive substances at the micronutrient level, such as vitamins, minerals, amino acids, nucleotides, oligosaccharides, and immunoglobulins [5]. The loss of some crucial nutrients due to processing techniques like heating, pasteurization, homogenization, and ultrahigh temperature treatment could be made up through various fortification strategies which also helps in maintaining stability and shelf life of the product. Besides fat soluble vitamins, and occasional folic acid, pantothenic acid, and biotin, milk products have been fortified with microelements like calcium, phosphorus, iron, zinc, and more [6]. Patel *et al*. (2006) assessed the growing interest in producing omega-3 fortified milk products as they offer potential health benefits to consumers. To achieve this supplementing the diet of cows with sources of omega-3 fatty acids, such as sunflower or flaxseed or nutrient enrichment, where omega-3 fatty acids are added directly to milk or dairy products during processing are employed Particularly intriguing has been the alteration of the carotenoid composition of milk and related dairy products by early manipulation of the animal diet and subsequent supplementation [7].

2.2 Yogurt

Yogurt, a very nutrient-dense meal that is relished all over the world, is made by is made by fermenting acidified milk with good bacteria from Lactobacillus and Streptococcus strains. Yogurt is an overlooked chance to support a healthy lifestyle because it is a good to great source of protein, calcium, and good probiotics that may offer a variety of perks to human health [8]. Efforts have been made to fortify yogurt with essential nutrients and bioactive compounds to enhance its overall nutritional value. Yogurt may be strengthened by using vitamins like Vitamin D, A, C, iron, and essential oils [9]. Vitamin D is frequently added to yoghurt to support strong bones and a robust immune system. Vitamin C is a powerful free radical scavenger that aids the body to fight disease, and vitamin A is essential for good skin and vision. Yogurt that has been fortified with these vitamins has a better sensory profile, which increases its attractiveness and enjoyment while also improving its nutritional profile [10]. In addition to this, Calcium fortification using micronized tricalcium nitrate, Iron enrichment using ferric pyrophosphate, fiber enrichment using date and oat fiber, phenolic improvement using plant-based additives coming under the category of functional ingredients, augmentation with ω−3 fatty acids is also implemented [11]. In addition to being needed for strong bones and teeth, calcium is also necessary for the proper operation of the neurological and muscular systems. Yogurt's nutritional value may also be increased by enriching with omega-3 fatty acids, which not only makes useful fatty acid-rich oils more bioavailable, but also lowers the potential risks associated with obesity and the serum lipidemic balance [12].

2.3 Cheese

A dairy product called cheese is created by coagulating milk protein and removing the whey. It is a popular food item all around the world since it is a good source of protein, calcium, and phosphorus. Additionally, cheese has higher levels of nutrients than milk, such as zinc, iodine, and selenium. Fortifying cheese has gained popularity to increase its nutritional content in recent years. One of the major health constraints is the significantly higher proportions of saturated fatty acids which are primarily linked with the emergence of chronic diseases. Creating fortified cheeses from sources abundant in unsaturated or good fats(most commonly being omega fatty acids) is a great strategy to bypass this and microencapsulation techniques allow the oil entrapment and fat replacement with minimal effects on the cheese quality. Transferring active compounds into high quality nutritional foods generates greater value in the long run. Cheese fortification with unsaturated fatty acids has been carried out by either modifying the cow's diet or by directly incorporating oil globules into the food matrix [13]. The study however highlighted the need for devising a method to facilitate the retention of fatty acids. In the same vein, cheese has been fortified with Iron, Zinc, Selenium, Carotenoids such as lutein, Polyphenols, Polyunsaturated fatty acids, Conjugated Linoleic acid, Probiotics from Bifidobacterium, and Lactobacillus genera, and even by-products of agri-food industry [14, 10]. As cheese has a larger fat and protein composition and superior stabilizing capabilities than yoghurt, it is thought to be a better probiotic delivery system [9].

2.4 Butter

One of the major hurdles, in augmenting butter and clarified butter is their introduction into foods before or during cooking. The high temperature destroys many of the reinforced substances. Using flaxseed oil and whey protein to create omega 3 fatty acid supplemented butter, Pandule [15] and colleagues noticed that it not only improved the churning efficiency and textural qualities of butter but also increased the bioavailability of alpha linolenic acid. Mehta *et al.* [3] opined that a considerable boost in nutritional quality, particularly in omega-3 fatty acids, is produced by using encapsulated chia seed oil in the production of butter, with very minor effects on sensory qualities. Research done by Ivanova *et al.* [16] found that fortification with phytosterols before the pasteurization process leads to the creation of a functional product with potential health effects.

