MICROENCAPSULATION TECHNOLOGY AND ITS COMMERCIAL APPLICATIONS: A COMPREHENSIVE REVIEW

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Article History: Received: 07.03.2023 **Revised:** 20.05.2023 **Accepted:** 12.07.2023

Abstract:

Microencapsulation is a commonly employed method in the food, beverage, and healthcare sectors. It enables food processors to protect sensitive food components, avoid nutritional loss, use otherwise sensitive ingredients, and incorporate unusual or time-release mechanisms into the formulation, mask or preserve Flavors and aromas and convert liquids into easily handled solid ingredients. One crucial function can be offered by microencapsulation at the appropriate location and time. A targeted and timely release increases the efficiency of food additives, expand the variety of applications for food ingredients and assures the right dosage, all of which increase the cost benefits for food producers. The article gives an overview of reasons for microencapsulation, polymers used for coating, mechanism of core release, microencapsulation techniques, and application in various industries.

Keywords : Application; Cosmetics; Food industry; Microencapsulation; Polymer;

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DOI: 10.31838/ecb/2023.12.s3.654

1. Introduction:

Commercially, the microencapsulation process is used to create a variety of food and beverage products. The method is employed in the industry for a variety of consumer-pleasing qualities, including flavor enhancement, increased solubility, antimicrobial control, scent or odor masking, continuous energy release and appearance modification.[1] Microencapsulation of food ingredients has become an extraordinary tool in providing solutions to consumers' demand for more convenient, nutritious, safe-to-eat, natural, energy-providing, experiential and interactive foods and packaging as global food consumption habits continue to change.[2] As a result, microencapsulation has evolved into dynamic and crucial technology with applications spanning the entire food and beverage spectrum, from well-being and health to flavor and taste creation, interactive food and packaging, and food safety. While microencapsulation of food ingredient technologies is widely accessible, the market is fully saturated with ready-to-eat food and beverage products. These technologies enable precise processing, packaging, distribution, longer shelf life and bioavailability of particular nutrients after consumption. [3]

Microencapsulation is a rapidly developing technique in which polymeric material encloses or coats very small droplets or particles of liquid or solid substance. [4] In simple words, a microcapsule is a tiny sphere with a consistent wall surrounding it. The wall of a microcapsule is commonly known as the shell, coating, or membrane whereas the substance inside is known as the core, internal phase or fill. [5] The stability of the core material is strongly affected by the choice of shell material, which may be a film made of natural, semi-synthetic or synthetic polymer.[6] Most of the microcapsules have diameters of a few microns to a few millimeters. [5] The majority of microcapsules have a size between 1 to 1000 µm. [7]

Green and Schleicher introduced the concept of microencapsulation for the first time in the 1950s with a patent application for the development of capsules containing dyes that were designed to be inserted into paper for copying purposes. [8,9] It is possible to encapsulate all three states (solid, liquid and gas), which may change the size and shape of the capsules. The resulting capsule may have an asymmetrical shape if the core is made of a solid or crystalline substance. If the core is made from liquid, the resultant capsules are simple and spherical in shape. [10]

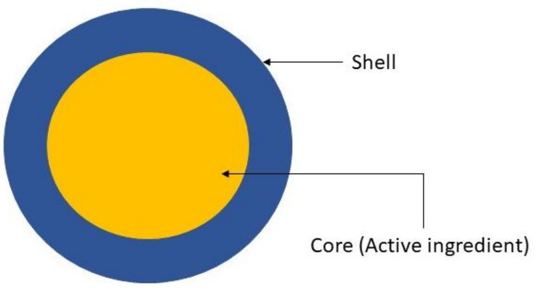

Figure 1. Microcapsule

Microcapsules are divided into three categories based on the composition of the core and the method used to produce the shell.

1) Mononuclear/single core: - Microcapsule contains the shell around the core.
2) Polynuclear/ multiple cores: - In polynuclear capsules, the shell encloses several cores.
3) Matrix type: - Matrix encapsulation includes uniform distribution of core material throughout the shell material.

