Diverse Approaches to Microencapsulation in Food Processing

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Microencapsulation can be defined as a process of enclosing or enveloping wherein solids, liquid or gaseous material (core particle) are compactly packed with thin polymeric coatings (matrix) to form small particles referred to as microcapsules in the micrometer (µm) to millimeter (mm) range (2-5000 µm) (Gibbs *et al.,* 1999).Microencapsulation is a versatile technology that has gained significant attention in the food industry due to its potential to enhance the stability, bioavailability, and controlled release of various bioactive compounds and ingredients. Microencapsulation involves the encapsulation of active ingredients, such as flavours, aromas, vitamins, minerals, probiotics, enzymes, and functional lipids, within a protective matrix or shell. This encapsulation process offers numerous advantages, including improved ingredient protection against degradation caused by environmental factors like light, heat, and oxygen, as well as the ability to mask undesirable tastes or odours. Several microencapsulation techniques are employed in the food industry to achieve these goals. Spray drying is a widely used technique that involves atomizing a liquid formulation into droplets, which are then rapidly dried to form encapsulated particles. Coacervation involves the phase separation of polymers around the active ingredient, leading to the formation of microcapsules. Inclusion complexation, electrostatic deposition, freeze drying and extrusion are other techniques that offer unique ways to encapsulate ingredients. The choice of microencapsulation technique depends on factors such as the nature of the ingredient, the desired release profile, and the intended application. Microencapsulation finds applications in a variety of food products, including beverages, baked goods, dairy products, and functional foods. The technology enables the controlled release of active compounds during consumption, which can result in extended flavour perception, improved nutrient absorption, and targeted delivery of bioactive compounds to specific areas of the digestive tract.Additionally, it improves sensory quality by reducing unpleasant tastes, aromas, and flavours, prevention of germ's growth (Hasanvand*et al.,* 2015).Various flavourings agents, lipids, antioxidants, essential oils, pigments, probiotic bacteria, and vitamins are several dietary components that are commonly encapsulated (Azeredo, 2005).

Using various protective wall materials that allow them to be released at a particular place, at a specific time, and under specific conditions. Microencapsulation can be a solution to the problems faced in the formulation of complex foods. Such foods have recently been put on display in the food sectors, such as the usage of some volatile flavours in instant mixes and fatty acidsin dairy products, which are especially susceptible to auto-oxidation. The solution to this problem is microencapsulation.

Classification of Microcapsules

The term "microcapsules" describes microparticles with a core surrounded by a coat or wall materials that are distinctly different from the core, payload, or nucleus, which may be solid, liquid, or even gas.

As shown in Figure 1, there are three categories of microcapsules:

a) Mononuclear: Containing the core in a shell.
b) Polynuclear: Having several cores encased in a shell.
c) Matrix type: Evenly distributed throughout the shell material

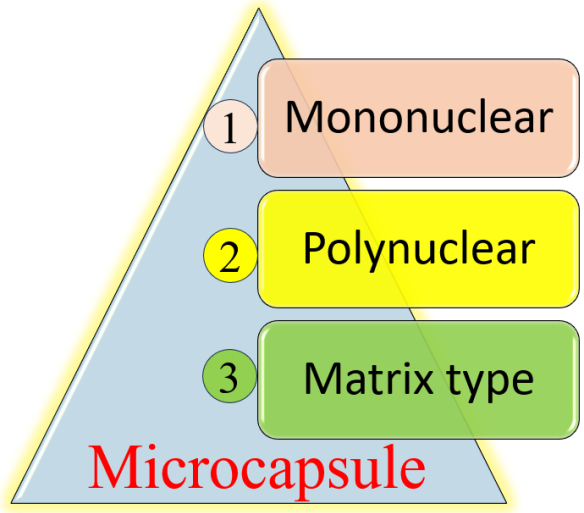

Fig. 1: Classification of Microcapsules

Methods of Microencapsulation Techniques

There are various techniques for microencapsulation, including freeze drying, fluidized bed coating, spray chilling, spray cooling and coacervation.

Spray drying: Probiotic cultures in the dairy and pharmaceutical industries are encapsulated through spray drying. This involves rapidly evaporating water from a suspension solution of microbial cells with wall material in a drying chamber (Fig. 2). The hot, dry air contacts the atomized spray droplets, resulting in the collection of dried solid particles at the chamber's bottom. This technology enables the fast and cost-effective production of spherical powder particles with desired qualities, such as uniform shape, size, and residual moisture content.