2.5 Ice cream

Popular desserts like ice cream provide a special chance to include components that are good for human health. Ice cream is a particularly appealing carrier for the stabilization and delivery of beneficial microorganisms and functional chemicals due to its structural and colloidal composition and capacity to be kept at low temperatures. Recent research has suggested that adding probiotics, prebiotics, dietary fiber, natural antioxidants, polyunsaturated fatty acids, minerals, and sweeteners with a low glycemic index might improve ice cream's nutritional value [17]. Studies show that food products that were not previously thought to be probiotic-friendly can be functionalized. Because of the possible health advantages that probiotics may offer, their usage in ice cream has received a lot of interest lately. Beneficial probiotic bacteria can help the host's health when given in sufficient doses and have been demonstrated to enhance gut health and treat digestive issues including constipation and diarrhea in ice cream [18, 19]. Soukoulis *et al*. [17] detected that the integration of polyunsaturated fatty acids to ice creams decreased the risk of heart disease and stroke. PUFAs are necessary fatty acids that must be received through food because the body cannot generate them. While augmenting food products with essential nutrients may offer significant health benefits, there are also questions about their effectiveness and safety that need to be addressed. Discussions should include how fortification practices affect a population's overall dietary habits, and any flaws should be addressed with appropriate legislation and active monitoring.

3. Techniques of Encapsulation

The initial step in the encapsulation process is the construction of a barrier around the object to be encased. The building of this wall can involve the utilization of a variety of components, including lipids, proteins, and polysaccharides. These materials are chosen for their capacity to produce durable coatings and for being compatible with the bioactive agent that will be enclosed. The bioactive agent and encapsulating material are commonly combined during the wall creation stage and treated using several methods, including spray drying, coacervation, and electrostatic deposition. With the use of these methods, the bioactive substance may be coated uniformly and steadily to shield it from environmental challenges including heat, light, and moisture. Preventing accidental leaking of the enclosed substance is the second phase in encapsulation. This is crucial when the bioactive substance is meant to be released gradually over time or in a particular area. Leakage can happen when the covering material is insufficiently stable or when the encapsulating material is broken, such as during handling or transportation. Several methods, such as cross-linking the encasing substance, making a multi-layered coating, and utilizing permeable membranes, can be used to avoid unintentional leaking. These methods can increase the material's stability and toughness, which can assist in guaranteeing that the bioactive ingredient is only released when and where it is needed. Controlling the purity of the encapsulated product is the last stage in the encapsulation process. This is crucial when the encapsulated substance is meant to be used in food, medicine, or cosmetic purposes. When unwelcome substances like microbes, allergies, or chemical residues get into the encapsulated product, contamination can happen. Several methods, including sterile processing, quality control testing, and regulatory compliance, can be used to assure product purity. These methods can aid in making sure the enclosed product is secure, efficient, and in compliance with rules and regulations.

3.1 Spray Drying

Microencapsulation is a new method that uses a hard core surrounded by a wall of uniform thickness to create microscopic particles that cluster into thin layers. The coat has a thickness of (0.2-500.0 mm) and protects against chemical processes. The maker of encapsulated food components has created several encapsulating procedures. Gum Arabic is used to produce encapsulated flavors via spray drying, an established and popular encapsulation technique in the food industry. Spray drying is extensively used, affordable, and easy to maintain [80].

Spray drying encapsulation is generally favored due to cost savings over other encapsulating processes. By protecting the bioactive components, oils are encapsulated using the spray drying technique to enhance the handling characteristics of the products and to promote oxidation stability [20].

Pomegranate seed oil was encapsulated using the most common spray drying technique since it is a highly unsaturated fatty acid that quickly oxidizes, protecting its bioactive components and extending shelf life. Whey protein (WP) was utilised both on its own and in a 1:4 weight ratio with maltodextrin (MD). Feed emulsion, droplet size, encapsulation efficiency (EE), moisture, bulk density, powder form, particle size, hygroscopicity, and solubility were the variables examined. The following spray drying settings were used: feed rate of 5.2 g/m, pump rate of 40%, airflow rate of 40-42 m3/mint, and output temperature range of 60 to 67 °C. The particles had dents on their surfaces and were round and rounded. The oxidative stability was assessed after encapsulation for 15 days at 60 °C. (8 h daily). The emulsion's total solid content was 35%, and the droplet size was smaller. In terms of EE (90%) and oxidative stability, WP alone outperformed WP and MD as wall materials [78].

Spray drying produces microcapsules of the matrix kind. The core might be found as micro panicles or microdroplets dispersed throughout the dry solid matrix. Despite growing efforts to distinguish between encapsulated and entrapped goods, spray drying is technically classified as a microencapsulation technique. Although the distribution of capsule size during microencapsulation depends on numerous process parameters, spray drying generally results in microcapsules smaller than 100 pm n size [62].

In general, spray drying is an accessible and cost-effective encapsulation technique. To enhance the handling qualities and oxidation stability of flavors and oils, it is utilized to encapsulate them. The features of encapsulating pomegranate seed oil included feed emulsion, droplet size, encapsulation efficiency, moisture, bulk density, powder form, particle size, hygroscopicity, and solubility. Whey protein alone beat whey protein + maltodextrin in terms of encapsulation effectiveness and oxidative stability. Matrix microcapsules are produced by spray drying, and the core may be seen as tiny particles or droplets dispersed throughout the dried solid matrix.

