EDITORIAL : Encapsulation: an essential technology for functional food applications

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Since the last world war, i.e. more than 60 years ago, we have witnessed a revolution of often underestimated importance. The improvements in agricultural production methods have led to an abundance of food in the Western World such as mankind has never experienced before. Despite the criticism towards the extensive use of agrochemicals, we can now live without wondering how to survive the next winter. Our fridge is full!

High performance agriculture allows us to consider and include sustainable development today, even if it leads to a reduction in productivity. Microencapsulation may offer some solutions to reach this objective, such as slow fertilizer release, copper replacement by encapsulated natural bioactive compounds, and the inoculation of soil by immobilized rhizobacteria . Microencapsulation is also an efficient way of ensuring good practice in livestock farming by supplementing feed with vitamins or antibiotic alternatives.

This food abundance is associated with a diversification of foodstuffs. Some products, considered luxury items a few decades ago, are now part of our daily dietary intake (salmon, duck fillet, etc.), while our fruit and vegetables come from all over the world. This evolution is linked to a change in productivity methods. Fishing, for example, is replaced by aquaculture, and microencapsulation is probably one of the main technologies capable of developing a suitable diet for fish without causing pollution or the spread of disease. Finally, food abundance has also driven people to demand more from the food they eat apart from just its energy supply, e.g. safety/quality, ease/convenience, health, and - why not – fun/pleasure.

FROM TRADITIONAL COOKING TO INDUSTRIAL FOOD INDUSTRY

We have progressively moved from traditional and familial cooking to industrial food. Pre-cooked food, such as fast food or take-away food, represents a large part of our consumption. Recomposed powders, mixes, long-term storage periods, and the need for innovation have fundamentally modified the handling of 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 often has negative effects on the texture, flavour and solubility of the rehydrated food. As a result, it is often necessary to add aromas, vitamins and other properties to food powders. In this respect, microencapsulation is a highly important tool for food processing engineers. Protected during storage or processing and released at the right time and place, encapsulated additives can deliver their full potential to the food.

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Conferences : 20th year anniversary !

XIX International Conference on Bioencapsulation

Amboise, France - October 5-8, 2011

1991-2011 : Our association is already 20 years old, one generation so to say; it was therefore decided to organise an exceptional event on the occasion of the 20th anniversary.

Our annual international conference will then take place in one of the most beautiful touristic area of France, the Loire Valley.

Conference and accommodation will be both located in an charming castle-like resort, near to the beautiful town of Amboise. For three days you can meet other experts in Bioencapsulation from all over the world in a friendly atmosphere, enjoy the French gastronomy and visit Leonardo da Vinci's last residence.

October 5th, 2011
Registration & buffet

October 6th, 2011
Registration
Welcome
Session 1 : **Missing Challenge**
chairperson : Dr. E. Perier, LVMH, Fr
Session 2 : **Wine, beer, cider and other drinks**
Chairperson : Prof J.P., Eurobiotech, Be
Session 3 : **Probiotic : reality or myth ?**
chairperson : Prof. C. Lacroix, ETHZ, Ch
Session 4 : **Encapsulation and Nutrition**
Chairperson : Dr C. Champagne, CRDA, Ca
Conference banquet

October 7th, 2011
Session 5 : **Cell immobilization Story**
Chairperson : Prif. J.N. Barbottin, Univ. Amiens, Fr
Session 6 : **Engineering from the lab to the manufacture**
Chairperson : Prof. R.J. Neufeld, Queen's Univ. Ca
Session 7 : **Biopolymers, first key of success**
Chairperson : Prof. G. Skjak-Braek, NTNU, No
Guided tour to Chateau le Clos de Lucé & French specialities buffet

October 8th, 2011
Session 8 : **Deliver biopharmaceuticals**
Chairperson : Prof. Thierry Vandamme, Strasbourg Univ., Fr)
Session 9 : **New therapies using microcapsules**
Chairperson : Prof. L. Marckvicheva, IBCH, Ru

More information at : http://bioencapsulation.net/2011_Amboise

By allowing grants to students and researchers from all over the world to attend, we wish to increase the quality of the conference BUT we need the support from our industrial partners as sponsors or as exhibitors. For more information see the conference web site or do not hesitate to contact contact@bioencapsulation.net.

A GREAT SUCCESS :
XIV Industrial Symposium and V Trade Fair on Microencapsulation
San Antonio, Tx, USA - March 5-8, 2011

The symposium took place in The San Antonio Sheraton hotel. More than **120 industrial attendees** followed **10 conferences from specialists** in different technologies of microencapsulation.

Alternativelly with the conferences, **more than 500 one-to-one meetings** underwent. During these meetings, participants could exchange, create contact and **pre-establish collaboration** from R&D projects to sale contracts.

In parralel, **exhibitions was organized** allowing to see latest innovations in microencapsulation equipments and technologies.

To close the symposium, a visit to the South West Research Institute was organized, with **demontrations on pilot scale equipmen**t.

The symposium was a real success. We wish to thanks all the people that help making this event: participants, speakers, exhibitors and especially people from SwRI. A great thanks to James Oxley, who was a very efficient local organizers.

Contribute to the next Bioencapsulation Innovations
Deadline for contribution : May 15, 2011

TOPIC OF NEXT ISSUES : DRIPPING

By dripping, we mean technologies of producing droplets from a nozzle either **drop-by-drop or jet-breaking-in-drop**. The issue will concentrate on **equipments and technologies for producing the droplets**.

The process for microcapsule formation will be covered in future issues. However, **methods and set-up allowing to realize this process** may be included in the May issue. This may include cooling column or flowing system to promote microcapsule formation.

Contribution on **modelling and control systems** of the dripping are also welcome. We may also be interested by a review of the latest publications and patents on the subject.

DIVERSIFIED CONTRIBUTIONS

Bioencapsulation Innovations is your tool for communicating with our community (9000 persons). Through the web site (http://bioencapsulation.net), you could submit for example the following information:

- Future conferences, training school ...
- Open position and request for PhD candidates
- Your latest publications

However, we wish to open a specific section **for news of PhD defenses**, providing title, abstract and place and date of defense. This will not only allow people we are intereted to attend PhD defense but also **future employers to identify specialists** or **researchers to find partners for collaborative projects**.

Microencapsulation for the controlled release of probiotics in foods and the gastro-intestinal tract

Dr. Claude Champagne (CRDA, St Hyacinthe, Canada)

Probiotics: what is the problem?

