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Micro- and nano-encapsulation in food industry

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ABSTRACT

Encapsulation can be defined as a process of entrapping one substance within another substance producing particles with diameters of a few nm to a few mm. The entrapped material is usually a liquid, but may be a solid or a gas. The main reason of using encapsulation is the fact that some nutrients do not remain in the food for a significant amount of time or may react with the other food components causing undesirable effects. It is possible to use micro- and nanoencapsulation techniques. The first one, microencapsulation, is a technology that can improve the retention time of the nutrient in the food and allow controlled release at specific times, during food consumption or in the intestinal gut (microencapsulation of vitamin). Nanoencapsulation has the potential to protect sensitive bioactive food ingredients from unfavourable environmental conditions, enhance solubilisation, improve taste and odour masking, and enhance bioavailability of poorly absorbable function ingredients. In this review, some relevant aspects of encapsulation methodologies, coating materials and their uses in food technology were discussed.

Introduction

In the last two decades, the „nano-world“ has caught the eye of the food industry creating a new range of materials and processes aimed for improving not only the organoleptic characteristics of food, but also nutritional characteristics, their safety and packaging, among others. Nano-scale control of food molecules may lead to the modification of many macro-scale characteristics, such as texture, taste, some sensory attributes, processability and stability during shelf life.

Encapsulation may be defined as a process of entrapping one substance within another substance, thereby producing particles with diameters of a few nm to a few mm. The substance that is encapsulated is the core material, the active agent, fills, internal phase, or payload phase. The substance that is encapsulating is the coating, membrane, shell, carrier material, wall material, external phase, or matrix (Zuidam and Nedovic, 2010). The wall material protects the sensitive ingredients against adverse reaction and controls the release of the ingredients (Bakowska-Barczak and Kolodziejczyk, 2011).

Micro- and nanoencapsulation technology is a very promising area in food industry that will have a great impact on a wide variety of products including functional foods, packaging, preservatives, antioxidants, flavours and fragrances. (Javier Paredes et al., 2016).

Functional foods can be considered to be those whole, fortified, enriched or enhanced foods that provide health benefits beyond the provision of essential nutrients (e.g., vitamins and minerals), when they are consumed at efficacious levels as a part of a varied diet on a regular basis. Functional food ingredients such as flavours, vitamins or antioxidants are sensitive to environmental stress during manufacturing, storage and composition of the food product. Unsaturated fatty acids are recognized as beneficial for health. However, they sometimes have an unpleasant taste, which can become unacceptable when they oxidize . Encapsulation largely overcomes this problem by taste masking and limiting oxidation.

Microencapsulation

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Microencapsulation is a process by which small particles of solid, liquid or gas (active core) are packed within a secondary material (encapsulant) to form a capsule (microcapsule – micron size range 1-1000 μm and nanocapsules – submicron range). Microencapsulation has numerous applications in areas such as pharmaceutical, agricultural, medical and food industries, being widely used in the encapsulation of essential oils, colourings, flavourings, sweeteners and microorganisms, among others. Microencapsulation can represent an excellent example of microtechnology applied to food science and biotechnology. Microencapsulation can serve as an effective means of creating foods that are not only a source of nutrients with sensory appeal but also a source of well-being and health for individuals, increasing the level of calcium to prevent osteoporosis, using microorganism-produced lactic acid to decrease cholesterol and adding phenolic compounds to prevent heart problems (da Silva et al., 2014).

Microencapsulation of bioactive components can be performed through the use of water and oil. The water-oil-water (W-O-W) emulsion is formed with small water droplets, dispersed in large oil droplets, dispersed in an outer aqueous phase. The functional component can be encapsulated within the inner phase, the oil phase or the outer water phase after drying; thus, a single delivery system can contain multiple functional components. Microencapsulation has been used to encapsulate fish oil to increase n-3 polyunsaturated fatty acid intake (Higgins et al., 1999), to encapsulate probiotic bacteria in frozen dairy foods (Shah and Ravula, 2000) and among other things, to encapsulate 2-acetyl-1-pyrroline (ACPY; a major flavour component of aromatic rice) to retain this. Additionally, incorporating flavours in the coating helps to make the functional food pleasant to consume.