Along with these three fundamental morphologies, microspheres can also be mononuclear with many shells or form microsphere clusters. [10]

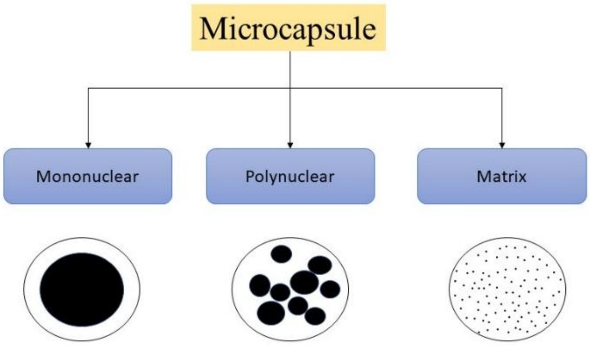

Figure 2. Types of Microcapsules

1.1. Reasons for Microencapsulation:

- The major purpose of microencapsulation is either prolonged or sustained medication release.
- To increase patient compliance, this approach has been frequently employed to alter the taste and odour of several medications.
- To reduce unfavorable impacts and health consequences.
- Microencapsulation can be used to protect medications that are susceptible to oxygen, light and moisture.
- Microencapsulation can be used to prevent drug incompatibility.
- Microencapsulation prevents the vaporization of volatile drugs.
- To lessen toxicity and GI discomfort, many medications have been microencapsulated, e.g., ferrous sulfate and KCl.
- Microencapsulation also has the potential to change the absorption site. For medications with toxic effects at lower pH levels, this application has been helpful.
- Vitamin A palmitate is microencapsulated to increase stability and stop oxidation. [11]

1.2. The material used in microcapsule synthesis:

1.2.1. Core material –

The core material is referred to as the substance that will be coated, whether it be solid or liquid. The solid core consists of active substances, stabilizers, diluents, excipients, and release rate retardants, Whereas the liquid core includes dissolved or dispersed ingredients. [12]

1.2.2. Coating material –

The ability of the coating material is to produce a coat that is cohesive with the core substance. The ideal properties of coating material include,

- ✓ Compatible and non-reactive with core material
- ✓ Inert towards active substance
- ✓ Should be capable to form a film
- ✓ Controlled release under specific condition
- ✓ It should be stable, non-hygroscopic, tasteless, soluble in water and economical. [13]

1.2.3. Different polymers used for coating in microencapsulation:

Following natural and synthetic polymers are used for coating microcapsules. [15]

Table 1. Different polymers used for coating in microencapsulation

Types of polymers	**Examples**
Natural polymer:	
Protein	Albumin Gelatin Collagen
Gums	Gum Arabic Sodium alginate carrageenan
Cellulose	Carboxymethylcellulose Methylcellulose

Lipids	Bees wax Stearic acid Phospholipids
Carbohydrates	Starch Dextran Sucrose Agarose Chitosan
Chemically modified carbohydrate	Polystarch polydextran
Synthetic polymer:	
Biodegradable	Lactides Glycolides and co-polymers Poly alkyl cyanoacrylates Poly anhydrides
Non-biodegradable	Acrolein Glycidyl methacrylate Epoxy polymers Poly methyl methacrylate

2. Mechanism Involved In Drug Release From Microcapsules:

The only way when microencapsulation is considered to be effective is when the core material is properly protected until the release is required. The release of the core material is achieved by a variety of mechanisms. Degradation, diffusion, dissolution and erosion,[14] include some of these. The qualities of the core and the wall material are used to determine the mechanism.[15]

2.1. Degradation:

In this process core release, proteins and lipids in the wall material are degraded by enzymes such as proteases and lipases, which causes the wall to break and the core to be released.[15]

2.2. Diffusion:

It is the most typical method of drug release from the core material when dissolution fluid enters the shell, contacts the core and causes leakage through interstitial channels or holes. Drug release is based on

1 The speed at which drugs dissolve in solution.

2. Rate of dissolution fluid entering the microcapsules and the speed at which the dissolved medication eludes the microcapsules.[16]

2.3. Erosion:

As a result of pH or enzymatic hydrolysis of the coat, the drug is released by the erosion process. It has become difficult to release drugs from microcapsules, because of size, shape, material compositions of the core and coat of microcapsules can vary physically.[16] Physical and chemical characteristics of the covering material, such as thickness, porosity as well as the solubility, diffusibility and partition coefficient of the core material. This makes modeling drug release challenging. However, based on several studies examining the release characteristics, the consideration is possible such as drugs released from microcapsules according to zero order kinetics. The first half of the total drug release from monolithic microcapsules is $t^{1/2}$ dependent, whereas the remaining half is exponentially decreasing.[17]