Table 1. Microencapsulation Techniques and Their Principle

Microencapsulation process	Principle	Nature of core material
Spray drying	Forming an emulsion or dispersion and atomizing the mixture into the drying chamber.	Solids and liquids
Spray cooling	Condensing the core within a liquid shell and ejecting it through a heated nozzle into a controlled cold setting.	Solids and liquids
Freeze drying	Transforming ice into vapor rapidly.	Liquid and solid
Fluidized bed coating	Core material particles are suspended in an air stream and coated with molten polymer.	Solids
Emulsification	Create an emulsion by mixing core and wall materials, then stabilize it with an emulsion stabilizer.	Solids and liquids
Coacervation	Creating three immiscible chemicals, coating deposition, and coating digitization.	Solids and liquids

Spray cooling: Spray cooling utilizes cold air in the process, distinguishing it from spray drying. The mixture of core and wall materials is atomized in a chamber with cold air, causing the microdroplets to solidify and form microencapsulated powder. This method has great growth potential and has been successfully used for various encapsulation applications. For example, it has been used to achieve high encapsulation efficiency of tocopherols in a lipid matrix (Gamboa *et al.*, 2011) and to create highly stable microcapsules for encapsulating iron, iodine, and vitamin A in hydrogenated palm oil for salt fortification (Wegmüller*et al.*, 2006).

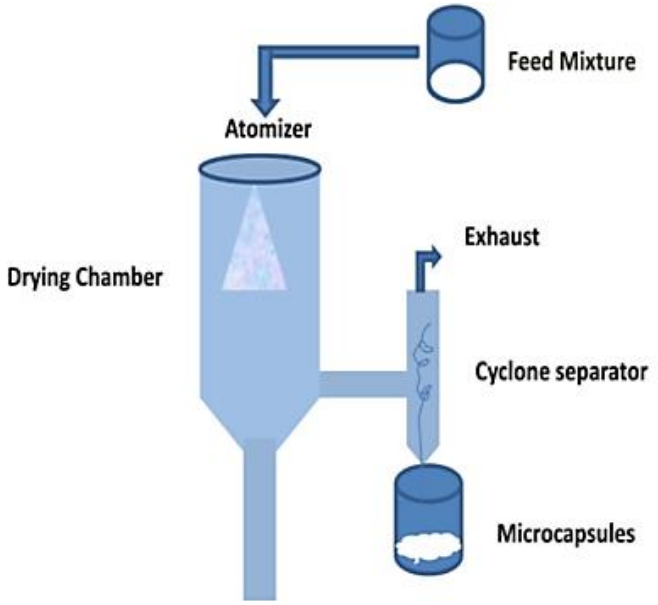

Fig. 2 Microencapsulation by Spray Drying

Freeze drying: Freeze drying operates on the principle of sublimation, where ice rapidly transforms into vapor. The process consists of three steps: freezing, primary drying, and secondary drying. Freezing causes water to crystallize and separate at extremely low temperatures. Sublimation then eliminates frozen water during primary drying, while desorption-based secondary drying removes any remaining non-frozen water. It's important to note that low freezing temperatures can potentially impact protein structures and the physical state of membrane lipids.

Fluidized bed coating: Fluidized bed coating involves covering the fluidized core material with a coating material. Air is used to fluidize the core material, and then the coating material is sprayed onto it, as shown in figure 3. There are three methods for coating a fluidized bed: top spray, bottom spray, and tangential spray. The effectiveness of the coating depends on factors such as the feed rate of the wall material, atomization pressure of the nozzle, temperature, and velocity of the incoming air, etc.

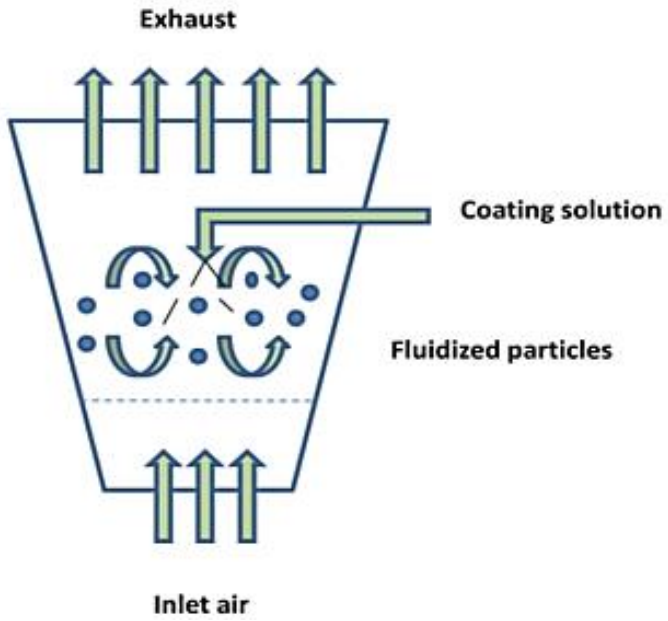

Fig. 3 Microencapsulation by Fluidized Bed Coating

Coacervation: Coacervation involves forming a uniform layer of polymeric wall material around the core (Fig. 4). This is achieved by modifying the physicochemical properties of the wall material through temperature, pH, or ionic strength changes. The wall and core materials are mixed to create an immiscible mixture. By adjusting the ionic strength, pH, or temperature, phase separation occurs, forming

dense polymer-rich liquid droplets called coacervates. These coacervates then encapsulate the core substance, creating microcapsules.