Sometimes these food ingredients slowly degrade and lose their bioactivity during digestion in the stomach and intestine. Some nutrients do not remain in the food for a significant amount of time or may react with other food components causing undesirable effects. Microencapsulation is a technology that can improve the retention time of the nutrient in the food and allow controlled release at specific times, during food consumption or in the intestinal gut (Wilson et al., 2007). Microencapsulation may be defined as the packaging technology of solids, liquid or gaseous material with thin polymeric coatings, forming small particles called microcapsules (Gharsallaoui, et al., 2007). Microencapsulated ingredients in the food industry could protect core compounds from the environmental effects (heat, moisture, oxygen and light). They can also reduce the loss from vapourization, improve stability and safety (e.g., reduced flammability of volatiles like aroma, no concentrated volatile oil handling) and adjust properties of active components (particle size, structure, oil-/water-solubility, colour).

Nanoencapsulation

The term nanoencapsulation describes the application of encapsulation on the nanometre scale with films, layers and coverings. The encapsulation layer is clearly of nanometre scale forming a protective layer on the food or flavour molecules/ingredients (Paredes et al., 2016). Nanoencapsulation technologies have the potential to meet food industry challenges concerning the effective delivery of health functional ingredients and controlled release of flavour compounds. Nanoencapsulation packs substances in miniature by using techniques such as nanocomposite, nanoemulsification and nanostructuration and provides final product. Nanoencapsulation serves as a vehicle for carrying the functional ingredient to the desired site of action. They protect the functional ingredient from chemical or biological degradation during processing, storage and utilization. They have to be capable of controlling the release of the functional ingredient. Finally, the delivery system, as well as being compatible with the physical-chemical and qualitative attributes of the final product. Typically, nanocarrier systems can be carbohydrate, protein or lipid based.

In this review, some relevant aspects of micro- and nanoencapsulation, such as encapsulation methodologies, coating materials and some of their uses in food technology, will be briefly discussed. Among several techniques, ionic gelation is a mild, simple and organic solvent-free approach for the formation of stable nanosize particles. This approach is based on interaction between positively charged polymers such as chitosan (Ch) and polyanions such as pentasodium tripolyphosphate (TPP) which lead to the formation of inter- and intra-molecular cross-linkages without using high temperatures and toxic crosslinking agents. In the study of Nayeresadat Hasheminejad et al. (2019), they focussed on the loading of clove essential oil (CEO) into chitosan nanoparticles (ChNPs), using the two-step approach of emulsion-ionic gelation, to improve the antifungal activity of oil against A. niger through the controlled release of oil. The encapsulated essential oil (EO) revealed superior performance, compared with free EO, against the identified A. niger isolate under in vitro conditions, probably due to the controlled release of the preserved volatile oil from ChNPs during the experiment, leading to better inhibitory effect, as well as the inhibitory effect of ChNPs itself. Considering the impressive antifungal activity of CEO-ChNPs, the application of these NPs as a natural fungicide to extend the shelf life of fresh-cut fruits and vegetables is proposed.

İnanç Horuz and Belibağlı (2018) recently reported that nanoencapsulation by electrospinning technique is efficient to improve thermal stability and water solubility of carotenoids extracted from tomato peels. They also discovered that encapsulated extract inside gelatin fibers had better retention of lycopene and antioxidant activity during 14-days storage than non-encapsulated one. More interestingly, the water solubility of the carotenoid extract was highly enhanced compared to non-encapsulated one. By this study, it was realized that nanoencapsulation by electrospinning is an effective way to stabilize carotenoids and improve their water solubility; therefore, it is promising in food processing, especially including aqueous food matrix. There is also the recent study of de Oliveira Cavalcanti Medeiros et al. (2019) which shows that the yogurt added with the nanoencapsulate of Cantaloupe melon carotenoids in porcine gelatin remained stable for 60 days, unlike the crude extract. The results show that the nanoencapsulation using gelatin increased water solubility and the potential of application of melon carotenoids in food as natural dyes.

Encapsulation methodologies

The success of an encapsulation process is often linked to know-how of the formulation or chemistry to achieve stabilisation. This is especially the case in the food industry where the number of acceptable materials is very limited. As in most cases, researchers are essentially concerned with finding the optimum formulation matching with a specific method. The "engineering" aspects are often neglected, while probably a substantial part of success to maintain the integrity of active compounds, provide the right properties to the microcapsules and reduce the cost, is directly related to the design and operating parameters (Poncelet et al. 2011).