Probiotics are live microorganisms which, when administered in sufficient amount, confer a health benefit to the host [1]. The benefits are mainly linked to the prevention of gastro-intestinal diseases (lactose maldigestion, diarrhoea, constipation), but could potentially extend to reduction of blood cholesterol levels and cancer. As the definition states, the cells should be alive when consumed. Unfortunately, many food processing steps as well as storage conditions are detrimental to the viability of probiotics (Table 1). In some cases, viability losses can reach up to 6 logs of cells over a few weeks of storage [2]. Since the quantity of viable cells is also critical to functionality, it is imperative that not only should some live bacteria remain in the product, but also that a given number be delivered. Therefore, tools which can enhance the delivery of viable probiotics in foods and to the gastro-intestinal tract (GIT) are needed. This review will look at some benefits of microencapsulation (ME) towards this goal.

Table 1. Conditions which can lead to the loss of viability during processing or storage of foods, and for which microencapsulation has shown protective benefits.

Processing	Storage
• Heating (pasteurized foods, chocolate, cooked foods such as cookies or bread) • Freezing (ice cream, frozen desserts) • Acidification / starter cultures (yoghurt, cheese) • Drying (powders)	• Acidity (yoghurt, fruit juices) • Oxygen (powders, pasteurised milk)

Technologies used for probiotics

Many encapsulation technologies are available to the suppliers of food ingredients. However, spray-coating and droplet extrusion have been the two main technologies used. The other widely used techniques in food ingredients (spray-drying, coacervation, emulsions) have limited application to probiotics because of their thermosensitivity and size (often well above 1 µm, Figure 1).

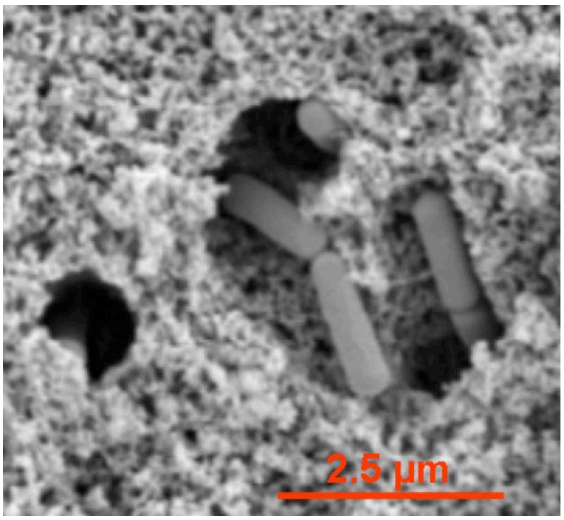

Figure 1. Lactobacillus rhamnosus R0011 cells microentrapped in a whey-protein gel particle. 12000 X multiplication factor. Red bar represents 2.5 µm [modified from Reid et al, 8].

Release mechanisms

In the world of encapsulated ingredients for foods, textiles, pharmaceutical and cosmetics, numerous mechanisms can trigger the release of the ingredients: pressure, pH, temperature, water etc. With probiotics, there are three main mechanisms: growth at the surface of the encapsulation matrix, dissolution in an ion-chelating environment and dissolution by solvents. Let's examine three products which illustrate each system:

1. continuous inoculation of cultures for the production of fermented milks
2. dissolution of alginate beads in the intestines
3. dissolution of fat-based coatings in the intestines.

Release in milk: from Kefir to continuous inoculation systems

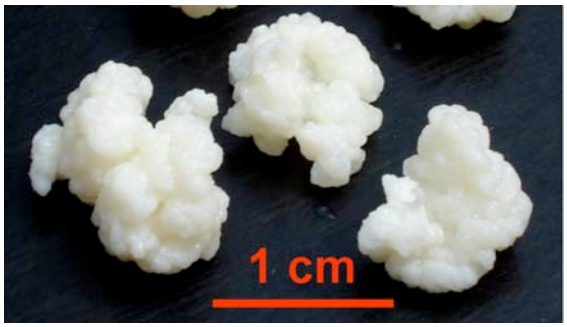

Figure 2. Kefir grains used to inoculate milk with yeast and lactic acid bacteria

Kefir is a fermented milk product which probably constitutes the best example of a food fermentation initiated though controlled release of cells into the milk. The Kefir grains are irregular in appearance (Figure 2) and are mostly made of yeast and lactic acid bacteria. Traditionally, the grains are placed into pasteurized milk, incubated at 20-25°C until coagulation and then sieved. In larger plants, such a sieved curdle is added to the milk inside the processing vat and, therefore, serves as a starter culture. With kefir grains, growth occurs at the surface of the particle and cells are continuously released into the milk.

Gel-based technologies inspired by the kefir system have been developed. Originally, it was destined for the continuous inoculation of milk with yoghurt starter cultures [3]. Basically, cells are microentrapped in gel particles, typically alginate or kappa-carrageenan, which are added into a bioreactor. A continuous-feed fermentation is then carried out. Cells at the surface of the gel beads are released, and the milk which exits the bioreactor is highly inoculated (Figure 3). This system has two technological advantages. First, it eliminates the daily requirement for starter preparation. Secondly, high inoculation level attained with this system, which can be 10 times higher than the traditional inoculation method, actually shortens the fermentation time.

More recently, the technology has been applied to biomass production of probiotic cultures [4]. With biomass production, cell release is discouraged, while in continuous inoculation of milk (such as Kefir) it is desirable. Therefore, steps must be taken to control the release of cells from the gel particles as a function of the application. The cell release level can be controlled by agitation rate, bead size, feed rate and incubation temperature [5, 6]. High agitation rates, small beads and an incubation temperature close to that which is optimum for growth all favour cell release from the particles.

DISSOLUTION OF ALGINATE BEADS IN THE INTESTINES

Numerous data show that the viability of probiotic bacteria may be enhanced during the storage in yoghurt and exposure to gastric solutions when they are encapsulated in alginate [7] or whey protein gel beads [8]. This system consists of a matrix entrapment system (Figure 1) rather than a separate core-and-coat particle.