3.2 Coacervation

A common encapsulation method termed coacervation involves separating the hydrocolloid from the main solution, which creates a different liquid phase known as a "coacervate." The coacervate is the continuous phase of the three-phase system created by this process, and the equilibrium solution is the second phase. Four processes make up the coacervation process: suspending the core material particles in the liquid phase, secreting the second liquid phase (coacervate), depositing liquid polymer around the core, and lastly gelling and forming the microcapsule wall. There are two categories of coacervation: simple (SC) and complex. (CC).

When just one polymer is involved, simple coacervation takes place. It can be salted out by electrolytes (sodium sulphate), desolated by the addition of a water-miscible non-solvent (ethanol), or changed by altering the temperature [76].
One illustration of simple coacervation is sodium alginate. Here, sodium alginate is dissolved in water together with the active ingredient that must be enclosed, which is often an oil. The resultant emulsion is then released in drops into a gel-forming medium like calcium chloride. Sodium alginate and calcium chloride mix ionically to produce calcium alginate. Numerous research has been published that shows how successful this method is for microencapsulation [21].
A proposed method for creating nanoparticles with a lipid core is encapsulation by complicated coacervation. Complex coacervation is a unique and reliable microencapsulation method because it is thought to be the spontaneous liquid/liquid phase separation in colloidal systems caused by the electrostatic interaction between two oppositely charged colloids [22].
Gelatin, alginate, and polymers are common examples of intricate coacervation. To get positive charges, gelatin must be dissolved in water with an acidic pH, whereas alginate must be dissolved in water with a basic pH. The alginate solution fully incorporates the active ingredient to be encapsulated. The alginate and gelatin phases are then aggressively combined, and the temperature is raised until the chemical reaction between the alginate and gelatin phases starts. A polycationic-polyanionic insoluble polymer develops around the active component, encasing it. Flaxseed oil was encapsulated and stabilized by Liu *et al*. (2010) using a sophisticated coacervation technique. In this instance, two polymers with opposing charges, gelatin, and gum Arabic, made up the wall components [21].
Coacervation procedures for encapsulation generally fall into two categories: simple coacervation and complex coacervation. Simple coacervation involves a single polymer that is either dissolved by the addition of a water-miscible nonsolvent or salted out by electrolytes. In a simple coacervation, sodium alginate is dissolved in water and combined with the active ingredient to create an emulsion that is discharged in drops into a gel-forming medium like calcium chloride. In complicated coacervation, the use of two colloids with opposing charges causes spontaneous liquid/liquid phase separation in colloidal systems. Alginate and gelatin are two examples of complex coacervation that occur often. In this technique, the active component is absorbed into the alginate solution and then coupled with the active component.

3.3 Extrusion

This process involves dropping aqueous polymer solution droplets into a bath solution that is gelling. Sodium alginate (0.6-3%) is the polymer that is most frequently used in a calcium chloride gelling bath solution. The dropping tool might be a pipette, syringe, vibrating nozzle, spraying nozzle, jet cutter, or vibrating disc. This method is frequently employed to stabilize volatile flavors. Co-extrusion is used for highly concentrated and viscous cores or encapsulant incorporation and particle fabrication, resulting in the formation of matrix microstructure. Conventional extrusion is typically used for particle fabrication by forcing a mixture of core and encapsulants through the nozzle. Small encapsulates with a mononuclear microstructure are produced by co-extrusion, which happens when the core and encapsulants flow at high frequency from the same outlet. Shell thickness is determined by the flow rate of the encapsulants and core materials as well as the vibration frequency. Alginate may create hydrogels by cross-linkages with cations and possesses a negative charge over a wide pH range. Due to the manufacture of a desired product, Ca+2 is the most used cation. Enough cross-linking is formed at higher alginate and cation concentrations, such as calcium chloride solution, and increased encapsulation efficiency. To boost storage stability, extruded encapsulates can be dried by freeze drying or fluidized bed drying; however, freeze drying produces a porous structure and lower encapsulation efficiency [3].
Sodium alginate was employed as the coating material to encapsulate a mixed bacteria culture of Streptococcus thermophilus and Lactobacillus bulgaricus to boost survival during spray drying of sweetened yoghurt. The impact of nozzle air pressure (200, 300, 400, and 500 kPa), sodium alginate concentration (1%, 1.5%, 2%, 2.5%, and 3% w/v), calcium chloride concentration (0.1, 0.2, and 1 M), and hardening time (15, 30, 45, and 60 min) on the survival of encapsulated bacteria was investigated. The microcapsules got bigger when the alginate concentration was higher; they got smaller when the nozzle air pressure was higher. The size of the microcapsules boosted encapsulation effectiveness. Up to 30 minutes, hardening time had a beneficial impact; beyond that, it was insignificant. When the sodium alginate level was increased, the survival rate of the encapsulated bacterial cells significantly increased. S. thermophilus encapsulated and free cells had a survival ratio of 2.48 101 and 2.36 103 during spray drying of sweetened yoghurt, whereas L. bulgaricus had a survival ratio of 7.26 101 and 8.27 103, respectively. According to this study, microencapsulating yoghurt culture in sodium alginate is a successful way to protect bacterial cells against abrasive drying conditions [23].
Using instruments like a pipette or syringe, droplets of a polymer aqueous solution are added to a gelling bath solution to encapsulate volatiles and unstable flavors. The most common polymer in a calcium chloride gelling bath solution is sodium alginate. For particle manufacturing, conventional extrusion and co-extrusion are utilized, with co-extrusion producing small encapsulated with a mononuclear microstructure. Ca+2, the most common cation, forms cross links with alginate to make hydrogels. To improve storage stability, extruded encapsulates can be dried using fluidized bed or freeze drying. To maximise survival during spray drying of sweetened yoghurt, a mixed bacterium culture of Streptococcus thermophilus and Lactobacillus bulgaricus was encapsulated with sodium alginate using an improved extrusion spraying method. The survival ratio of encapsulated bacterial cells was investigated in relation to nozzle air pressure, sodium alginate concentration, calcium chloride concentration, and hardening time, with increased sodium alginate content resulting in higher survival ratios. Bacterial cells may be effectively protected from extreme drying conditions by being microencapsulated in sodium alginate with yoghurt culture.