Encapsulation can also be used as a tool for innovation. For example, the Orbitz company from Canada sells a drink containing a suspension of coloured capsules containing different aromas and/or some vitamins, thus making functional food consumption a "fun experience". The Salvona company (USA) has developed encapsulation technologies allowing sequential release of aromas and sensory ingredients in functional foods (Poncelet et al., 2011).

Table 1. Physical processes and general consideration

Method	Principle	Comments	Reference
Spray drying	Core is dispersed into aqueous encapsulant solution and atomized into a drying chamber	Most commonly used method, cost-effective	Santos et al., 2018
Spray chilling	Core is dispersed into coating solution and sprayed into a cold environment to solidify the carrier material	Used for protection of water – soluble cores, also suitable for cores that are sensitive to temperature	Kiyomi Okuro et al., 2013
Extrusion	Emulsion dispersion containing the core passed through a die at high temperature and pressure unto a bath for solidification of the particle	Used primarily for encapsulation of flavours and volatile cores in glassy matrices	Risch, 2009
Fluidized bed coating	Particles are suspended in air and a coating is applied	Used for achieving finer control over release properties of the core	Dewettinck and Huyghebaert, 1999
Inclusion complexation	An inclusion complex is formed between cyclodextrin and the core	Encapsulation of flavours and lipophilic nutrients	Martina et al., 2013
Coacervation	Coacervates are formed when two oppositely charged biopolymers associate and phase separate	Can entrap high loadings of cores, has been used in encapsulation of flavours and many nutrients.	Koupantsis et al., 2014

Encapsulation methodologies are divided in following main groups:
i) *Physical processes* such as spray drying-coating, extrusion, and spray drying, use of supercritical fluids,
ii) *Physiochemical processes,* such as simple or complex coacervation and entrapment into liposomes
iii) *Chemical processes* such as interfacial polymerization and molecular inclusion, solvent evaporation. All processes and general consideration are given in Table 1

The development of a successful encapsulation system for a target application is based on the need of a good knowledge about the stability of the chosen component, biomolecules or cells to be encapsulated (core), the properties of the materials used for encapsulation (encapsulant matrix) and the suitability of the delivery system (microcapsule) for its ultimate application (Augustin and Sanguansri, 2008).

The most available technology for microencapsulation uses a liquid (complex coacervation, interfacial and in situ polymerization or solvent evaporation from emulsions) or a gas as suspending medium (spray-drying or spray-cooling, fluidized-bed coating or co-extrusion) (Nazzaro et al., 2011).

Spray drying

Spray drying is a rapid, continuous, cost effective, reproducible and scalable process for the production of dry powders from a liquid material. The liquid is sprayed through an atomizer into a hot drying gas medium, usually air. The spray droplets lose the solvent in the drying chamber leading to a solid particle which is subsequently removed from the air stream and collected. This technique is used in food industry to decrease water content and ensure a microbiological stability of products. Spray drying techniques are for encapsulation of food ingredients such as flavours, lipids and carotenoids (Gharsallaoui et al., 2007).

Spray drying involves atomization of a suspension of probiotics and carrier material into a drying gas, giving rise to a rapid evaporation of water. Spray-drying prepares the cells so that they can be better stress adapted to subsequent environmentally adverse conditions, such as high temperatures, acidic environment, or presence of bile salts.

Spray chilling

Spray chilling or spray - cooling is another technology to produce lipid – coated active agent. The active agent might be soluble in the lipids, or be present as dry particles or aqueous emulsions. Firstly, droplets of molten lipid(s) are atomized into a chilled chamber which results in solidification of the lipids and finally their recovery as fine particles. The initial set-up of spray-chilling technique, the particles are kept at a low temperature in a set-up similar to the fluidized bed spray granulation on which molten lipid droplets may adhere to already hard lipid particles before solidification. In general, the melting point of the lipid used is in the range of 34-42 °C for spray – chilling and higher for spray-cooling (Zuidam and Nedovic, 2010).

Extrusion

Extrusion microencapsulation has been used almost exclusively for the encapsulation of volatile and unstable flavours in glassy carbohydrate matrices. The main advantage of this process is the very long shelf life imparted to normally oxidation – prone flavour compounds, such as citrus oils. 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 flavour oils, compared to typically one year for spray dried flavours and a few months for unencapsulated citrus oils. Carbohydrate matrices in the glassy states have very good barrier properties and extrusion is a convenient process enabling the encapsulation of flavours in such matrices (Zasypkin and Porzio, 2004).