2.4. Dissolution:

When the polymer coat is soluble in the fluid used for dissolution, the rate at which the drug is released from the microcapsule is determined by the rate at which the coat dissolves. The release rate is influenced by the coat's thickness and its solubility in the dissolution fluid.[18]

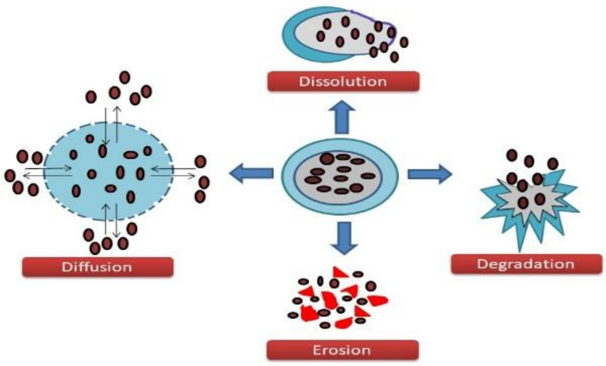

Figure 3. Drug release mechanism from the microcapsule

3. Methods for preparation of microcapsules:

Methods used for preparation of microcapsules are as follow [6]

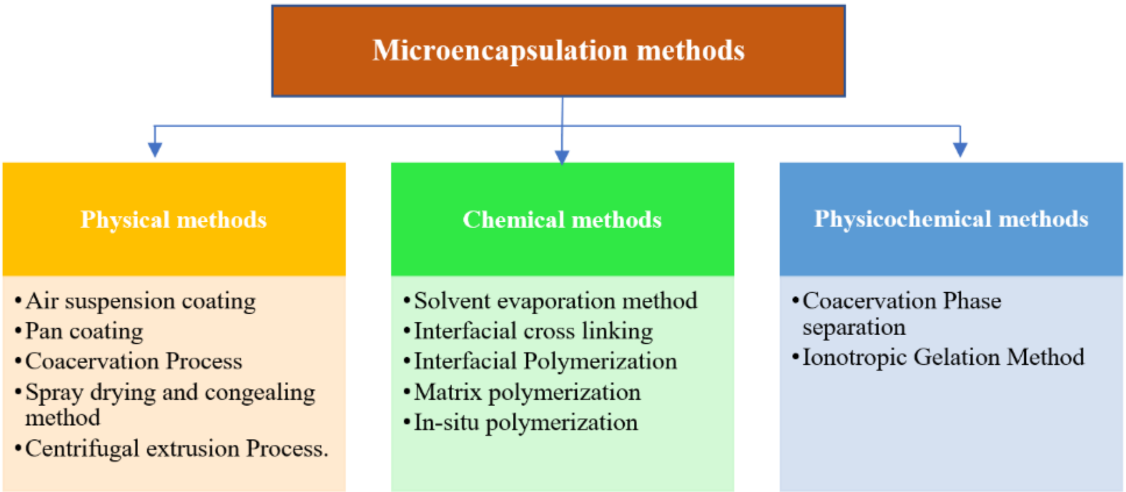

Figure 4. Methods for preparation of microcapsules.

Table 2. Various techniques used for microencapsulation

Sr. No	Core material	Shell material (polymer)	Microencapsulation method	Application	Reference
1	Peppermint oil	Hydroxypropyl methylcellulose/ chitosan	Emulsification	Medicinal	[19]
2	Turpentine oil	polydopamine	Emulsification	Agriculture	[20]
3	Rosemary oil	Sodium alginate	Extrusion	Agriculture	[21]
4	Lemongrass oil	Poly (vinyl alcohol)	Simple coacervation	Pharmaceutical	[22]
5	Lavender oil	Gelatin/gum Arabic	Complex coacervation	Cosmetics	[23]
6	Rose oil	Apricot peel pectin	Complex coacervation	Food	[24]