As a rule, cell release from alginate beads is not desirable in foods nor in the stomach. Ideally, in these two situations, the beads should remain intact and do not dissolve. However, dissolution of the gel particle with the resulting cell release is favoured when it reaches the small intestines. Data show that alginate beads indeed remain intact in the stomach environment and dissolve in duodenum [9]. In this case the release mechanisms is linked ionic interactions. Calcium acts as a gelling agent for alginate molecules, and

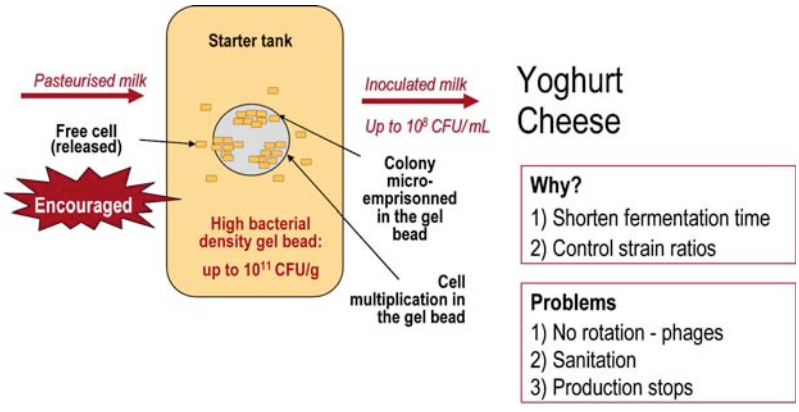

Figure 3: Continuous inoculation of milk with probiotic or starter cultures

compounds which sequester calcium will weaken the gel. Many calcium chelating compounds exist. In foods, citrates and phosphates are the most common. In the GIT, the carbonate and phosphate salts in the duodenum bind calcium and provoke cell release.

Dissolution of fat-based coatings in the intestines

In this application, powders of freeze-dried probiotic bacteria are spray-coated with a lipid compound [10]. Therefore this has more the appearance of a capsule with a defined coating than does the alginate bead system mentioned previously. The lipid coating increases the size of the freeze-dried powder particles [11] but they still remain well below 500 µm and keep the appearance of free flowing powders (Figure 4).

Figure 4: Powder of a freeze-dried probiotic culture microencapsulated by spray-coating.

With lipid coatings, the release mechanism is often triggered by temperature. In this instance, when the temperature of the food reaches the melting point of the fat, the ingredient is released. The release of mould inhibitors in bakery products during cooking (when the yeast activity is complete) is an example of such a system. In a GIT delivery application, however, the lipid coating is chosen not to dissolve at the temperature of the body. Thus, the cell-carrying powder is not released in the stomach and the coating protects the cells against the detrimental effect of gastric acid. Rather, the bile salts dissolve the coating once it reaches the duodenum. If a triglyceride was used for the lipid envelope, rather than a pure fatty acid, lipases from the pancreas will also contribute to the breakdown of the coating. Once the cells are freed in the duodenum, they can exert their potential benefit to health.

Conclusion

In most applications, the ME of probiotics is carried out in order to prevent cell release into the food, but there are exceptions as the Kefir-simulating systems have shown. When ME is indeed carried out to protect cells from the many stressful conditions of food processing and storage, there still is a need to have the cells released in the GIT. But even in this GIT system, cell release must be prevented in the stomach. At least two mechanisms are available for the specific purpose of cell release in the duodenum.

The survival of probiotics in foods is often strain-dependent. Thus, in some instances where a strain does not need protection to remain stable in the food product, ME might still be of use for the sole purpose of enabling a controlled release in the GIT. Thus it can be predicted that ME of probiotics in foods will principally be used for controlled cell release in the GIT rather than for their technological benefits.

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New COST action - FA1005 INFOGEST : Improving health properties of food by sharing our knowledge on the digestive process
http://www.cost.esf.org/domains_actions/fa/Actions/fa1005

The main objective of the Action is to spread and improve current basic knowledge on food digestion, on the release during digestion of protein beneficial food components known to have a potential effect on human health and to promote harmonization of currently used digestion models. EU legislation, as advised by EFSA, demands proper scientific data in nutrition and health claims. There is a lot of data being generated on the link between the food digestion and human health and a significant effort continues to be expended separately in each EU country on optimizing food for preventing the development of food-related diseases. This COST Action will gradually build a European network that will spread and improve current basic knowledge on food digestion and promote harmonization of currently used digestion models used including validation with human data from different populations such as infants, elderly, sport professionals etc. A multidisciplinary scientific community will be built on this topic gathering scientists from different disciplines (food science, nutrition, physiology, immunology, cell biology…). The Action will facilitate the transfer of new scientific advances to European food companies (large groups as well as SMEs) for developing new functional foods and reinforcing their competitiveness in a growing world market.
Please contact your COST National Coordinator for further information

Coming Conferences

South-America Workshop on Bioencapsulation
Valdivia, Chile, April 2011
http://bioencapsulation.net/2011_Valdivia

2nd Symposium on Biomaterials
May 1-8 , 2011, Heraklion Crete
http://www.bionanotox.org/

Colloids and Materials 2011 8-11 May 2011, Amsterdam, The Netherlands
http://www.colloidsandmaterials.com/

8th Scientific & Technical Forum: Innovative Drug Delivery Systems
May 12-13, 2011, Basel, Switzerland
www.pharmatrans-sanaq.com

11th International Hydrocolloids Conf. 14-17 May 2012 , West Lafayette Indiana USA
http://www.international-hydrocolloids-conference.com/

2011 EFFOST Annual meeting November 9-11, 2011, Berlin, Germany
http://www.effostconference.com/

Continuous particle processing
June 7 - 8 , 2011, Binzen, Germany
http://www.ttc-binzen.de/cm/index.php?id=265

5th International Granulation Workshop
June 20-22, 2011, Lausanne, Switzerland
http://www.shef.ac.uk/agglom2011

3rd PharmSciFair
June 13-17, 2011, Pragues, Czech Republic
http://www.pharmscifair.org/

Multiparticle Dosage Forms
July 5 - 7, 2011, Binzen, Germany
http://www.ttc-binzen.de/cm/index.php?id=277

Particles 2011: Stimuli Responsive Particles and Particle Assemblies
July 9-12 , 2011, Berlin, Germany
http://nanoparticles.org/Particles2011/

Granulation Course Sheffield on 21-22 July 2011
http://www.shef.ac.uk/agglom2011/course

38th Annual Meeting of the Controlled Release Society
July 30 - Aug. 3, 2011 - National Harbor, Ma, U.S.A.
http://www.controlledrelease.org/meeting/default.cfm