3.4 Emulsion

The emulsion solvent evaporation/extraction process involves emulsifying a drug-containing polymer solution in an immiscible/miscible solvent known as non-solvent. Polymer deposition around the drug particles is the result of the partitioning of the polymer solvent from the dispersed phase to the continuous phase followed by the removal of the polymer solvent through evaporation/extraction [79].

In order to encapsulate hydrophobic medications, the oil-in-water (o/w) emulsification technique has mostly been used in the single emulsion approach. The drug is dissolved or suspended in a polymer solution that has been dissolved in a volatile organic solvent like dichloromethane that is immiscible with water. The final combination is emulsified in a sizable volume of water when an emulsifier is present. When the solvent in the emulsion is extracted in a sizable amount of water or evaporates at high temperatures, compact microparticles are created. It has been proposed that the speed of solvent evaporation affects the final shape of microparticles. How rapidly the solvent is eliminated depends on several factors, including the solvent being used, the medium temperature, and the solubility characteristics of the polymer [77].

Recently, membrane emulsification has been researched as an innovative encapsulation platform, with droplet solidification acting as the next stage in particle manufacturing. It has been used to manufacture a wide range of particulate systems, including solid lipids, polymers, inorganic oxides, carbon, and microcarrier microspheres such chitosan gel beads, alginate beads, and chitosan alginate beads. To produce microcapsules as well as other porous and core/shell morphological particles. However, membrane emulsified aqueous core microencapsulation has not yet been demonstrated using UV-initiated radical polymerization. To the authors' knowledge, membrane emulsification has not yet been applied to the creation of materials that can cure themselves [24].

Overall, the method of encasing pharmaceuticals in a polymer solution uses the emulsion solvent evaporation/extraction process. The medicine is dissolved or suspended in a polymer solution that is dissolved in a volatile organic solvent that is immiscible with water when using the single emulsion method. This combination is emulsified using an emulsifier in a sizable volume of water to create compact microparticles. The rate of solvent evaporation, which is influenced by several factors including the solubility of the polymer, the medium temperature, and the solvent being used, determines the ultimate shape of the microparticles. The production of solid lipids, polymers, inorganic oxides, carbon, metals, and micro-carrier microspheres, among other particulate systems, has recently been investigated as a cutting-edge encapsulation platform to produce microcapsules and other porous and core/shell morphological particles. However, the microencapsulation of aqueous cores produced by membrane emulsification has not yet been shown using UV-initiated radical polymerization.

4. Bioactive Compounds

Bioactive compounds are substances found in foods or dietary supplements that can alter the health of people or animals who consume them. Small amounts of bioactive chemicals are found in food, mostly in fruits, vegetables, and whole grains, and supply health benefitss above their fundamental nutritional worth. Despite making up a small fraction of a food source, these substances have the potential to activate processes that will change and enhance human health. Major bioactive compounds used in dairy fortification are Carotenoids, Phenolic compounds, Phytosterols, Enzymes, Essential oils, Fatty acids, Vitamins, and Minerals [25]. In addition to plants, these invaluable molecules are also extracted from animal tissues and even agro-industrial byproducts [26]. Bioactive compounds are supposed to possess antioxidant, immunity-boosting, and antimicrobial characteristics, and are reported to abate allergic, cardiovascular, cancerous, and inflammatory complications [27]. Milk fortified with Probiotics, prebiotics, and synbiotics is reported to have a positive impact on the management of metabolic ailments such as diabetes [19]. Nutraceutical foods are those enriched, or improved foods that, when ingested at effective levels, offer health advantages in addition to the delivery of vital nutrients while also being instrumental in treating many diseases [28, 29] and are offered to consumers in the form of functional foods, drinks, personal care items, and supplements. The market for functional foods is increasing at a remarkable pace as more conscious consumers are demanding enriched items. Martirosyan *et al.* [29] also stated that the positive effects of functional foods are mainly driven by bio-active compounds which is in congruence with inferences made by Mondal *et al.* [30] In addition to having intrinsic health properties, milk products are ideal substrates for integrating bioactive ingredients, making them real functional food items [31, 32]. Milk-based beverages, fermented milk, yogurts, and cheese which are fortified are very well taking up the space of their nonfunctional, traditional counterparts and creating a niche in the whole dairy food industry. The pace at which various bioactive substances are effectively utilized determines how well functional foods work. In fact, the actual utilization effect of functional products is greatly influenced by the stability, form, and consumption rate of healthy functional foods [33].