7	Lemongrass oil	polyurea	Interfacial polymerization	Agriculture	[25]
8	Cinnamon oil	Poly (melamine formaldehyde)	In-situ polymerization	Agriculture	[26]
9	Lavandin and tea tree	Melamine /formaldehyde	In-situ polymerization	Paints	[27]
10	Citrus oil	Maltodextrin	Spray drying	Food	[28]
11	Ginger oil	Palm trunk	Spray drying	Food	[29]
12	Fish oil	Sodium caseinate and casein hydrolyzate	Spray drying	Food	[30]
13	Lycopene	Cyclodextrin	Spray drying	Pharmaceutical	[31]
14	Epoxy, mercaptan	Poly methyl methacrylate	Solvent evaporation	Pharmaceutical	[32]
15	Glauber's salt	Poly methyl methacrylate	Solvent evaporation	Textile	[33]
16	*Lactobacillus casei* ATCC 393	Skim milk	Spray drying	Beverages	[34]
17	*Lactobacillus casei*	Sodium alginate, Chitosan	Emulsification	Beverages	[35]

4. Applications:

Microencapsulation technique is extensively utilized in many industries, particularly the food, beverage and healthcare industries. Because it can enhance solubility, stability and controlled drug release properties of compounds such as essential oils, antioxidants, enzymes, drugs and so on.[36]

4.1. Food:

Functional ingredients are used in the food industry to increase the Flavor, color, texture qualities of products and to lengthen their shelf lives. Moreover, nutrients that have functional health advantages, such as probiotics and antioxidants, are of great interest.[37] The synthesis of high-stability bioactive compounds is essential, because low-stability compounds are easily decomposed by environmental conditions. Using the microencapsulation method can solve these problems. There has been a huge amount of research recently on the production of high-efficiency microcapsules and their use in the food sector.[38]

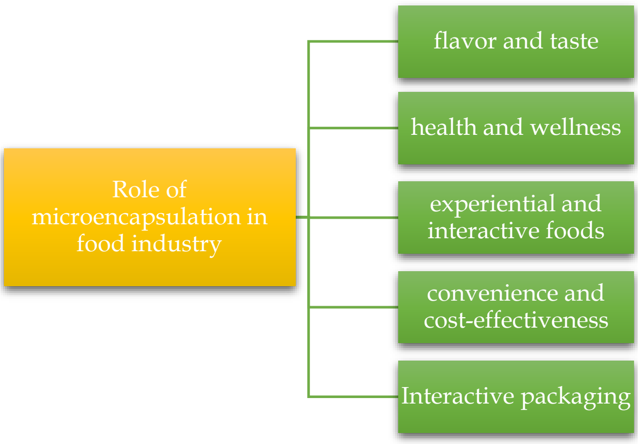

Figure 5. Role of microencapsulation in the food industry

❖ Dairy Products: By introducing probiotic microorganisms, various ice creams have recently been made. However, probiotic bacteria viability is impacted by processing and storage conditions.[39] The viability of probiotic bacteria in ice cream is studied in relation to the effects of microencapsulation using the spray-drying method.[40]

- ❖ Poultry and meat: Increased bacterial cell viability was achieved via the microencapsulation technology, which contained the bacteria inside a protective polymer membrane or matrix.[41] Omega-3 fatty acid microcapsules from fish oil are added to frozen chicken nuggets.[42]
- ❖ Bakery products: Vegetable shortening was encapsulated to boost oxidative stability and turn fat into a stable powder for use in making short bread biscuits.[43]

There are various uses for microencapsulated olive oil in the food industry. Antioxidant-rich diet has become increasingly popular and in demand all over a range of societies due to its benefits for overall health. [44] Olive oil and lemon juice were mixed in a 1:1 ratio and the encapsulated mixture was successfully used in an immediate salad sauce.[45] It has also been reported to use microencapsulated olive oil in spread cheese and yoghurt. [46]

4.2. Beverages:

Functional products are the largest and fastest-growing market sector and a unique trend in the creation of healthy food. Customers favour prebiotics and probiotics as they play important role in the diet.[47] Prebiotics are food element that is hardly digestible and that encourages the development and activity of one or a small number of good bacteria in the intestine. [48]

To stop the degradation of both curcumin and catechin in beverage systems, water-in-oil-in-water emulsions are used to create curcumin and catechin microcapsules.[49] The spray-drying method is used to encapsulate lemon oil with maltodextrin. Lemon oil is mostly utilized as a flavouring component in food and beverages because of its strong, pleasant aroma.[50]

Anthocyanins are a type of water-soluble pigment that is frequently employed as food and beverage colorants. [51] However, anthocyanins are unstable pigments that can break down into colorless substances in response to a variety of conditions, including pH, temperature, light, oxygen and the food matrix. [52] Thus microencapsulation is used to increase the stability of this compound. [53]

