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MICROENCAPSULATION TECHNOLOGY: A REVIEW

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ABSTRACT

The development of new functional foods requires technologies for incorporating health promoting ingredients into food without reducing their bioavailability or functionality. In many cases, microencapsulation can provide the necessary protection for these compounds. Microcapsules offer food processors a means to protect sensitive food components, ensure protection against nutritional loss, utilize sensitive ingredients, incorporate unusual or time-release mechanisms into the formulation, mask or preserve flavors/aromas and transform liquids into easy to handle solid ingredients. Various techniques cab be employed to form microcapsules, including spray drying, spray chilling or spray cooling, extrusion coating, fluidized-bed coating, liposomal entrapment, lyophilization, coacervation, centrifugal suspension separation, cocrystallization and inclusion complexation. This article describes the recent and advanced techniques of microencapsulation. Controlled release of food ingredients at the right place and the right time is a key functionality that can be provided by microencapsulation. Timely and targeted release improves the effectiveness of food additives, broadens the application range of food ingredients, and ensures optimal dosage, thereby improving the cost effectiveness for the food manufacturer.

Currently, there is a trend towards a healthier way of living, which includes a growing awareness by consumers of what they eat and what benefits certain ingredients have in maintaining good health. Preventing illness through diet is a unique opportunity to use innovative functional foods (Hilliam, 1996 and Sheehy and Morrissey, 1998). Microencapsulated products often present new challenges to food product developers. Existing ingredients that are incorporated into food systems slowly degrade and lose their activity, or become hazardous, by propagating a chain of oxidation reactions. Ingredients also react with components present in the food system, which may limit bioavailability, or change the colour and taste of the product. In many cases, microencapsulation can be used to overcome these challenges. Microencapsulation is a technology that may be useful for generating small particles that aggregate into thin layers. The simplest of the microcapsules consist of a core surrounded by a wall or barrier of uniform or non-uniform thickness. The thickness of the coat ranges from several to hundreds of micrometres (0.2–500.0 mm) and protects against degradative chemical processes (Rodrigues and Grosso, 2008).

Microencapsulation is defined as a process in which tiny particles or droplets are surrounded by a coating or embedded in a homogeneous or heterogeneous matrix, to give

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small capsules with many useful properties. Microencapsulation can provide a physical barrier between the core compound and the other components of the product. It is a technique by which liquid droplets, solid particles or gas compounds are entrapped into thin films of a food grade microencapsulating agent. The core may be composed of just one or several ingredients and the wall may be single or double-layered. The retention of these cores is governed by their chemical functionality, solubility, polarity and volatility. Shahidi and Han (1993) proposed six reasons for applying microencapsulation in food industry: to reduce the core reactivity with environmental factors; to decrease the transfer rate of the core material to the outside environment; to promote easier handling; to control the release of the core material; to mask the core taste and finally to dilute the core material when it is required to be used in very minute amounts. In its simplest form, a microcapsule is a small sphere with a uniform wall around it. The material inside the microcapsule is referred to as the core, internal phase or wall, whereas the wall is sometimes called shell, coating, wall material or membrane. Practically, the core may be a crystalline material, a jagged adsorbent particle, an emulsion, a suspension of solids or a suspension of smaller microcapsules.

Microencapsulation has many applications in food industry such as to protect, isolate or control the release of a given substance which is of growing interest in many sectors of food product development. Converting a liquid into a powder allows many alternative uses of ingredients. One of the largest food applications is the encapsulation of flavours (Shahidi and Han, 1993).

The objective of this paper is to review the state of the art techniques of microencapsulation of food ingredients by different processes and present necessary theoretical and practical information on these processes. The influence of processing technology and matrix materials used on the stability and bioavailability of these ingredients is also discussed.