4.1 Micro and Nano-capsules

A lot of naturally occurring bioactive substances are unstable and susceptible to oxidation, which is accelerated by light exposure and influenced by temperature, pH, and moisture content [34]. The microencapsulation and Nano encapsulation techniques, which retains a component susceptible to unfavorable environmental conditions inside of a protective polymeric substance, is touted to increase the stability of bio active materials [35].

The method of microencapsulation involves enclosing minute components of a substance in a protective coating or shell to produce a tiny capsule. These capsules can be used to fortify food products with a variety of functional components, including vitamins, minerals, tastes, and bioactive chemicals [1].

Micro-particles, microspheres, and microcapsules are frequently used components in multi particulate drug delivery systems and offer many benefits based on their unique structures and functionalities. One advantage of microencapsulated products over nanoparticles is that they are larger than 100 nm, and therefore do not move into the interstitial tissue and are transported only by the lymph, allowing them to act locally [36]. This implies that potentially dangerous compounds can be transported safely within the encapsulation and that liquids can be dealt like dried solids. Due to their excellent technological characteristics and adaptability, composite molecule delivery strategies such micro and nano pellets, microgranules, microsponges, and liposomes have received interest throughout the years [36, 34].

In contrast to microcapsules, where a number of cores are coated by the wall material (mono nuclear or poly nuclear) such that the wall material used for coating the active ingredient can be either a single layer or multiple layers, the core material in microspheres is dispersed within and on the surface of the matrix. On the other hand, the shape of micro-particles can vary depending on their content [37].

Microspheres are particularly useful for sustained release applications, as the active ingredient will be scattered across the medium. Microcapsules, on the other hand, can be utilized for targeted delivery to specific sites in the body, with the option of a single or multiple layer wall material. The use of micro-particles, which can have various shapes, allows for the handling of liquids as solids, making them easier to store and handle [36].

Microencapsulation produces different proportions ranging between 1 and 1000 micrometers, with microspheres, microcapsules, and micro-particles being most notable. When utilized to enhance dairy products or milk, nano-materials can act as transporters or encapsulating material for added flavor, antioxidants, minerals, vitamins, or other beneficial compounds. They can also be used as components in biosensor devices, as agents that defend against harmful microorganisms, or in the creation of next generation packaging materials [38].

4.2 Probiotics

Probiotics are helpful microorganisms, which include bacteria and yeast strains that can provide a variety of health benefits when consumed in adequate amounts. Probiotic bacteria can create a variety of functional substances, such as bacteriocins, metabolites, proteins and peptides, lipids, antioxidants, inflammation and immunity regulating substances, and extracellular polysaccharides [39]. By introducing helpful bacteria and decreasing harmful bacteria, probiotics can maintain a balanced gut microbiome improving the overall health and immune response [40]. Because probiotics' viability is significantly decreased during food storage and gastrointestinal transit, the potential health advantages of these organisms may not be achieved. The resilience of these microbes can be improved through numerous microencapsulation techniques [41]. Extrusion, emulsion, and drying are the three main types of microencapsulation techniques used for probiotics. Techniques like lyophilization and coacervation are also employed during the commercial manufacturing of encapsulated probiotic cells [42]. Different bacterial strains have been found to exhibit probiotic properties, however, the most prevalent ones found in the digestive system are from the genera Lactobacillus and Bifidobacterium [43].

4.3 Prebiotics

Prebiotics are non-digestible carbohydrates with short chains that, upon consumption, assist in advancing desirable, beneficial microbial populations within the colon while simultaneously having an antagonistic effect on pathogenic microbes. Prebiotics are usually added directly to food products as an ingredient, such as inulin being added to yogurts, snacks, and beverages [44]. Commonly used prebiotic molecules fructooligosaccharides, Gluco and galacto saccharides, and soluble dietary fibres like beta-glucan, and psyllium husk are primarily derived from sources like plant, animal, and microbes [40]. Single *et al.* [45] observed that prebiotics alter the final texture, fiber content, and sensory and physiological properties of the consumable favorably. These particles are able to traverse through the digestivel tract undamaged and be fermented by helpful gut bacteria in the colon as they are already tolerant to the hardy sour environment of the stomach and the digestive juices. Hence, prebiotics does not require microencapsulation to be protected when traveling to the gut. Yet, some researchers have looked into the advantages of prebiotics that have been microencapsulated. Nami *et al.* [46] found that the progression of microencapsulated probiotic cells in the intestinal tract was aided by herbal gums acting as prebiotics. Prebiotics can be shielded from heat, light, and other environmental elements that could diminish or obstruct their effectiveness. Microencapsulation also enhances prebiotic stability in food products. Prebiotics that are microencapsulated could be consolidated into multiple food items, including beverages, cereals, and baked goods. For instance, Nanoparticles and microcapsules were used by Ismail *et al.* [47] to entrap chit-oligosaccharide which had prebiotic and antioxidant activities to extend its stability in yogurt.