Extrusion: The extrusion method of microencapsulation is used to produce highly dense microcapsules. This method requires the core material and the wall material to be immiscible, as shown in figure 5. Using concentric nozzles, the wall material surrounds the core material and is pushed out in the form of droplets. These droplets then solidify either through complex creation in a gelling bath or by cooling. Compared to other methods, the microcapsules produced through extrusion tend to be larger in size. However, the range of materials that can be used for the walls in this method is limited.

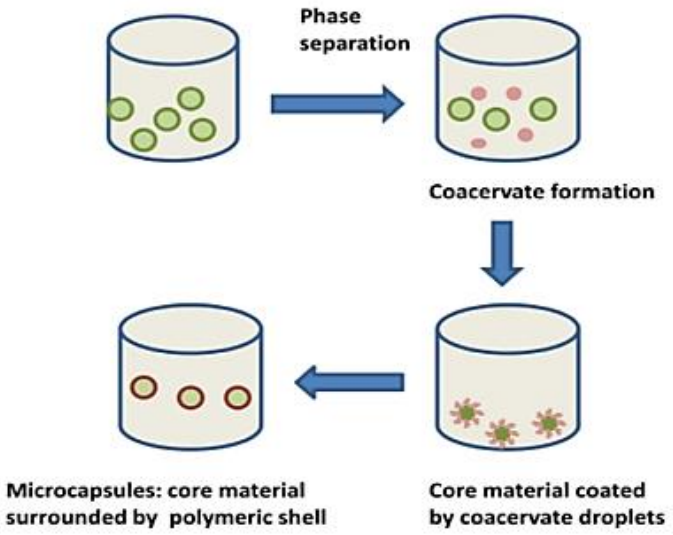

Fig. 4 Microencapsulation by Coacervation

Emulsification: In the emulsification process of encapsulation, the core is dispersed in an organic solvent with the wall material. An emulsion stabilizer is added and the mixture is emulsified in oil or water. As the solvent evaporates, a tight polymer layer forms around the core, enclosing it. This method is commonly used for encapsulating enzymes and bacteria. Song *et al.* (2013) encapsulated probiotics in alginate-chitosan using this technique and demonstrated improved resistance of the probiotics to stimuli in the gastrointestinal tract.

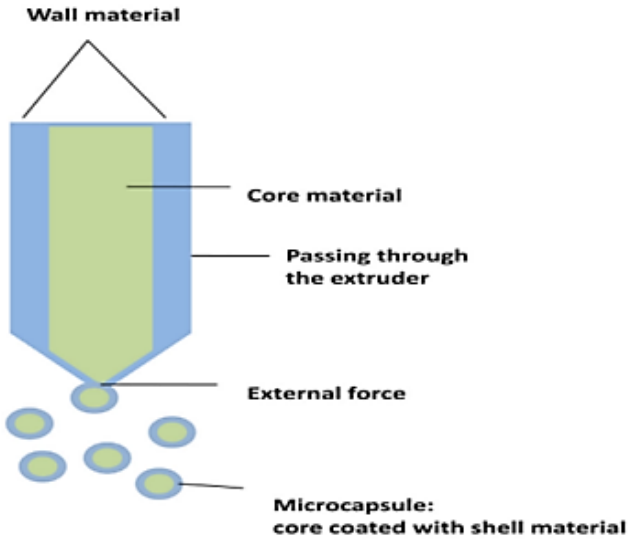

Fig. 5 Microencapsulation by Extrusion

Advantages and disadvantages of the Microencapsulation Process

(A) Advantages of microencapsulation:

a) Providing environmental protection to the encapsulated active agents or core materials.

b) Liquids and gases can be changed into solid particles in the form of microcapsules.

c) Surface, as well as colloidal characteristics of various active agents, can be changed.

d) Modify and delayed drug release from different pharmaceutical dosage forms.

e) Formulation of sustained controlled-release dosage forms can be done by modifying or delaying the release of encapsulated active agents or core materials.

(B) Disadvantages of microencapsulation:

a) Expensive techniques.

b) This causes a reduction in the shelf-life of hygroscopic agents.
c) Microencapsulation coating may not be uniform and this can influence the release of encapsulated materials.
d) There are a number of restrictions when encasing food items since the wall materials must be food grade or generally recognized as safe (GRAS).

Conclusion

Microencapsulation techniques, including extrusion, freeze drying, fluidized bed coating, spray chilling, spray cooling, and coacervation which are help to extend the shelf life of products and improve it improves sensory quality by reducing unpleasant tastes, aromas, and flavours, additionally, it raises food safety to inhibit the growth of pathogenic microorganisms.

Microencapsulation has proven and is further considered to prove as an effective tool in creating novel food products with numerous functional properties. Microencapsulation technology has applications for many commercial food products, including juices, chocolates, meat and poultry products, etc. Microencapsulation has been applied widely in a variety of food and pharmaceutical products. Studies have shown its enormous potential to provide superiorly featured core, resulting in advanced quality products applicable in the food and pharmaceutical industry. It provides an effective protection for active agent against oxidation, evaporation or migration in food as well as facilitate conversion of liquids to powders.

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