Structures of microcapsules

Most microcapsules are small spheres with diameters ranging between a few micrometers and a few millimeters. However, many of these microcapsules bear little resemblance to these simple spheres. In fact, both the size and shape of formed micro particles depend on the materials and methods used to prepare them. The different types of microcapsules and microspheres are produced from a wide range of wall materials like monomers and/or polymers (King, 1995; Shahidi and Han, 1993). Depending on the physico-chemical properties of the core, the wall composition and the microencapsulation technique used, different types of particles can be obtained (Fig. 1): A simple sphere surrounded by a coating of uniform thickness; A particle containing an irregular shape core; Several core particles embedded in a continuous matrix of wall material; Several distinct cores within the same capsule and multi walled microcapsules.

Microencapsulation Techniques

Encapsulation of food ingredients into coating materials can be achieved by several methods. The selection of the microencapsulation process is governed by the physical and chemical properties of core and coating materials and the intended application of food ingredients. The microencapsulation processes that are used to encapsulate food ingredients are given in Table 1, which outlines various methods used for the preparation of microencapsulated food systems. Sophisticated shell materials and technologies have been developed and an extremely wide variety of functionalities can now be achieved through microencapsulation. Any kind of trigger can be used to prompt the release of the encapsulated ingredient, such as pH change (enteric and anti-enteric coating), mechanical stress, temperature, enzymatic activity, time, osmotic force, etc. However, cost considerations in the food industry are much more stringent than in the pharmaceutical or cosmetic industries.

In general, three precautions need to be considered for developing microcapsules: formation of the wall around the material, ensuring that leakage does not occur and ensuring that undesired materials are kept out. Encapsulation techniques include spray drying, spray chilling or spray cooling, extrusion coating, fluidized-bed coating, liposomal entrapment, lyophilization, coacervation, centrifugal suspension separation, cocrystallization and inclusion complexation (Table.1) (Gibbs *et al*.1999).

The selection of microencapsulation method and coating materials are interdependent. Based on the coating material or method applied, the appropriate method or coating material is selected. Coating materials, which are basically film-forming materials, can be selected from a wide variety of natural or synthetic polymers, depending on the material to be coated and characteristics desired in the final microcapsules. The composition of the coating material is the main determinant of the functional properties of the microcapsule and of how it may be used to improve the performance of a particular ingredient. An ideal coating material should exhibit the following characteristics (Goud and Park, 2005):

1. Good rheological properties at high concentration and easy workability during encapsulation.
2. The ability to disperse or emulsify the active material and stabilize the emulsion produced.
3. Non-reactivity with the material to be encapsulated both during processing and on prolonged storage.
4. The ability to seal and hold the active material within its structure during processing or storage.
5. The ability to completely release the solvent or other materials used during the process of encapsulation under drying or other desolventization conditions.

6. The ability to provide maximum protection to the active material against environmental conditions (e.g., oxygen, heat, light, humidity).
7. Solubility in solvents acceptable in the food industry (e.g., water, ethanol).
8. Chemical nonreactivity with the active core materials.
9. Inexpensive, food-grade status.

Table 1. Various microencapsulation techniques and the processes involved in each technique

No	Microencapsulation technique	Major steps in encapsulation
1	Spray-drying	a. Preparation of the dispersion b. Homogenization of the dispersion c. Atomization of the infeed dispersiond. Dehydration of the atomized particles
2	Spray-chilling	a. Preparation of the dispersion b. Homogenization of the dispersion c. Atomization of the infeed dispersion
3	Spray-cooling	a. Preparation of the dispersion b. Homogenization of the dispersion c. Atomization of the infeed dispersion
4	A. Extrusion	a. Preparation of molten coating solution b. Dispersion of core into molten polymer c. Cooling or passing of core-coat mixture through dehydrating liquid
	B. Centrifugal extrusion	a. Preparation of core solution b. Preparation of coating material solution c. Co-extrusion of core and coat solution through nozzles
5	Fluidized-bed coating	a. Preparation of coating solution b. Fluidization of core particles. c. Coating of core particles