HI events - Microencapsulation workshop
August 9-10, 2011, Sao Paulo, Brazyl
http://www.hi-events.com.br/index.php?canal=eventos&pgID=070409-171141-6bb48454

2nd ISEKI_Food Conference
Aug -31- Sept 2, 2011, Milan, Italy
www.isekiconferences.com/milan2011/

18th International Symposium on Microencapsulation
September 12-14, 2011 - Ankara, Turkey
http://www.microencapsulation2011.org/

Industrial Workshop on Microencapsulation of Flavors and Bioactives for Functional Food Applications, September 14 -15, 201, Bloomington, Minnesota http://www.bioactivesworld.com/microencapsulation.html

Poorly Soluble Drugs Workshop
15 September, 2011, Lille, France
http://www.apgi.org/2011_WS/

XIX International Conference on Bioencapsulation
October 5-8, 2011 - Amboise, France
http://bioencapsulation.net/2011_Amboise

Selection of coating materials for stabilization of probiotic micro-organisms

Dr. Arnaud Picot (Capsulae, Nantes, France) & Denis Poncelet (Oniris, France)

Introduction: Encapsulation of probiotics

The use of live microbial agents, or probiotics, as dietary adjuncts is currently a subject of intense and growing interest. Probiotics have been defined as "Probiotics are live microorganisms which, when administered in sufficient amount, confer a health benefit to the host" (Ararya, 2005). Beneficial bacteria, such as *Lactobacillus acidophilus* and *Bifidobacterium* species., can be found worldwide in a variety of products, including conventional food products and dietary supplements. One of the most important prerequisites for use of probiotics is that they survive and keep their health-promoting properties throughout the production process or during technological food treatment and storage until the end of shelf life. Moreover, because viable and biologically active microorganisms are usually required at the target site in the host, it is essential that probiotics withstand the host's natural barriers against ingested bacteria.

Among the different approaches proposed to improve the survival of probiotics during the food manufacturing process and the passage in the upper part of the GI tract, microencapsulation has received considerable attention. Cell immobilization generally tends to increase the viability and the stability of microorganisms during their exploitation. However, efficiency can vary according to the method used and the culture considered. In almost all cases, gel entrapment using natural biopolymers such as calcium alginate and kappa-carrageenan has been favored by researchers for probiotic applications (Picot, 2004). Although promising on a laboratory scale, the technologies developed to produce gel beads present all serious difficulties for large-scale production (Poncelet, 1996). In addition, encapsulation in such matrices does not necessarily protect efficiently the cells from the effect of pH, organic acids, or other soluble compounds like oxygen that can easily diffuse in a very hydrated medium. Consequently, the development of cell encapsulation technologies that use effective, food-grade, and economic coating materials, constitutes a real priority to generalize the use of encapsulated probiotics in the food and feed industries.

Several elements must be taken into consideration when designing microcapsules to preserve the viability of probiotics in food and feed products. First, dry microcapsule preparations with low and controlled particle size are desirable for various reasons, including higher stability, easier handling and storage of the cultures, and limited effects on sensorial properties of the final product, especially texture (human consumption).

Second, considering the number of detrimental factors encountered during processing and storage, the development of multiphase microcapsules using coating materials with multiple barrier properties seems to be the most promising way to insure process effectiveness. Barrier properties of coating materials include resistance to elevated temperatures and pressures, low permeability to moisture and oxygen, low hygroscopicity, low solubility in water, resistance to low pH or gastro-resistance. Among the food grade coating materials available on the market, polysaccharides and proteins form films that are generally permeable to moisture, especially at high relative humidity values (hygroscopic materials). On the other hand, they usually exhibit good barrier properties to gases and lipids. Lipid-based coatings present excellent water barrier properties, retard gas migration, and are relatively heat-stable (compounds with a high melting point). However, their mechanical properties are often weak.

Finally, the method used to encapsulate probiotics must lead to a high number of viable and metabolically active cells. To this end, the use of bacterial cultures in dried form (easier to handle, less vulnerable and less reactive to their environment) can prove to be a particularly relevant strategy. Among the numerous techniques that can be employed to encapsulate cells, fluidized air bed coating of powder particles of dried microorganisms constitute certainly the most promising technology so far (Siuta-Cruce, 2001).

Case Study: MEPPHAC project

Stability of probiotics in food and feed is a major challenge because of their high sensitivity to several stresses. In the field of animal nutrition, incorporation of probiotics into pellets requires a high compression force and leads to a large increase in temperature, thus inducing a high mortality. This study was carried out within the framework of the CRAFT European project MEPPHAC, whose main objective was to develop a protective technology that maintains probiotics alive in final food and feed products, via micro-encapsulation. In order to increase the survival of *Saccharomyces cerevisiae* during pelletization, 25 coating materials or formulations were selected according to their barrier properties, and tested using spray- and hot-melt coating as microencapsulation techniques.

Spray- and Hot-melt coating processes

Table I: Coating materials or formulations tested to increase cell viability during pelletization

Products	Coating materials
A-C	Hydrophilic coatings (8)
D-E	Hydrophobic coatings (15)
F	Double-coating formulations (2)

The 25 coating materials or formulations tested are listed in Table I. The double-coating formulations consisted of two successive coatings, the first one with an aqueous-based coating material, and the second one with a lipid-based coating material.

The coating equipment used for spray- and hot-melt coating was a Uni-Glatt pilot (Glatt Gmbh, Binzen, Germany) equipped with a Wurster insert. The use of a Wurster fluidised bed coater (bottom spray) is rarely considered for hot-melt coating. Some changes of the equipment and the process operations were carried out in order to allow delivery of the molten material on the solid particles in the fluidized bed without any discontinuity due to solidification or hardening of the melt: insulation of the tube delivering the coating material from the reservoir to the spray coater, heating of the atomization air, pre-heating of the delivery tube in the spray nozzle through which the coating agent passes before being atomized and sprayed, insulation of the spray nozzle at the bottom of the coating chamber.

Figure 1: Particle aspect before and after coating

Depending on the coating material or formulation tested, a fine adjustment of one or several operating parameters (e.g. fluidisation air flow

rate, fluidisation air temperature, atomization air pressure, atomization air temperature, coating solution flow rate, coating solution temperature, outlet air temperature) was necessary in order to avoid spray-drying (spray-coating process) or spray-congealing (hot-melt coating process) and agglomeration/defluidisation phenomena (weight gain objective = 50%).

