Encapsulation: an essential technology for functional food applications

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Since the last world war, i.e. more than 60 years, we attended a revolution of which many of us underestimated the importance. The improvement of the agricultural production methods has led to an abundance of food in our occidental countries like mankind has never known before. Despite the criticisms made regarding the extensive use of agrochemicals, we can live now without wondering how to survive next winter. Our fridge is full!

The high performances of agriculture allow us to consider and include sustainable development today, even if it leads to reduction of the productivity. To reach this objective, microencapsulation may bring some solutions such as slow fertilizer release, copper replacement by encapsulated natural bioactive compounds, and inoculation of soil by immobilized rhizobacteria (Ivanova, 2004). Microencapsulation is also one efficient way to ensure good practice in livestock farming by supplementing feed with vitamins or antibiotic alternatives.

This food abundance is associated with diversification of the foodstuffs. Some products, considered a few decades ago as luxury, now find their place in our almost daily food (salmon, duck fillet…), while fruits and vegetables reach us from all over the world. This evolution is linked with change in our productivity methods. Fishing has to be replaced by aquaculture, and microencapsulation is probably one of the main technologies to develop a suitable diet for the fishes without leading to pollution or illness propagation. Finally, food abundance has also driven people to request more from the food they eat over and above energy supply; for example, to provide safety/quality, ease/convenience, health, and – why not – fun/pleasure.

From traditional cooking to industrial food industry

From a traditional and familial cooking, we have progressively moved to industrial food. The pre-cooked food, consumed as catering (fast food) or brought back home, represents a large part of our consumption. Recomposed powders, mixes, long term storage period, and the need for innovation have fundamentally modified the handling of the foodstuffs. From an industrial point of view, it is much more simple and less costly to transport, store, and handle powders than hydrated food products. Unfortunately, dehydration has often negative effects on the texture, flavour and solubility of the rehydrated food. Consequently, it is frequently necessary to supply food powders with their inherent aromas, vitamins, and other properties. In this context and for this particular application, microencapsulation becomes a highly important tool for food process engineers. Protected during storage or processing, released at the right time and place, the encapsulated additives will provide all their potential to the food.

Traditional foods contain many different bacteria beneficial for health called probiotics. However, pasteurization, drying and long-term storage reduce strongly the concentration of these friendly microorganisms, most often below the minimum required to observe health effects. Food must then be "resupplied" with selected microbial strains. Unfortunately, the most efficient ones are generally fragile cells, and therefore need to be protected.

Microencapsulation of probiotics can be considered an optimal strategy against adverse conditions in food and also during the gastrointestinal tract transit (Picture 1). We have previously demonstrated that coating of probiotics could enhance the cell survival by a factor 100 during warm pellet extrusion (Picot, 2005) and by a factor 400 during storage in yogurt (Picot, 2004). Microencapsulation also allows the combination of probiotics with materials promoting their growth and attachment in the intestine (prebiotics). It is therefore possible to develop optimum cocktails of probiotics and prebiotics in a single formulation called "symbiotic".

Aromas, spices and herbs constitute the core of the pleasure linked to food consumption. They also contribute to the health as nutraceuticals. During storage, freezing, and pre-cooking, they may interact with the other food ingredients, giving bad taste sometimes and losing their health potential properties. Microencapsulation allows their protection and controlled release (e.g. during cooking), offering therefore a unique approach for maintaining optimum quality and nutritive status.

Picture 1 (Capsulae©): Probiotic powder particles protected in an oil droplet stabilized with a hydrogel membrane

New properties and functions

Encapsulation also constitutes a competitive tool to create new properties to usual materials. Getting stable functional ingredients is one thing, but it is not enough if we cannot integrate them easily in the food. Many vitamins, plant extracts, unsaturated fatty acids are hydrophobic liquids. Mixing such compounds in a hydrophilic food powder can prove to be a real challenge. In addition to protection, microencapsulation allows the conversion of ingredients to free-flowing, easily suspendable (e.g. hydrophobic vitamins in fruit juices), and dispersable (e.g. cocoa in cold milk) powders.

Unsaturated fatty acids are recognized as beneficial for health. However, they sometimes have an unpleasant taste, which can become

Picture 2 (Capsulae©): Coloured coated powder particles

unacceptable when they are oxidized.

Encapsulation largely overcomes this problem by taste masking and limiting oxidation. Additionally, incorporating flavours in the coating helps to make the functional food pleasant to consume.

Functional food ingredients may be incorporated into food or may be consumed independently as pills or fine powder. This does not require a prescription from a doctor. However, consumer must be advised in order to limit its daily dose. Coating particles with a colouring material enables to differentiate functional ingredient from both a drug and a food (Figure 2).

Innovation tool

Encapsulation can also be used as a tool for innovation. For example, the company Orbitz (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 company Salvona (USA) has developed encapsulation technologies allowing sequential release of aromas and sensory ingredients in functional foods.