Fluid bed coating

Fluid bed coating is a technique in which a coating is applied onto powder particles in a batch process. The powder particles are suspended by an air stream at a specific temperature and sprayed with an atomized, coating material. The coating material must have an acceptable viscosity to enable pumping and atomizing, must be thermally stable and should be able to form a film over a particle surface. The coating material might be an aqueous solution of cellulose derivates, dextrins, proteins, gums and/or starch derivates, and the evaporation of its water content is then controlled by many factors such as the spray rate, the water content of the coating solution, the air flow, the humidity of the air inlet in the chamber, and the temperature of the coating solution, atomized air, and the material in the chamber. The air flow rate is typically 80% in the centre flow in the inner column and 20% in the periphery, which brings the powder particles into circulation. This increases the drying rate and reduces agglomeration (Zuidam and Nedovic, 2010).

Inclusion complexation

Inclusion complexation generally refers to the encapsulation of a supramolecular association of a ligand (encapsulated ingredient) into a cavity bearing substrate (shell material) through hydrogen bonding, van der Waals force or an entropy-driven hydrophobic effect. The inclusion complexation technique is mainly used in the encapsulation of volatile organic molecules (essential oils and vitamins). It is useful to mask odours and flavours and preserve aromas. β-cyclodextrins and β-lactoglobulin are suitable for encapsulation through this method.

Coacervation

Coacervation is a term used to describe the basic process of capsule wall formation. Coacervation is a colloid phenomenon, which is carried out under continuous agitation to encapsulate liquids and solids. Coacervation is the technique that involves the deposition of the polymer around the core by altering the physicochemical properties of medium, such as temperature, ionic strength, pH and polarity. Coacervation is a relatively simple, low-cost process that does not require high temperatures or organic solvents. It is typically used to encapsulate flavour oils. One of the main disadvantages of the coacervation is that it occurs only within limited ranges of pH, colloid concentrations and/or electrolyte concentrations. In simple coacervation, a single colloidal solute is involved while complex coacervation requires two or more colloidal solutes in the continuous phase of the fluid system. Gelatin and cellulose derivates are most widely used polymers in simple coacervation, although various other polymers have been used for the production of microcapsule in pharmaceutical practice.

Systems of encapsulation

Capsules are stable during storage that is disallowing transport of material. When the trigger event occurs, there is a release of the core into the surrounding environment or transport. Typical trigger events are heat, osmotic pressure, addition of water, mechanical rupture, alteration of pH and enzyme action. Release rates are affected by diffusion coeficient of the substance, thickness of the shell/matrix, saturation concentration of the substance (degree of loading), mechanical and chemical stability of microcapsule (degree of cross-linking).

Sometimes, microcapsules have a certain number of particles located at their surface. This type of microencapsulation is known as matrix encapsulation, and often provides more protection during spray drying and storage of probiotics, as well as during their passage through the stomach (Filomena Nazzaro et al., 2011).

Different techniques are used in microencapsulation of probiotics: coacervation, emulsion, extrusion, spray-drying, and gel-particle technologies (including spray-chilling). Coacervation is a fluid–fluid phase separation of an aqueous polymeric solution, where a change in pH enables the formation of the shell by the polymer complex (Champagne et al., 1992, Oliveira et al., 2007).

Micro-emulsions (ME), with droplets sizes less than 500 nm diameter, are produced by micro-fluidization or micelle formation techniques. ME can be successfully applied to entrap natural compounds, like essential oils (EOs) or vegetal extracts containing polyphenols with well-known antimicrobial properties. This aspect represents an important starting point for industries, which can try out new natural and safe materials or systems of packaging capable to prolong the shelf life of foods, such as highly perishable fresh foods (vegetables, fruits, meat, etc.), without lessening their characteristics in terms of quality and hygiene. ME can be considered as a real resource for food packaging also to mask unpleasant flavours and odours, or to supply barriers between the sensitive bioactive materials and the environment (represented by food or oxygen).

Polyphenols play a well-known essential role in food quality and safety, as well as in human health. In food science, their stabilization could be improved by using encapsulation and spray drying, which could protect them against oxygen, water or any conditions that could affect their stability (Desai and Park, 2005).