No	Microencapsulation technique	Major steps in encapsulation
6	Liposomal entrapment	a. Microfluidization b. Ultrasonication c. Reverse-phase evaporation
7	Lyophilization	a. Mixing of core in a coating solution b. Freeze-drying of the mixture
8	Coacervation	a. Formation of a three-immiscible chemical phases b. Deposition of the coatingc. Solidification of the coating
9	Centrifugal suspension separation	a. Mixing of core in a coating material b. Pour the mixture over a rotating disc to obtain encapsulated tiny particles c. Drying
10	Cocrystallization	a. Preparation of supersaturated sucrose solution b. Adding of core into supersaturated solution c. Emission of substantial heat after solution reaches the sucrosecrystallization temperature
11	Inclusion complexation	Preparation of complexes by mixing or grinding or spray-drying

Because no single coating material can meet all of the criteria listed above, in practice either coating materials are employed in combinations or modifiers such as oxygen scavengers, antioxidants, chelating agents and surfactants are added. Some commonly used biocompatible and food-grade coating materials are listed in Table 2. However, chemical modifications of the existing coating materials to manipulate their properties are also being considered. Those modified coating materials exhibit better physical and mechanical properties when compared to individual coating materials.

Category	Coating materials	Widely usedmethods	References
Carbohydrate	Starch,maltodextrins, chitosan, corn syrup solids, dextran, modified starch, cyclodextrins	Spray- and freeze-drying, extrusion, coacervation, inclusion complexation	Godshall (1988); Flink and Karel (1970); Reineccius and Coulter (1989); Reineccius (1989); Reineccius (1991).
Cellulose	Carboxymethyl cellulose,methyl cellulose, ethylcellulose, celluloseacetate-phthalate, celluloseacetate butylate- phthalate	Coacervation, spray-drying,and edible films	Greener and Fennema (1989a); Greener and Fennema (1989b)
Gum	Gum acacia, agar, sodium alginate, carrageenan	Spray-drying, syringemethod (gel beads)	Dziezak, (1991)
Lipids	Wax, paraffin, beeswax, diacylglyerols, oils, fats	Emulsion, liposomes, film formation	Kamper and Fennema, (1984); Kim and Baianu, (1991)
Protein	Gluten, casein, gelatin, albumin, peptides	Emulsion, spray-drying	Ono, (1980)

Ref: Goud and Park, 2005

1. Spray Drying:

Spray drying is the most common microencapsulation technique used in food industry. Spray drying technique for producing encapsulated flavouring was discovered by A Boake Roberts in 1937, when acetone was accidently added to tomato puree which helped him to maintain colour and flavour of tomato powder during spray drying. Subsequently, spray drying has become the most important commercial process for making dry flavourings. Vitamins, minerals, colorants, fat and oil flavour, aroma compounds, oleoresins and enzymes have been encapsulated using this technique. It is an economical, as well as an effective

method for protecting materials and is most widely employed, particularly for flavours for which specialized equipment is not required.

For encapsulation purposes, modified starch, maltodextrin, gum or others are hydrated to be used as the carrier or wall material. The material for encapsulation is homogenized with the carrier material usually at a ratio of 1: 4. The mixture is then fed into a spray dryer and atomized with a nozzle or spinning wheel. Water is evaporated by the hot air contacting the atomized material. The capsules are then collected after they fall to the bottom of the drier (Gibbs, 1999).

Microencapsulation by spray drying offers advantages over conventional microencapsulation techniques by producing microcapsules via a relatively simple, continuous process. The spray drying equipment used is same as is used for the production of dry milk.