4.3. Pharmaceutical applications:

It was discovered that microencapsulation decreased the rate of oil evaporation and provided a viable way to extend citronella oils potential for use as a mosquito repellent.[54] Textile fibers are being used in medicine more frequently every day. Such materials should possess desired qualities for medical application including Flexibility, softness, strength, elasticity, good biostability, permeability and sterilizability. It has been discovered that adding jojoba oil microcapsules to the compressive knits used to treat severe burns kept the knits' original qualities including softness, flexibility and lightness in addition to hydrating the skin and preventing sebum buildup.[55] Encapsulation olive oil is used in healthcare companies as a treatment to reduce oxidative stress, which is linked to cancer, arteriosclerosis and cardiovascular disorders.[56]

4.4 Cosmetic Applications:

Encapsulates can be used in a variety of ways in cosmetics and household products, where creams, shampoos, gels, soaps, surface cleaning solutions and perfumes are frequently hidden. Demands from consumers are growing, as interest in natural fragrances. Once a product is used, the scent is anticipated to linger for a very long period.[57] To meet the high expectations of consumers, scent components might be encapsulated. So far, using essential oils with antibacterial activities in place of preservatives can be beneficial commercially as well.[58] Volatile essential oils can be encapsulated for controlled release application over time. [59]

4.5 Textile:

The textile industry also employs a microencapsulation process to enhance the operational qualities of fabrics. [60] Natural essential oils are increasingly popular with consumers and are frequently used in the textile industry. In addition to their sensory qualities, these oils also have antibacterial, antiviral, antifungal, anti-inflammatory and insect-repellent effects. Essential oils can have skin-care, anti-aging or odor-controlling effects, when they come into contact with the skin through microcapsules on clothing. [61] Chitosan microcapsules have been utilized in textiles to create materials with antibacterial and antioxidant activity,[62] insect repellency,[63] Persistent scents,[64] and a thermoregulating response.[65] The behavior of cotton fabrics containing microcapsules attached to their fibers was explained by Monllor, Bonet and Cases. Who also identified the connection between their macroscopic and microscopic characteristics. [66]

4.6 Agriculture:

Crop protection is one of the most significant uses of microencapsulated products. Insect pheromones are a biorational substitute for traditional hard insecticides that are becoming more and more effective today. Particularly, by preventing the insect from mating, sex-attractant pheromones can lower insect populations. Few amounts of species-specific pheromones are released during the breeding season, increasing the background level of the pheromone to the point where it hides the pheromone plume released by its female mate. By spraying the capsule dispersion, polymer microcapsules, polyurea, gelatin, and gum arabic act as effective delivery vehicles for the pheromone. Also, during storage and release, encapsulation shields the pheromone from light and oxidation. [67]

4.7 Printing and paper industry:

The creation of carbonless copy paper, one of the most well-known and earliest uses of mechanically activated functionality on paper substrates, has been one of the first sectors to successfully utilize microcapsules. Together with other pressure measurement applications, pressure-sensitive films incorporating microcapsules are used in the manufacturing of paper, packaging and other graphic materials to monitor and regulate the pressure difference and intensity [68] The visual impact of the printed matter is nearly entirely responsible for the printing industry's perception of product quality. By applying scents that are securely contained inside microcapsules, advancements in printing technology allow humans to use their olfactory and physical senses in addition to their sensory awareness. [69]

5. Conclusion:

In the microencapsulation process solids, liquids and gas are entrapped**.** It has been used in a wide range of products from various industries. The use of microencapsulated food ingredients for controlled-release applications is a promising alternative to solving the major problem of food ingredients faced by food industries. Although there is an extensive range of encapsulated products developed, manufactured, and successfully marketed in the pharmaceutical and cosmetic industries, microencapsulation has found a much smaller market in the food and beverage industry. The biggest challenge of microencapsulation is selecting the proper conditions to create highly efficient microcapsules. The preparation methods, types of core material and types of wall material are just a few of the many elements that influence the efficiency of microcapsules. Studies have demonstrated that microencapsulation has a significant potential to add beneficial qualities to the core, producing goods of higher quality. Even though there are many different encapsulation techniques, research is constantly being done to develop new and better ways to encapsulate different materials.

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