Coating materials for encapsulation of food

The correct choice of the wall material is very important because it influences the encapsulation efficiency and stability of the microcapsule. The ideal wall material should have the following characteristics: not to be reactive with the core; ability to seal and maintain the core inside the capsule; ability to provide maximum protection to the core against adverse conditions; lack an unpleasant taste in the case of food applicability and economic viability.

Different encapsulating agents are used for spray drying: polysaccharides (starch, maltodextrins, corn syrups and gum arabic), lipids (stearic acid, mono and diglycerides), and proteins (gelatin, casein, milk serum and soy). Products from starch are used in food, pharmaceutical, drug delivery, and chemical industries, as well as in agriculture and environmental engineering.

Table 2. Coating materials for encapsulation of food

Carbohydrate	Starch, maltodextrins, corn syrup solids, dextran, modified starch, sucrose, cyclodextrins, marine carbohydrates (anionic, cationic)	Geraldine et al., 2008; Szente and Szejtli, 2004; Nilsson and Bergenstahl, 2007; Loksuwan, 2007; Augustin et al., 2008; Chung et al., 2008 Laos et al., 2007
Cellulose	Carboxymethylcellulose, methylcellulose, ethylcellulose, nitrocellulose, acetylcellulose, cellulose acetate-phtalate, cellulose acetate-butylate-phtalate	Kester and Fennema,1986; Balasubramanium, 2007; Nelson and Fennema, 1991; Koelsch and Labuza, 1992; Debeaufort et al., 1993; Park et al., 1994; Bourtoom, 2008; Andrady and Xu, 1997
Gum	Gum acacia, agar, sodium alginate, carrageenan	Phan et al., 2005; Rhim, 2004; Rojas-Grau et al., 2007; Karbowiak et al., 2006
Lipid	Wax, paraffin, beeswax, tristearic acid, diaciylglycerols, monoacylglycerols, oils, fats, hardened oils	Debeaufort et al., 1993.
Protein	Gluten, casein, gelatin, albumin, hemoglobin, peptides	Cho et al., 2003; Chen et al., 2003; Gunasekaran et al., 2007

Maltodextrins have high solubility in water, low viscosity, bland flavour and colourless solutions.

Cyclodextrin ,as a “carrier” molecule, is used in order to facilitate the dissolution of lipid-soluble vitamins and hormones which have very low solubility in aqueous solutions.

Over the past several decades, several biopolymers have received increased attention for their applications in chemical, biomedical, and food industries (Geraldine et al., 2008).

For example, *chitin* suture is resorbable in human tissues from which chitosan–collagen composites for an artificial skin are commercially produced (Park et al., 2001).

These polymers are not only biodegradable, but also edible. Another area of growing interest is the preparation of antimicrobial edible films and coatings (Cagri et al., 2004) where chitosan plays an important role due to its well-documented antimicrobial properties (No and Meyers 2007). Chitin is an abundant, naturally occurring biopolymer and is found in the exoskeleton of crustaceans, in fungal cell walls and in other biological materials. It is mainly poly (β-(1–4)-2-acetamido-D-glucose).

Actually, *chitosan* is a copolymer consisting of β-(1–4)-2-acetamido-D-glucose and β-(1–4)-2-amino-D-glucose units with the latter usually exceeding 60%. The antimicrobial action of chitosan is hypothesized to be mediated by the electrostatic forces between the protonated amino group (NH_2) in chitosan and the negative residues at cell surfaces (Tsai et al., 2002).

The number of protonated amino groups (NH_2) present in chitosan increases with increased degrees of deacetylation (DD) which influences the antimicrobial activity. Liu et al. (2004) state, that the bactericidal activity of chitosan is caused by the electrostatic interaction between NH^{3+} groups of chitosan and the phosphoryl groups of the phospholipid component of the cell membrane.

Chitosan used as coating-material for functional food or pharmaceutical purposes, lower cholesterol and cellulose used for edible-film, encapsulating material for enzyme and cells. *Polyvinyl alcohol (PVA)* might be one of the most promising materials. PVA, a highly polar, nontoxic, water-soluble synthetic polymer prepared by the hydrolysis of polyvinyl acetate, is used in polymer blends with natural polymeric materials. Furthermore, it is utilized for a variety of biomedical applications (Xu et al., 2009), because of its inherent non-toxicity, non-carcinogenicity, good biocompatibility and desirable physical properties, in addition to excellent film forming properties. In Table 3 are summarized the selected cores and the reasons for encapsulation.