Common encapsulating wall materials used in spray drying

The most important step in encapsulation of any core material by spray drying is the selection of suitable wall material, which should form a continuous thin film and should protect the core material from deterioration. The material should be low in cost, should have mild taste and should be stable during storage.The desired functional profile of encapsulating material includes high solubility, effective emulsification, low viscosity at high level of solids, low hygroscopicity, easy release of core material and efficient drying properties. (Lee *et al.,* 2003)

a) Gum arabic (Acacia)

It is one of the oldest and traditional wall materials or carriers used in spray drying. It is a natural exudate from the trunk and branches of leguminous plants of the family Acacia. Although it is one of the most preferred wall materials, alternative carriers are being used for dry flavouring and other core materials due to its low production (300g/plant/year) and high cost.

b) Modified starches:

Chemically modified starches most closely reproduce the functional properties of gum arabic. Natural starches virtually have no emulsifying property. Esterification with cyclic dicarboxylic acid anhydride imparts emulsifying power to partially hydrolysed starches. This technique is practiced on a commercial scale to have the wall material tailor made. The modified starches are found to be superior to gum acacia in emulsifying properties and in retention of volatile flavours during spray drying (Varavinit, 2001).

c) Hydrolyzed starches:

This is one of the most common wall or carrier materials. The hydrolysed starches are available in dextrose equivalent (DE) ranging from 2 to 36.5 and offer good protection against oxidation. These are low in viscosity at high total solid contents. However, they lack in emulsifying properties. It is therefore used along with gum acacia or other emulsifying agents like protein, whey protein concentrates and whey protein isolates. Maltodextrin and low dextrose equivalent (DE) corn syrup solids (CSS) when dried, show matrix forming properties important in the wall system. (Kenyon & Anderson, 1998). When Maltodextrins or CSS are used as wall constituents, it is necessary to incorporate other wall material such as gelating agent, sodium caseinate, whey proteins, lecithins etc. for improving emulsifying characteristics. (Lin, *et al*. 1995).

d) Whey proteins:

As starch and related products lack emulsification properties, they are used as wall materials alongwith surface active wall constituents (Lin, *et al* 1995). Whey protein owing to their structure gives functional properties desired for effective microencapsulation of anhydrous milk fat. Whey protein in combination with maltodextrins and corn syrup solids are reported to be the most effective encapsulation material during spray drying (Kenyon and Anderson, 1998).

2. Spray Chilling

In spray chilling, the material to be encapsulated is mixed with the carrier and atomized by cooled or chilled air as opposed to heated air used in spray drying (Risch, 1995). The outer material is usually vegetable oil in the case of spray cooling (45 to 122°C) or a hydrogenated or fractionated vegetable oil in the case of spray chilling (32 to 42°C). Frozen liquids, heat-sensitive materials and those not soluble in the usual solvents can be encapsulated by spray chilling / spray cooling. It is the least expensive encapsulation technology and is routinely used for the encapsulation of a number of organic and inorganic salts like ferrous sulfate, vitamin, mineral or acidulents as well as textural ingredients, enzymes, flavors and other functional ingredients to improve heat stability, delay release in wet environments, and/or convert liquid hydrophilic ingredient into free flowing powders.

3. Spray Cooling

Spray cooling is called as ‘matrix’ encapsulation because the particles are more adequately described as aggregates of active ingredient particles buried in the fat matrix, while ‘true’ encapsulation is usually reserved for processes leading to a core/shell type of microencapsules. A matrix encapsulation process leaves a significant proportion of the active

ingredient lying on the surface of the microcapsules or sticking out of the fat matrix, thus having direct access to the environment. Particles produced by a matrix encapsulation process generally release their entire content within a few minutes after being incorporated in the food. A non negligible proportion of active ingredients can also be found on the surface of a core/shell type of microcapsule, but the bulk of the ingredient is encapsulated and much slower release kinetics are typically obtained. Even though the process does not lead to a perfect encapsulate, the properties obtained by spray cooling/ chilling are sufficient to achieve the desired delayed release of the ingredient in the actual application. However, a strong binding of the ingredient to the fat matrix can prevent the release of the ingredient even if the fat matrix is melted and/or damaged during processing. (Gouin S, 2004).