Survival to the coating process

Viable cell counts were determined before and after coating in order to evaluate the effect of the encapsulation process on cell viability. As shown in Figure 2, the survival rate of *Saccharomyces cerevisiae* to the coating process varied significantly according to the coating material or formulation tested. The percentage of viable microorganisms following encapsulation ranged from 52.5 to 95.9% with an average value of 75.9%.

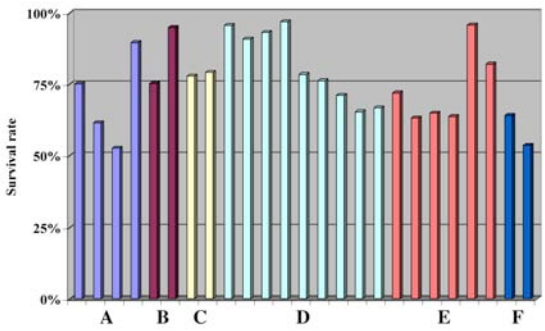

Figure 2: Survival rate of *Saccharomyces cerevisiae* to the Wurster coating process according to the coating material or formulation tested

For experiments carried out with the spray-coating technique (products A-C + aqueous resin), the processing time was a function of the concentration of solids in the coating solution, which certainly had an impact on the cell survival. Not surprisingly, the lowest survival rates were obtained with hydrophilic formulations having a low total solid content (≤ 15% w/w).

The hot-melt coating technique is a solvent-free coating technique, which means a shorter processing time compared to the spray-coating technique, and consequently less drastic coating conditions (time/temperature effect) for probiotics. However, encapsulation with 5 out of the 14 lipid-based coating materials tested (products D and E – aqueous resin) led to survival rates below 70%, probably because of the high melting point of these products (≥ 70°C) and the resulting elevated fluidization air temperature necessary (up to 65°C) to avoid blockage of the nozzle.

Finally, the cell viability decreased by about 35-45% with the two double-coating formulations, which was expected since the cells experienced two coating processes successively.

Survival to the pelleting process

The ability of the coated microorganisms to survive pelletization was evaluated and compared with uncoated control. Coated and uncoated microorganisms were introduced into a feed formulation for lamb before pelletization using a laboratory pelleting press (Press type 14-175, Kahl, Germany). Viable cell count in the feed formulation was determined before and after pelletization.

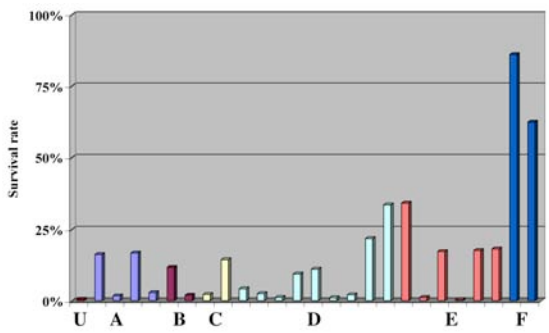

Figure 3: Survival rate of uncoated (U) and coated *Saccharomyces cerevisiae* to pelletization according to the coating material or formulation tested

As illustrated in Figure 3, the survival rate of coated Saccharomyces cerevisiae to pelletization varied significantly according to the coating material or formulation used. Only 14 out of the

25 products tested showed a significant protective effect compared to uncoated control. Best results were obtained using the two double-coating formulations, with a survival rate as high as 86.1%. Considering the loss of viability during the double-coating process, about 55% of the initial cell population finally survived pelletization, which is more than 100 times higher than without coating (survival rate lower than 0.5%). Similar results were obtained at industrial scale (pelleting temperature = 65°C vs 55°C at lab scale, data not shown), thus demonstrating the interest of encapsulation for the technological exploitation of probiotics in the feed industry.

Conclusions

The selection of suitable coating materials is of crucial importance to ensure efficient protection of probiotics, as demonstrated in the case study above. Unfortunately, the ideal coating material does not exist. Combining barrier properties of several coating materials in multilayered microcapsules seems to be the key for a successful encapsulation of probiotics. Of course, a compromise between process efficacy and cost must be found. The use of suitable coating materials and encapsulation technology should allow probiotics to be formulated into food/feed systems more readily, thus increasing the number of applications. It should also allow manufacturers to place assurances on the viability and quantity of probiotics in finished products, which is not currently the case.

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Journal of Microencapsulation

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Journal of Encapsulation and Adsorption Sciences (JEAS)

A new periodical journal on encapsulation and adsorption research has just been launched. Journal of Encapsulation and Adsorption Sciences (JEAS) is an international, specialized, English-language journal devoted to publication of original contributions concerning with the processes and technology of encapsulation and adsorption for applications including among others:

- Biomedical and pharmaceutical applications focusing among others on the development of drug delivery systems (transdermal, oral), nano-taggants and biomarkers encapsulation for nanomedicine and theranostics
- Food technology
- Cosmetics
- Biochemistry
- Optics, photonics
- Environment, energy storage, thermal insulation and reinforcement materials

It is an open-access, peer-reviewed journal describing scientific and technological advances that cover the basic sciences, engineering aspects and applied technology of molecules (proteins, enzymes, food, fragrance, gas…) encapsulation and adsorption with preparative manipulation and related materials properties (controlled release, molecular interactions studies, surface properties among others), technical processes and analytical methods. Host matrices include, but are not limited to the following materials: hydrogels, polymers, (sol-gel) glasses, ceramics, inorganic-organic hybrid materials, porous materials and metal-organic framework as bulk or films, multi-functional particles, nanocapsules, and any other materials supports of interest.

The journal publishes the highest quality original full articles, communications, notes, reviews, special issues and books, covering both the experimental and theoretical aspects. It has a distinguished editorial board ensuring that the journal maintains high scientific standards with a broad international coverage.

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Microencapsulation: applications in micronutrient fortification through "engineered" staple foods

Yao Olive Li (Tennessee State University, Nashville, TN, USA) and Levente L. Diosady (University of Toronto, Ontario, Canada)

Malnutrition, in one of the three forms – hunger, micronutrient deficiencies, and over-consumption, is threatening one-third to one-half of the world's population, and has greatly slowed down the social and economic development. The cause of malnutrition is indeed related to all aspects of a highly interconnected agro-food system consisting of agriculture production, post-harvest processing, food distribution, and consumption patterns. Technical solutions then range from agricultural innovations to food-based interventions, with respect to increases in food supply, affordability, and dietary quality.