4.4 Omega-3 fatty acids

Omega fatty acids are unsaturated lipid molecules that have been linked to a number of health advantages, including improved cardiovascular health, better brain function, reduced inflammation, improved eye and joint health, and even diminished chances of developing certain cancers and autoimmune disorders [48]. Eicosapentaenoic acid along with docosahexaenoic acid are the two primary forms most used for augmentation [6]. These molecules are typically supplied straight to the food item or encapsulated using different methods including emulsification or liposome production. Omega fatty acids are established for their health advantages but because of their oxidative instability, it can be challenging to add them to human diet. These fatty acids can easily oxidize and take on unfavorable tastes when exposed to air or heat. This oxidative process can also result in the development of toxic substances such as peroxides and aldehydes, which can lower the food's nutritional value and perhaps have detrimental consequences on health [49]. The emergence of undesirable smells and scents can also have a detrimental effect on the product's sensory qualities, lowering its general quality and consumer acceptance. These bio-actives could be better protected and given to the body by adopting microencapsulation techniques [48], which have a stronger positive impact on health. By incorporating these nutrients in a wider variety of foods as part of a balanced diet, this technique provides the door for people to ingest more omega-3 fatty acids, improving their overall health and wellness. Complex coacervation and spray-dried emulsions are the two commercial methods that are most frequently employed for this purpose [50, 12].

4.5 Vitamins

Vitamins are organic compounds responsible for various important physiological function and also has antioxidants, immunoregulatory, and anti-inflammatory neuroprotection properties. The human body requires a very small amount for normal functioning but deficiency can cause severe health issues in a person [51]. Various methods and strategies are used for the formulation of lipo-soluble vitamin carriers, considering many factors such as physicochemical properties, process choice, the interaction between determined particle and encapsulated protein with morphology, efficiency, and permeability resulting in 2 types of particle generation which are vitamin soluble in lipo based formation and another one with polymer entrapment around vitamin. After the completion of the processing these encapsulations are applied for oral administration to check its compatibility with the human digestive process including it bio-accessibility and bioavailability. On the intestinal track and digestive juices [75]. Vitamin C and vitamin B Which are water soluble vitamin are easily degraded because of several reason such as pH, sunlight, moisture, oxygen which effect it shelf life, encapsulation of such vitamins have gain popularity in recent year as it is easily accessible and vitamin content for not get degraded overtime [52].

4.6 Minerals

Minerals are essential for sustaining the body's regular function and for a balance diet, bioactive compounds improve the health benefits by elevating the food organic compounds. Encapsulation help delivering the necessarily bio active compound in food application [53]. Mineral fortification into food is still under development and not a mainstream research moreover sometimes these micronutrient can effect the flavor, texture, smell and taste which can make people not savor it and additional mineral in the food more than required category can lead to oxidation but the answer to this question is encapsulation technology allowing then to disperse With great stability into the medium. Emulsion techniques is better suited for encapsulation of mineral and can be done in two ways seperated with the difference of droplets and continuous phase. First one consust of oil droplets in continuous water phase called oil in water(O/W) and the other one consist of water droplets in continuous oil phase called water in oil(W/O). With the help of different medium which increases the solubility of mineral for emulsion encapsulation for example oil in water help in fortification of water based food product and water in oil help in fortification of oil based food products basically dairy product such as milk, yogurt, cheese and many more [54].

4.7 Polyphenols

Polyphenols have been of great interest in different fields such as nutraceutical and pharmaceutical and functional food has several health benefits such as preventing cancer, and inflammation, antiviral, anti-bacterial, reduces the chances of cardiovascular, diabetes, and osteoporosis nerve system degeneration and it's associated diseases, and aging but due to their unstable structure proper utilization of polyphenol has not been done but due to new technological advancement and discovering different high-efficiency encapsulation Techniques, especially emulsion we have to render the potential of polyphenols by maintaining its chemical and structural stability and bio-accessibility by encapsulation Techniques. Emulsion-based polyphenols can include single, multiple, and Nano-emulsion depending on varietal composition and range of emulsion properties focused on providing bioactive nutrition such as unsaturated fatty acid with many other nutrients in the same synergy without changing the food taste also enhances the bioavailability of half-life compounds of polyphenol in both *in vivo* and *in vitro* [55]. Other encapsulation Techniques can also be effective such as coacervation used in the separation phase of hydrocolloids in the initial solution and also for the accumulation of coacervate around active ingredient suspended or emulsified depending on the process resulting in a stable colloidal structure of gum or gelatin [56].