4. A. Extrusion:

Extrusion microencapsulation has been used almost exclusively for the encapsulation of volatile and unstable flavors in glassy carbohydrate matrices. The main advantage of this process is the very long shelf life imparted to normally oxidation-prone flavor compounds, such as citrus oils, because atmospheric gases diffuse very slowly through the hydrophilic glassy matrix, thus providing an almost impermeable barrier against oxygen. Shelf lives of up to 5 years have been reported for extruded flavor oils, compared to typically 1 year for spray dried flavors and a few months for un encapsulated citrus oils. Carbohydrate matrices in the glassy states have very good barrier properties and extrusion is a convenient process enabling the encapsulation of flavors in such matrices (Zasypkin and Porzio, 2004). This process can be used for encapsulating nutraceuticals. These processes could, theoretically use glassy carbohydrates as shell material, such as fluidize bed coating, but extrusion remains the most suitable process for such shell materials. The basis of the process was developed by Schultz *et al.,* (1956) and later improved by Swisher (1957). A lower temperature process is developed, in which a mass of potato starch, glycerol and water is processed and gelatinized in a twin screw extruder at about 100°C. The mass is then cooled down and the bioactive formulation is injected in the last barrel, where the temperature should approximately be 50°C. The extruded ropes are cut into pieces and dried (Quellet *et al,* 2001).

B. Centrifugal Extrusion

Centrifugal extrusion is another encapsulation technique that has been investigated and used by some manufacturers. A number of food-approved coating systems have been formulated to encapsulate products such as flavorings, seasonings, and vitamins. These wall materials include gelatin, sodium alginate, carrageenan, starches, cellulose derivatives, gum acacia, fats, fatty acids, waxes, and polyethylene glycol. Centrifugal extrusion is a liquid coextrusion process utilizing nozzles consisting of a concentric orifice located on the

outer circumference of a rotating cylinder i.e., the head. The encapsulating cylinder or head consists of a concentric feed tube through which coating and core materials are pumped separately to the many nozzles mounted on the outer surface of the device. While the core material passes through the center tube, coating material flows through the outer tube. The entire device is attached to a rotating shaft such that the head rotates around its vertical axis. As the head rotates, the core and coating materials are co-extruded through the concentric orifices of the nozzles as a fluid rod of the core sheathed in coating material. Centrifugal force impels the rod outward, causing it to break into tiny particles. By the action of surface tension, the coating material envelops the core material, thus accomplishing encapsulation. The microcapsules are collected on a moving bed of fine-grained starch, which cushions their impact and absorbs unwanted coating moisture. Particles produced by this method have a diameter ranging from 150 to 2000 mm (Schlameus, 1995; Goud and Park, 2005).

5. Fluidized Bed Coating

Fluidized bed technology is a very efficient way to apply a uniform layer of shell material onto solid particles. Interestingly, fluidized bed technology is one of the few advanced technologies capable of coating particles with any kind of shell material like polysaccharides, proteins, emulsifiers, fats, complex formulations, enteric coating, powder coatings, yeast cell extract, etc. Therefore, the controlled release possibilities are considerably more versatile with the fluidized bed technology than with any other technologies. Aqueous solutions of hydrocolloids such as gums and proteins, ethanolic solutions of synthetic polymers and melted fats/waxes have all been used as coating formulations in fluidized bed microencapsulation processes. Spray dried microcapsules can also be further coated by fluidized bed, with a fat layer in order to impart better protection and shelf life. The use of melted fats, waxes or emulsifiers as shell materials is a relatively new but very promising and interesting concept.