Food-based interventions involve the production of novel food products with a balanced nutritional profile, or ideally "optimized nutrition", such as micronutrient-fortified and functional foods. Micronutrient fortification has been practiced globally for several decades, and resulted in remarkable improvement in human nutrition. Similarly, various nutraceuticals (biologically active compounds present in some traditional or unusual food materials) can be incorporated into processed foods through fortification techniques, leading to a specific group of functional foods.

Despite the relatively small quantities required for micronutrients and nutraceuticals in developing value-added foods for enhanced/improved nutrition, the technical challenge is the safe and effective delivery of these bioactives through food production, distribution, and consumption. This is mainly due to several factors: 1) disagreeable taste and appearance associated with most active ingredients, 2) chemical instability of the actives and undesirable interactions between them with other food components, 3) reduced bioavailability of the added actives when reaching the target sites in the digestive system, and 4) compromised functionality of the end food products. Therefore, innovative technologies are required. Micro- and nano-encapsulation are enabling technologies with promises in fulfillment of all technical requirements.

Microencapsulation has been used extensively in many fields, including pharmaceuticals, cosmetics, foods/feeds, agrochemicals, and biomedical applications, while nano-encapsulation as a part of nano-technology, is still in its infancy with main advances still remaining on the lab scale or small pilot scales. Particularly, in the area of food applications, encapsulation techniques at either micro- or nano- level are widely studied for the purpose of effective delivery of various bioactives through novel food product development for enhanced nutritional value.

As the modern food manufacturing processes are highly diversified, many specific sub-divisions have evolved, such as specialty food ingredient suppliers and commodity-based consumer food producers. As illustrate in Figure 1, if we regard the R&D process for novel ingredient formulations as the "upper-stream" processing, the applications of these ingredient preparations (liquid) and powders, leading to finished products, can be viewed as the "down-stream" processing. As there are many review articles in the literature that have summarized the recent advances in the "upper-stream" R&D process [1-3], this brief review will focus on the "downstream" applications of microencapsulation techniques. Particularly, based on our successful experience in micronutrient fortification through staple foods or food ingredients, such as salt, sugar, and rice, we will provide a perspective in establishing a flexible technology platform consisting of a series of encapsulation steps, instead of using a single encapsulation technique, for the production of "engineered" micro-particles resembling the characteristics of the selected food carriers. This

technology platform can be then adapted for other delivery applications.

With an initial goal of developing technically and economically feasible technologies for micronutrient fortification suitable for developing countries, where the populations are more prone to three major micronutrient deficiencies of vitamin A, iron, and iodine, we decided to choose staple foods as the fortification carriers. This is because people in developing countries, unlike the populations living in industrialized countries, have limited access to processed foods. Staple foods or food ingredients, such as salt, sugar, and rice, are desirable due to the fact that they are consumed on a regular basis and at a constant rate. Furthermore, fortification of these commonly-eaten foods guarantees that the added micronutrients can reach the largest number of population in the affected areas in a more cost-effective manner, and the fortification programs are economically viable to initiate and maintain.

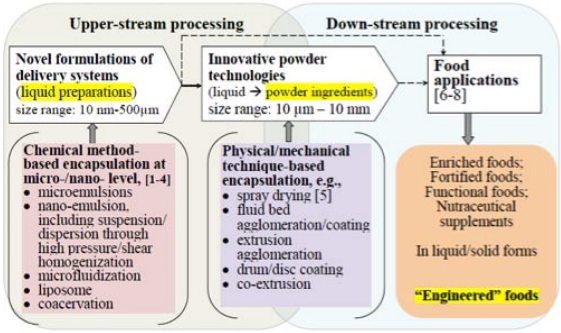

Figure 1. An overview of applications of advanced micro- and nano-encapsulation techniques in the development of novel food ingredients and finished products

Staple foods or food ingredients are typically presented to the consumer as solids with particle sizes ranging from several microns to several milimeters. To prevent particle segragation, which may result in potential under- or over-dosing, micronutrients must be added in forms that either stick to the food carrier, or match the particle size, and if possible, the particle density of the granular food. Successful food fortification processes require that the added micronutrients are evenly distributed and are unnoticeable to the consumer. Thus the completed delivery system must match the food carrier in colour and appearance, and must not alter the food flavour. Therefore, the added micronutrients must be introduced in a form that meets these criteria. We then hypothesized that single or combined microencapsulation methods can form the technological basis of multiple micronutrient fortification for a wide variety of staple foods.

To develop a microencapsulation-based approach for food fortification, we started with investigation of several encapsulation techniques, including physical processes such as extrusion, fluidized-bed coating, rotating disc coating, spray drying, and chemical methods such as gelation and microemulsions. Based on a consideration that the resulting food fortification programs should be technically and economically feasible for commercialization in developing countries, we decided to use extrusion as a basic agglomeration process to form micro-particles with wanted sizes, due mainly to its low operational cost and ease for implementation. The extrusion agglomeration process could be combined with other techniques, such as internal or in-situ gelation during extrusion and post-extrusion surface modification/coating, in order to produce micro-particles with desired physical and chemical properties.

A flexible microencapsulation-based technology platform was then developed, based on extrusion agglomeration followed by hydrophilic polymer coating [9-10]. For example, the selected micronutrients, such as vitamin A, folic acid, iron, and zinc, were incorporated into appropriate binder materials and extruded to form salt grain-sized or rice grain-sized analogues, which were further coated or colour-masked if necessary. The micro-particles thus formed, concentrated in the selected micronutrients and resembling the physical characteristics of the food carriers (as shown in the illustrations, Figures 2 & 3), were

blended into market salt or rice at certain ratios to generate end fortified foods. This technology platform has demonstrated technical feasibility for effective delivery of multiple micronutrients in selected staple foods on different size scales [10-11]. The added micronutrients - vitamin A, iron, zinc, and folic acid - had excellent stability and bioavailability in the resulting multiple-fortified foods, i.e., salt, sugar, and rice, which also maintained desirable organoleptic properties [12-14].

Through the sponsorship of two International NGOs – the Micronutrient Initiative (MI) and the Program for Appropriate Technology in Health (PATH), the salt and rice platforms are currently under field-studies and pilot-testing in Asia and South America, involving several hundred thousands of school children and production rates of 500-600 kg per day of the micronutrient-concentrated premixes. Successful implementation of the technologies, i.e., multiple-fortified Ultra Rice® and double fortified salt (DFS) with iron and iodine, is expected to bring immediate benefits to human health, particularly to the target populations in developing countries. Hence, Ultra Rice® and DFS technology have been selected as 2009 and 2010 Tech Award Laureates, respectively, due to their "innovative approaches to addressing global micronutrient malnutrition" [15-16].