Listeria represents a high risk in processed meat. An encapsulation technique consisting of a core containing two substrates (glucose and thiocyanate), coated first with two enzymes and then with protecting polymers, has been developed (Jacquot, 2000). Under a dry form, the mix is stable for a long period, but as soon as it is in contact with moisture, it starts to release an end product with high bacteriostatic properties against Listeria. The system allows not only a long term action, but also easier handling and dosage of the complex substrate-enzyme mix (Jacquot, 2002).

Finally, microencapsulation can be used as a biocatalyst immobilization system to process food in a safer and more efficient manner. One can cite for example the reduction of the cheese ripening time and the increase of its shelf life by processing with encapsulated enzymes.

Developing encapsulated functional food ingredients?

There exists many classifications, often complex and confusing, for the encapsulation methods. The easiest classification may be based on the equipment needed to perform the encapsulation (Figure 1).

1) Dripping consists of extruding droplets from a nozzle in gentle conditions. Droplets may be solidified by cooling or by gelification. Productivity may be increased by forming a liquid jet and breaking it into small droplets, multiplying nozzles or working with spinning devices. The main advantage of this technology is the low size dispersion of the microcapsules. The main drawback is the productivity.

2) Spraying is one of the oldest approaches for producing capsules. The small droplets are either cooled down (hot melt system) or dried (polymer solution). The use of spray drying is largely developed in the food industry, as the process is very similar to the one employed to produce classical food powder (e.g. milk powder). The technology allows large productions. However, the efficacy regarding protection of the actives is not always satisfactory.

3) Dispersed emulsion droplets may be turned into microcapsules by different processes (Picture 3). In the food industry, the main method used is coacervation, which consists first in dispersing an oil phase (containing the active to encapsulate) in a polymer solution, and then inducing the precipitation of the polymer(s) at the interface of the droplets. If the productivity is very good, this method has an important drawback: crosslinking with glutaraldehyde, a non food grade molecule, is necessary most of the time to obtain stable microcapsules.

4) Spray coating (not to be confused with spray drying) consists of fluidizing a powder (in a fluid bed or a pan) and spraying a coating solution on the fluidized particles. The coating is

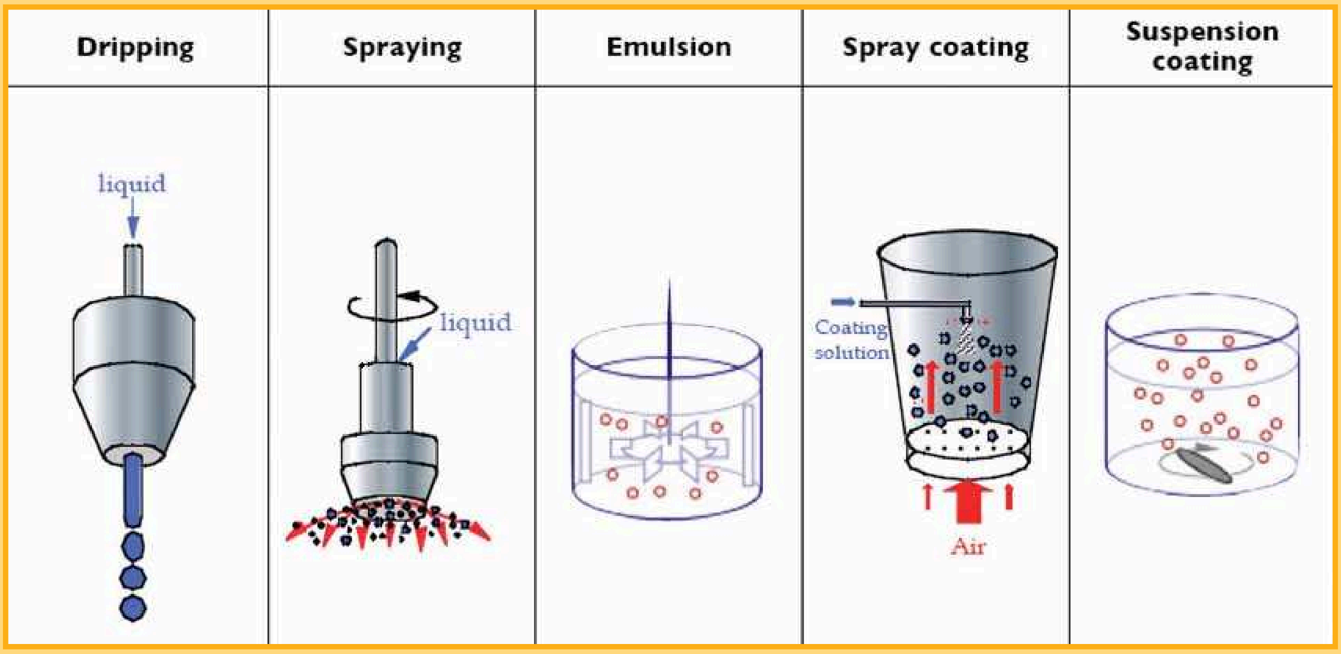
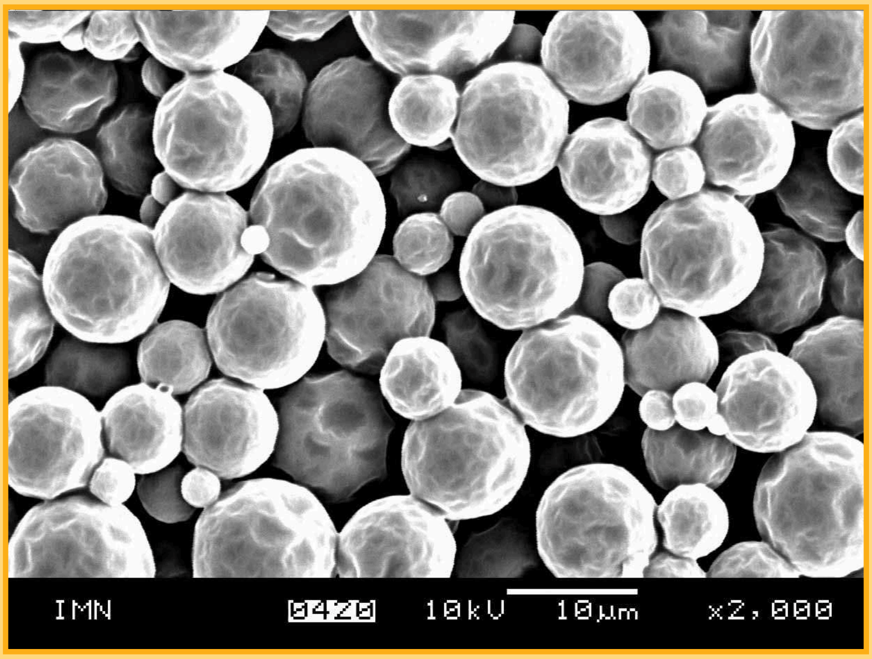