5. Stability and Bioavailability of Micro-Encapsulated Products

There are several difficulties when incorporating biologically active ingredients into nutraceutical foods, especially when it comes to the durability and steadiness of the compounds throughout processing, transit, and the requirement to avoid unfavorable reactions with the substrate [57]. The bioavailability and assimilation of these compounds in target areas can be hindered by a certain factors, such as the dietary matrix, the size of the molecules, environmental conditions, and interaction with gastrointestinal material [58]. Bioavailability is further defined by the terms bio-accessibility and bioactivity [59]. This is evident in a study done by Neuenfeldt *et al.* [60] in blueberry where sensitive phenolic compounds such as cyaninidins, delphinidins, pelargonidins, peonidins, petunidins, and malvidins were guarded through spray drying technique of microencapsulation resulting in greater assimilation. In the same vein, a study on polyphenolic compounds obtained from fruit juice extract found that microcapsules coated with maltosaccharide and gum produced greater stability in an environment of 25 degree celsius and 33 and 52% relative humidity [61]. Interestingly, encapsulated samples fared better in comparison to the non-coated compounds thus highlighting the enhancement in stability offered by microencapsulation techniques. Controlled release of biologically active substances and antimicrobial properties were observed in microencapsulated essential oil in toned milk at low concentrations against pathogenic Escherichia coli and Listeria monocytogenes [62]. The same study reported a surge in thermal durability of the encapsulated volatile compound. In addition to shielding the core material, microencapsulation techniques also ensure improvement in oxidative stability of essential oils, masking unpleasant tastes in the food matrix and even improving solubility and mixing properties [20]. Spray drying can produce oil-Lactic acid bacteria co-microcapsules that decrease lipid oxidation, stabilize emulsions, and increase bacterial survival rates, opening the way for an effective and reasonably priced approach in the food industry [63]. The sustenance of probiotic bacteria Bifidobacterium and Lactobacillus improved by using stevia extracts coupled with the microencapsulation technique [64]. Thus the organoleptic qualities of synthetic food items can be critically influenced by these techniques when the global interest in functional and alternative food choices is spiking. Research indicated that the increase and production of acid by Microencapsulated *Lactobacillus reuteri* were comparable to that of non-encapsulated ones, and the process of encapsulating it through spray-drying did not have an impact on its protein expression or its ability to prevent bacterial growth [65]. The findings of study done by Jiang *et al.* [66] showed that when exposed to simulated small intestinal fluid, the recombinant *Lactobacillus plantarum* that had been encapsulated and expressed cells containing morphogenetic proteins, completely released the active ingredient from the microcapsules. This release occurred within 12 hours, suggesting that the encapsulation process provided controlled release and the ability to withstand gastrointestinal stress. Furthermore, this controlled release and resistance to gastrointestinal stress could potentially lead to improved effectiveness of the recombinant Lactobacillus plantarum in target applications such as the delivery of therapeutic proteins to the gut. Likewise, Junzhang Lin *et* *al.* [67] focused on examining the *in vivo* properties of microcapsules made from alginate and chitosan encapsulating viable bacteria. The results showed that these microcapsules were stable when ingested by rats and passed through the gastrointestinal tract. The results showed that these microcapsules were stable when ingested by rats and passed through the gastrointestinal tract owing to the enhanced hardiness offered by microcapsules. The study proposes the potential of microcapsules as a promising platform for delivering live bacterial cells as a therapeutic strategy in various fields such as probiotics and biotechnology. The stability of the microcapsules ensures that the live bacterial cells are protected and remain viable during transit through the gut, thereby improving their potential efficacy and effectiveness in target applications clearing the path for a food that has a genuine functional purpose [68].

6. Application of microencapsulation in dairy products

Lately, several opportunities for microencapsulation have been discovered, including the creation of novel dairy industry processes and food products such as food processing, food packaging, ingredient advancements, and food safety and biosecurity all go hand in hand with creating new, better, and tastier meals. In contrast to plant-derived foods, animal-derived foods use microencapsulation technology much more frequently, particularly to preserve probiotics in dairy products [69]. As such, the rise of several dairy food items that are enhanced and fortified results in improvements in malnutrition abatement. One of the primary benefits is the ability to inhibit microbial growth, ensuring that the food remains safe for consumption [21]. In addition, microencapsulation could be applied to enhance the sensory and rheological features of food, such as texture, mouth feel, flavor release, as well as food structure, and prevents the incompatibility between different target biological compounds [70]. When added to food products in their original state, some substances, such as vitamins and minerals, might have undesirable off-flavors and aromas that can be covered up via encapsulation. Microencapsulation's protective layer serves as a barrier, regulating the rate of release and providing the ideal environment for the distribution of the encapsulated chemical effectively reducing the toxicity of certain compounds by preventing their immediate contact with sensitive tissues [62, 4]. As it can lower the frequency of doses required and prevent potential adverse effects, this can be particularly crucial for therapeutic foods or other types of foods. Microencapsulation is another method for incorporating antioxidants into food goods, which helps consumer health [71]. Microencapsulation can assist in stabilizing food by preventing the breakdown of fats and oils and so increasing the longevity of the good. A promising method for enhancing probiotic bacteria's efficacy during final refinements is to utilize microencapsulation, which can tailor the distribution to the gastrointestinal system allowing creation of a wide range of such augmented goods in the market [19]. Probiotic bacteria microencapsulation has gained popularity as a technique to enhance delivery in the host and increase the shelf life of products containing probiotics. By lowering the rate of bacterial loss and enhancing the uniformity of bacterial count, microencapsulation can prolong the shelf life of probiotic products. Dairy producers may elongate the usage span of their goods and provide customers with dairy products that maintain their nutritional and functional advantages for a longer length of time by adopting microencapsulation processes [772]. In addition to this, self-repairing characteristics of certain microencapsulated items are also being evaluated by researchers although literature regarding its application in the dairy industry is minimal.