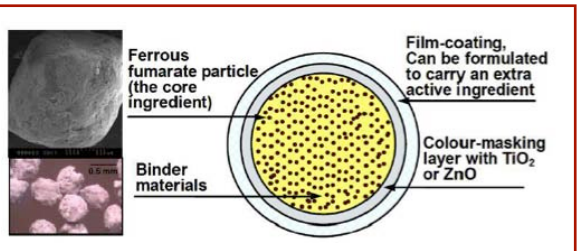

Figure 2. Schematic micro-particle structure and microscopic/SEM images of salt grain-size iron premix made by extrusion agglomeration and film-coating, with desirable characteristics suitable for salt and sugar fortification

The findings of this study enhanced the understanding of potential interactions between the added components and the food carriers, which will allow us to develop more stable delivery systems for food fortification. The technology platform is based on a broad concept of microencapsulation, and combines a series of unit operations, such as particle agglomeration via extrusion or fluidized-bed technique, surface modification, color/flavor-masking, film over-coating by the use of rotating disc or fluidized-bed coating process. The technology is then adaptable to formulating customized delivery systems for active ingredients in broader applications. Our current research focuses on extending this technology platform for developing "engineered" foods and food ingredients containing both essential micronutrients and desirable nutraceuticals, consequently leading to novel functional food products with added nutritional value for health promotion and disease prevention. Clearly, to achieve this research goal, an integrated approach of choosing several nano- and micro-encapsulation techniques and using them in a combination appropriate to the selected food carriers is essential, with respect to meeting the principle fortification criteria: technical and economical feasibility, clinical effectiveness, and consumer acceptance.

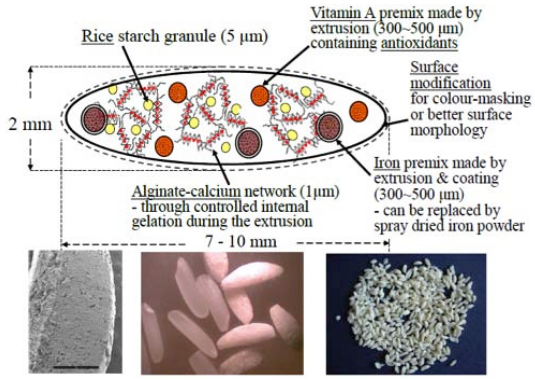

Figure 3. Schematic particle structure, SEM/microscopic image, and digital picture of rice grain analogues made by cold-forming extrusion and controlled internal gelation during extrusion, with desirable characteristics suitable for rice fortification

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Olive Li has extensive training and research experience in Food Science & Engineering. Particularly during her Master and PhD degree studies in the Department of Chemical Engineering at University of Toronto, Canada, she has acquired specialized expertise in the area of novel processing technologies for effective delivery of micronutrients and nutraceuticals through fortified or functional foods. She now joins Tennessee State University and leads her own research group in specialized area of Functional Food Engineering.

Job opportunities or requests

Integrating research training in particle & powder technology to deliver efficient products with high functionality.

Objectives of PowTech ITN

The objective of this network is to integrate inter-sectoral and multidisciplinary research in particle and powder technology into the training of 15 highly skilled young researchers, to strengthen the competitiveness of food and pharmaceutical industry and to strengthen the European Research Area.

The highly skilled human resources and the knowledge in powder technology to be developed in the PowTech network will contribute to the development of innovative products and effective powder processing in Europe by solving industrial problems and reducing knowledge barriers. The PowTech ITN comprises a PowTech Graduate School and a Focused research

Programme.

The Graduate School training aims to educate the students on how to conduct research and to manage projects, communicate results effectively, commercialise research, but also provide them with an in-depth education in particle & powder technology and to open their minds to innovation and transformation of research ideas into commercial reality.

The Focused Research programme is divided in three major research network teams. The R&D projects that each ESR will carry out were selected based on industrial needs highlighted by the industrial partners. All projects will use an engineering design approach consisting of an understanding of powder structure from a molecular to a macro disperse scale during powder formation/modification combined with modelling of fluid mechanical & thermal models and with kinetics of relevant powder properties (food flavour, nutrient/active compound release, etc).

Positions available

We are looking for 15 Early Stage Researchers (ESRs) to be employed within PowTech ITN during a three years period. The candidates will perform doctoral research sharing their time between main host and a secondment location (approx 6 months, generally an industry). During this period, they will also have the opportunity to attend several training courses that will be held within the PowTech Graduate School.

CODE	projects	Mainhost	Collaborators
Powder Formation			
ESR_P1	Production of nanoparticles for food surfaces	DSM	TUDelf
ESR_P2	Preparation of magnetic nanoparticlesfor drug delivery	Pannonia	Trigon
ESR_P3	Oil compounds encapsulation by spray drying	AgroParis	DSM
ESR_P4	Spray processing of powders with multiple emulsion structure	Nestle	ETH
ESR_P5	Particle structure formation in spray-drying	YKI	NIRO
Powder Modification			
ESR_P6	Particle properties design in fluid bed coating	ONIRIS	Capsulae
ESR_P7	Control of end-use properties of bio-powders by alt. coating	Armines	Capsulae
ESR_P8	Simulation tools for fluidized bed coating	AstraZeneca	CTH
ESR_P9	Gas phase process to coat particles with an ultrathin film	TU Delft	DSM
ESR_P10	Food composite structures with low water or fat	ETH	Nestle/ SIK
Control of Powder Processing			
ESR_P11	Design of complex powder mixtures to avoid segregation	SIK	Santa Maria
ESR_P12	Modelling tools for high shear wet granulation	CTH	AstraZeneca
ESR_P13	Low feed rate dosing of cohesive powders into processes	Greenwich	GSK
ESR_P14	Modelling tools for spray drying	CTH/SIK	Tetra Pak
ESR_P15	Control of crystal form, size and shape during crystallization	UCB	Pharma UCC

The PowTech ITN has started in March 2011, and the candidates are expected to be contracted from this date up to September 2011.