In this technique solid particles are suspended in a temperature and humidity-controlled chamber of high velocity air where the coating material is atomized (De Zarn, 1995). Optimal results are obtained with particle sizes between 50 and 500 microns. Particle size distribution should also be narrow. The amount of material that coats the particles is dependent on the length of time that the particles are in the chamber. This technique is applicable for hot-melt coatings such as hydrogenated vegetable oil, stearines, fatty acids, emulsifiers and waxes or solvent-based coatings such as starches, gums, maltodextrin (Tsutsumi, *et al* 1998; Matsuda, *et al* 2001; Gouin 2004).

6. Liposomal Entrapment

A liposome or lipid vesicle is defined as a structure composed of lipid bilayers that enclose a number aqueous or liquid compartments. They have been used for delivery of vaccines, hormones, enzymes and vitamins into the body. They consist of one or more layers of lipids and are nontoxic and acceptable for foods. Permeability, stability, surface activity and affinity can be varied through size and lipid composition variations. They can range from 25 nm to several microns in diameter, are easy to make, and can be stored by freeze-drying. Phospholipids make up the outer layer or layers of liposomes (Figure 3.A). The hydrophilic portion of the lipids is oriented towards the aqueous phase and the hydrophobic groups associate with the hydrophobic ones of other lipid molecules. Folding of the lipid sheet into a spherical shape forms a very stable capsule due to there being no interaction of the lipids with water (Figure 3.B). Aqueous or lipid-soluble materials, but not both, are entrapped in these membranes. Liposomes can range from a few nanometers to microns.

Food applications of liposomes in cheese making is well known (Kirby, 1991). The most common phospholipid in lectin, namely phosphatidyl choline, is insoluble in water and is isolated from soy or egg yolk. The composition of the phospholipids and the process used determine if a single or multiple layers are formed. Fatty acids also make up liposomes and their degree of saturation is dependent on the source. Animal sources provide more saturated fatty acids. They influence the transition temperature which is the conversion from a gel to the more leaky liquid form. Although sugars and large polar molecules cannot permeate through a liposome bi layer, small lipophilic molecules can. (Kim and Baianu *et al* 1991).

7. Lyophilization

Lyophilization, or freeze-drying, is a process used for the dehydration of almost all heat-sensitive materials and aromas. It has been used to encapsulate water-soluble essences and natural aromas as well as drugs. Except for the long dehydration period required (commonly 20 h), freeze-drying is a simple technique, which is particularly suitable for the encapsulation of aromatic materials. The retention of volatile compounds during the lyophilization is dependent upon the chemical nature of the system (Kopelman *et al* 1977).

8. Coacervation

Coacervation, often called ''phase separation,'' is considered as a true microencapsulation technique, because the core material is completely entrapped by the matrix. This technique involves the precipitation or separation of a colloidal phase from an aqueous phase (Dziezak, 1988; Bakan, 1973). Both, simple and complex methods of coacervation can be used. In simple coacervation, a nonsolvent or a more water-soluble

polymer is used. The polymer competes for the solubility for gelatin protein solution by hydrophobic interaction. In complex coacervation, the capsule is formed by the ionic interaction of two oppositely charged polymers, commonly the positive charges on protein molecules and anionic macromolecules such as gelatin and gum arabic (Versic, 1988; Soper, 1995; Brazel, 1999). The complex coacervate is produced when the two opposite charges are neutralized with each other (Soper, 1995).

Coacervation involves the separation of a liquid phase of coating material from a polymeric solution followed by the coating of that phase as a uniform layer around suspended core particles. The coating is then solidified. In general, the batch-type coacervation processes consists of three steps and are carried out under continuous agitation (Pagington, 1986; Kirby, 1991).

1. Formation of a three-immiscible chemical phase

2. Deposition of the coating

3. Solidification of the coating

A large numbers of coating materials have been evaluated for coacervation microencapsulation but the most studied and well understood coating system is gelatin/gum acacia system. However, other coating systems such as gliadin, heparin/gelatin, carrageenan, chitosan, soy protein, polyvinyl alcohol, gelatin/carboxymethylcellulose, B-lactoglobulin/gum acacia, and guar gum/dextran are also suitable for coacervation microencapsulation (Gouin, 2004). In recent years, modified coacervation processes have also been developed that can overcome some of the problems encountered during a typical gelatin/gum acacia complex coacervation process, especially when dealing with encapsulation of heat-sensitive food ingredients such as volatile flavor oils. (Arneodo, 1996; Ijichi *et al*, 1997; Soper and Thomas, 1997).