7. Challenges and future trends for microencapsulation in the dairy industry

Encapsulation technology has been used in many industries since it was formally introduced for commercial purposes. This technology has made major strides over the last 60 years and is gaining popularity as a highly effective method that may be used for a number of things in the nutraceutical, and functional food industries. Even though microencapsulation has a lot of potential for enhancing the functionality and quality of dairy products there are several problems and possible future advancements connected to this strategy in the realm of dairy industry.

Not every application or product is a good fit for microencaps ulation. Certain items might not hold up to the encapsulation procedure or be compatible with the materials employed for e ncapsulating [73]. Researchers are investigating encapsulation techniques for novel bio-actives and working to advance the process and product properties. The expensive cost of microencapsulation technology, which can restrict its usage in industrial-scale dairy production, is one of the key obstacles. Quality control testing is also essential in ensuring even distribution of active compounds and effectiveness of microcapsules in protecting them from environmental factors, which can be more challenging when scaling up production. The manufacturing process and storage conditions can have an impact on the credibility and functionality of the microencapsulated previotics and probiotics in dairy products, hence additional research is required on their stability and effectiveness [18]. A significant challenge to overcome is the potential for product degradation during the encapsulation process. The high temperatures and pressures involved in some encapsulation methods can guide to changes in the Physico-chemical composition or physical properties of active ingredient, which can affect its effectiveness [74]. The functional benefits offered by bioactive compounds to human wellness may also be sabotaged by different food manufacturing aspects such as processing, storage, and movement and absorption in the gastro-intestinal tract. The development of microencapsulation methods using organic, ecological, and biodegradable materials is gaining popularity. This may lessen the negative effects of microencapsulation on the environment while simultaneously satisfying consumer desire for greener products. However meeting strict regulatory standards, conducting extensive testing, and complying with labeling and marketing guidelines are necessary requirements for adding bioactive compounds to dairy products. As such the environmental soundness of the underlying technologies could be re-evaluated. Yang *et al.* [69] deemed the spray-drying method of microencapsulation the most advantageous because to its low cost and adaptability for mass production, however, it is not entirely free from environmental impact. This makes new, innovative pollution-free techniques such as that of layer-by-layer self-assembly and electrospray are prospective and worth looking into in the future. Individualized doses of minerals or supplements designed to satisfy particular nutritional needs through microencapsulation techniques could redefine the direction of research in this line. Sterile processing is also crucial to prevent contamination of the product during microencapsulation, which can be particularly difficult when working with dairy products that are highly susceptible to bacterial growth. Another category of functional dairy products is lactose-free milk and dairy alternatives, which are designed for people who are lactose intolerant [42]. Microencapsulation can aid in producing these items by shielding lactase enzymes, which break down lactose into simpler sugars that can be digested by lactose intolerant individuals, from acidic stomach conditions and preserving flavor and aroma compounds lost during lactose removal.

8. Conclusion

Probiotics, prebiotics, omega-3 fatty acids, vitamins, minerals, and polyphenols are just a few examples of bioactive chemicals that can be considerably improved by the use of encapsulation, a promising technique. This process entails enclosing the item to be encapsulated in a protective barrier, stopping unintentional leakage, and assuring product purity through stringent quality control testing. Microencapsulation is a commonly used technique that yields microspheres, micro-particles, and microcapsules in a variety of sizes. The most popular microencapsulation methods are spray drying, coacervation, extrusion, and emulsion. These methods can increase the stability and bioavailability of the chemicals that are encapsulated, avoiding environmental stresses like heat, light, and moisture from causing them to degrade. Due to the possible health advantages, functional dairy products with living microorganisms, such as probiotic yogurts, kefir, and fermented milk products, are gaining popularity. Probiotics, prebiotics, and other beneficial substances can be improved in dairy products by encapsulation, assuring their efficacy and safety for customers. There are difficulties in using encapsulation in the dairy business which should be addressed going forward. For encapsulated goods to be safe and effective, regulatory compliance and quality control testing are crucial. The sector is expanding, meanwhile, because of improvements in encapsulation techniques and rising consumer demand for beneficial dairy products. Encapsulation technology may be utilized to create novel goods like biosensors and next-generation packaging materials in addition to improving the nutritional value of dairy products. In summary, encapsulation is a promising technique that might completely transform the dairy sector by improving the nutritional value, stability, and bioavailability of functional dairy products. The invention of novel goods that satisfy the interests and desires of health-conscious consumers should be greatly encouraged by ongoing research and development in this area.

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