Traditional and functional food development

Traditional food processing implies the conversion of raw material to edible, safe, wholesome and nutrition foods with desirable physical-chemical properties, extended shelf-life and desirable sensory properties and convenient. Processing of functional foods adds extra dimensions to traditional food processing, because of the creation of functional bioactive components and appropriate delivery systems throw optimisation of the functional component and incorporation of food without compromising food quality which increases the level of complexity and monitoring.

Table 3. Selected cores and the reasons for encapsulation

Type of core	Examples	Potential benefit of encapsulation
Oils	Milkfat, omega -3 oils	Improved storage stability, target release
Flavours	Mint, orange oil	Preservation of flavours, controlled release in the mouth
Food aditives	Leaving agents	Controlled release during baking
Minerals	Iron salts	Avoiding undesirable interactions (catalyzing fat oxidation), target delivery on ingestion
Phytonutrients	Flavanoids, polyphenols, tocopherols, phytosterols, carotenoids, carotene, lycopene, lutein	Protection of sensitive ingredients from the environment and interactions with the food matrix, target delivery on ingestion
Probiotics	Bifidobacteria, lactobacilli	Improved survival during storage, survival on exposure to stomach acids

Food ingredients for microencapsulation

Food additives such as *acidulants* (citric, acetic, malic, fumaric acids) can control pH of foods, lower pH of food to permit sterilization under less harsh conditions to improve food quality and contribute to taste and aroma of foods. There are *vitamins*, fat soluble vitamins (A, D, E, K), water soluble vitamins (B vitamins, folic acid, niacin, vitamin C) and their function is fortification of foods providing a range of health benefits.

Impact of *mineral salts* (Ca and Fe) is in fortification of foods for health benefits. Ca salts may also function as texturizing agents in certain applications. *Antioxidants*, such as tocopherols, citric acid, ascorbyl palmitate, propyl gallate, thiodipropionates, can protect unsaturated lipids from oxidation. *Colourants* such as carotene, annatto extract, anthocyanins, caramels, chlorophylls, synthetic food dyes, can impart colour to foods to improve appearance and appeal of foods. *Emulsifiers*, which can be *low molecular weight* surfactants (tweens, phospholipids, mono- and di-acylglycerols) and they serve for lowering surface tension and stabilizing emulsion. Apart from that, there are emulsifiers *with high molecular weight* such as gum Arabic and sugar beet pectin that can stabilize emulsions. Various *enzymes* (glycosidases, pectinases, proteolytic enzymes, cellulases, lipases) can transform components in foods for specific functions (glycosidases for producing corn syrups, pectinases for facilitating extraction and clarification of juices, lipases for generating flavours in cheese). To enhance flavour of various food products *flavouring agents* such as salt, citrus flavours, spicy flavours, umami tastants (monosodium glutaminate) bitter tastants (quinine) are used. Various acids (citric, acetic, propionic, sorbic) can be used as *antimicrobial agents*. Nitrates and nitrites can inhibit the growth of microorganisms in meat products. *Sequestrants*, such as Ethylenediaminetetraacetic acid, polyphosphates andchelating of metal ions can stabilize foods against oxidation.

Conclusions

Considering the health tendencies of the modern food technology, the use of bio-based active films as packaging materials is very important. Many nutrition experts and food research institutes are looking for new ingredients with possible health benefits. Phytochemicals, probiotics and prebiotics, new types of carotenoids, trace minerals and polyphenols will be available in a purified form in the near future. Adding them to food systems will often require appropriate microencapsulation technique and encapsulating material. Up to date, microencapsulation has been used to deliver food ingredients and bioactives. Encapsulated ingredients have a superior performance, such as successful delivery of ingredients into foods, and a potential for enhancing bioavailability of bioactive components. Microencapsulated vitamins are used for nutritional purposes to fortify foods and as antioxidants. Nanoencapsulation particularly permits a wide range of applications ranging from increase/hide of flavours to the creation of biosensors for food expiration. Nanocapsules have been developed and applied differently. Furthermore, they are well established in the beverage segment of the food industry, especially with emulsions.

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