9. Centrifugal Suspension Separation

Centrifugal suspension is a more recent microencapsulation process. The process in principle involves mixing the core and wall materials and then adding them to a rotating disk. The core materials leave the disk with a coating of residual liquid. The microcapsules are then dried or chilled after removal from the disk. The whole process can take between a few seconds to minutes. Solids, liquids, or suspensions of 30 mm to 2mm can be encapsulated in this manner. Coatings can be 1–200 mm in thickness and include fats, polyethylene glycol (PEG), diglycerides, and other meltable substances. Since this is a continuous, high-speed method that can coat particles, it is highly suitable for foods. One application is to protect foods that are sensitive to or readily absorb moisture, such as aspartame, vitamins, or methionine (Sparks, 1989).

10. Cocrystallization

Cocrystallization is a new encapsulation process utilizing sucrose as a matrix for the incorporation of core materials. The sucrose syrup is concentrated to the supersaturated state and maintained at a temperature high enough to prevent crystallization. A predetermined amount of core material is then added to the concentrated syrup with vigorous mechanical agitation, thus providing nucleation for the sucrose/ingredient mixture to crystallize. As the syrup reaches the temperature at which transformation and crystallization begin, a substantial amount of heat is emitted. Agitation is continued in order to promote and extend transformation/ crystallization until the agglomerates are discharged from the vessel. The encapsulated products are then dried to the desired moisture if necessary and screened to a uniform size. It is very important to properly control the rates of nucleation and crystallization as well as the thermal balance during the various phases (Rizzuto *et al,* 1984)

11. Inclusion Complexation

Molecular inclusion is another means of achieving encapsulation. Unlike other processes discussed, this technique takes place at a molecular level; â-cyclodextrin is typically used as the encapsulating medium. â-Cyclodextrin is a cyclic derivative of starch made up of seven glucopyranose units. They are prepared from partially hydrolyzed starch (maltodextrin) by an enzymatic process. The external part of the cyclodextrin molecule is hydrophilic, whereas the internal part is hydrophobic. The guest molecules, which are apolar, can be entrapped into the apolar internal cavity through a hydrophobic interaction (Pagington, 1986; Goud and Park, 2005;). This internal cavity of about 0.65nm diameter permits the inclusion of essential oil compounds and can take up one or more flavor volatile molecules (Dziezak, 1998). In this method, the flavor compounds are entrapped inside the hollow center of a â-cyclodextrin molecule.

Conclusion

Many nutrition experts and food research institutes are looking for new ingredients with possible health benefits. Phytochemicals, wood-derived ingredients such as phytosterols, pro and prebiotics, new types of carotenoids, trace minerals and polyphenols are examples of such ingredients. Many of these ingredients will be available in a purified form in the near future. Adding them to food systems will often require technological innovations. The challenges are to select the appropriate microencapsulation technique and encapsulating material. Despite the wide range of encapsulated products that have been developed, manufactured, and successfully marketed in the pharmaceutical and cosmetic industries, microencapsulation has found a comparatively much smaller market in the food industry.

The technology is still far from being fully developed and has yet to become a conventional tool in the food scientist repertoire for several reasons. Microencapsulation will certainly play an important role in this process, although it will always make an ingredient more expensive to use where bioavailability should always be considered carefully. The use of microencapsulated food ingredients for controlled-release applications is a promising alternative to solve the major problem of food ingredient delivery faced by food industries, as well as in solving micronutrient deficiencies, especially in countries like India where they are widely prevalent.

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