Figure 1 (Capsulae©): Encapsulations systems



Picture 3 (Capsulae©): Microcapsules produced using an emulsion-based technique

solidified by drying (polymer solution) or cooling (melt system). This is the most promising method in terms of performances and flexibility, but process costs have to be significantly reduced.

5) Particles may also be suspended in a solution. Interactions between particles and the solution result in the formation of a coating layer around the particles. No process based on this technique seems to be really employed at the moment in the food industry.

Several constraints make the development of an encapsulation process difficult. First, encapsulation is an extra cost, which has to be minimized to be economically acceptable. This applies to the materials used to "build" the microcapsules, but also to the equipment or processing conditions. The number of food-grade materials suitable for microencapsulation is also very limited (some polysaccharides, a few lipids…). In the pharmaceutical industry, despite the strict rules to be respected for approval, many more materials are available. Consequently, the food engineer has to play finely with the coating/membrane formulation to achieve appropriate and specific properties.

Evolutions

The number of applications for microencapsulation technologies in foods, and especially in the field of functional foods and nutraceuticals, is increasing. The actual production of encapsulated food ingredients represents thousands of tons per year, and is estimated to be growing at around 10 per cent annually. However, many challenges still remain. For example, incorporation of water sensitive ingredients in high moisture foods is not solved yet, because most microcapsules impermeable to water are not soft enough and will be detected by the consumers. During a conference organized last year by the Bioencapsulation Research Group (http://bioencapsulation.net) on aroma encapsulation, a consensus between the one hundred participants was that more than 80% of applications were referring to one single technology (spray drying), underlining thus a real need for innovations.

The success of an encapsulation process is often linked to a know-how of the formulation or of the chemistry to achieve stabilisation. This is especially the case in the food industry where the number of acceptable materials is very limited, as mentioned previously. 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.

If we consider, for example, the spray-coating technique, small changes in the design of the reactor may lead to an important improvement of the process. Moving from the so-called "Würster" coating process to a spouted bed process reduces dramatically the temperature gradient inside the system (15°C), allowing an increase of the cell survival by a factor two when probiotic powders are coated (El Mafadi, 2006). Continuous coating processes diminish the process cost by a factor 3 in comparison to equivalent batch processes (Teunou, 2002). We are presently developing a control system allowing the reduction by two of the duration of the coating process in a fluidized air bed, while avoiding agglomeration (El Mafadi, 2003; Poncelet, 2009).

Developing an encapsulated product remains a challenge, requiring a multi-disciplinary and integrated approach. The key for success most often goes through the support and the expertise of specialized companies. Many encapsulation technologies currently exist, but many of them are still at the development stage. Once fully tested and validated, these new methods will undoubtedly broaden the spectrum of possible applications for this versatile technology.

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