For more information about each project please visit http://www.sik.se/powtech or contact the project coordinator: lilia.ahrne@sik.se

Job opportunities or requests

Research Scientist on encapsulation at Nestlé

For our Applied Science and Analytical Support department in Konolfingen near to bern (Switzerland), we are looking for a Research Scientist on Encapsulation to develop innovative products and concept on encapsulation. Candidate must hold a Ph.D. university degree in Food Science, Chemistry, Material Science (or related discipline) or equivalent experience in R&D. Experience in field of encapsulation and food is of advantage. Fluency in English is required. German is desirable.

More information : **www.careers.nestle.com**

Post-doctoral position in microencapsulation at University of Bourgogne (France)

A post-doctoral position is available in EMMA group (AgroSup / Université de Bourgogne) for one year with an industrial financial support. The subject focuses about the encapsulation of a lipophilic molecule with physico-chemical and bioavailability aspects. A knowledge in physico-chemical techniques and in formulation is recommended, particularly in the field of encapsulation by emulsion techniques.

More information : odile.chambin_at_u-bourgogne.fr

France/Canada co-supervised PhD position

We are looking for PhD candidates with an engineering background. The thesis will concern the development of microencapsulation process engineering aspects. Research will be shared between Oniris, Nantes and Queen's University in Canada.

More information : Denis.poncelet@oniris-nantes.fr or neufeld@queensu.ca

PEOPLE 2011
INDIVIDUAL FELLOWSHIPS

The European commission has open call for fellowship for experimented researchers (PhD or have at least 4 years of full-time equivalent research experience after their diploma).

- **IEF, Intra-European Fellowship**: provides financial support for trans-national mobility inside European Member State or an Associated Country
- **IOF, International Outgoing Fellowship**: offers the opportunity to realise a project in a third country (USA, China, Canada, India, Russia, South Africa, New Zealand, etc.).
- **IIF, International Incoming Fellowship**: aims to attract researchers from in a third country to come (back) to Europe and work on research projects.

The project may cover a period of 12 to 24 months. Annual living allowances is 58700 euros (<10 years experience) to 87500 euros (>10 years experience) time a national factor.. Deadline for submission for the three Calls: August 11, 2011, at 17:00, Brussels time.

More information in the Guides for Applicants published on

http://cordis.europa.eu/fp7/dc/index.cfm?fuseaction=UserSite.FP7CallsPage

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BRG proposes to help you either to find candidates or identify laboratories by publishing a request on the BRG web site (select contributions for submissions, select news to consult proposals).

We wish you great success in your application.

MicroMAX® - Microencapsulation technology for delivery of bioactives in food

Oliver, C. M., Sanguansri, L., and Augustin, MA (CSIRO, Weribee, Vic, Australia)

Introduction

Microencapsulation is the packaging of small particles of solid, liquid or gas (referred to as the core material) within a secondary material that protects and stabilises the core (Figure 1). Microencapsulation has been successfully employed in the pharmaceutical industry to target delivery of drugs in the body. The technology also has a range of applications in the food industry, such as protection and delivery of food flavours/aromas and bioactives (e.g. omega-3, probiotics, polyphenols, carotenoids, vitamins), and production of shelf-stable dry powders or oil-in-water emulsions. Bioactives are molecules that possess biological activity in addition to their nutritional value. Bioactives are typically very sensitive to their environment, prone to degradation, and sometimes have undesirable impacts on the organoleptic properties of the final food. By addressing these issues through microencapsulation, bioactives play a critical role in the burgeoning functional foods market.

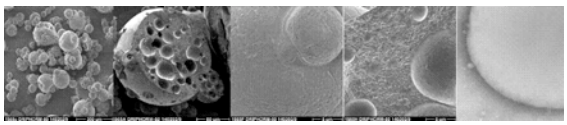

Figure 1: Images of MicroMAX® microcapsule structure and morphology at different land-scales

CSIRO's microencapsulation technology (MicroMAX®)

The Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) is a large and diverse research organisation with approximately one third of its research activities directed towards food production, improvement, quality, safety, eating for health and innovative processing. Within this research framework the increasingly important area of food bioactives, assessment of the bioactivity of food components, and development of new food-grade materials and methods to deliver bioactives into foods, and potentially target their delivery to particular sites along the gastrointestinal tract (GIT) is receiving particular attention (Sanguansri & Augustin, 2001; Head et al., 2005; Crittenden et al., 2005, 2006; Augustin et al., 2006; Rusli et al., 2006).

MicroMAX® is a suite of patented micro-encapsulation technologies developed by CSIRO that protects bioactive compounds at all stages – during manufacture and storage through to food application and potential delivery to specific sites along the gastrointestinal tract (GI tract). MicroMAX® relies upon the reaction between a protein or peptide (with free amino group(s) and a carbohydrate (containing a reducing sugar) (Figure 2) to form a very effective encapsulation matrix with exceptional film-forming and antioxidant properties.

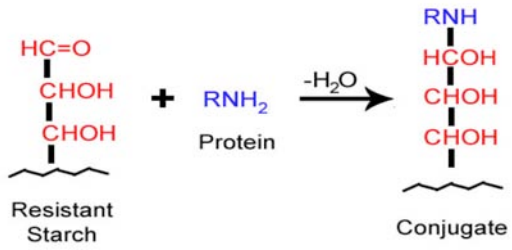

Figure 2: Non-enzymatic reaction between a protein or peptide (with free amino group(s)) and a carbohydrate (containing a reducing sugar) in the presence of heat.

MicroMAX® encapsulant has built-in antioxidant properties, therefore reducing the need for added antioxidants, and additional cost savings in the formulation. MicroMAX® process is adaptable to standard food processing equipments. The flexibility of MicroMAX® allows the choice of protein and carbohydrates in the encapsulant formulation to be selected from those already used in the target food application to avoid additional product labelling issues. MicroMAX® formulations and powder properties can be tailored to suit specific applications and ingredient formats and can be produced as a stable emulsion (UHT emulsion) or powder (spray dried powder) which optionally, can be further coated with another layer of encapsulant material to tailor the release characteristics of the final microcapsule (Figure 3). MicroMAX® was initially developed and optimised for encapsulation of fish oil, but has subsequently been adapted to the protection of other essential oils, oil-soluble bioactive components (e.g. vitamin E) and probiotic bacteria. The technology can be used to deliver a single bioactive core or a mixture of bioactives in

one formulation, offering a much wider application in functional food product development to enhance the nutritional contents of food.

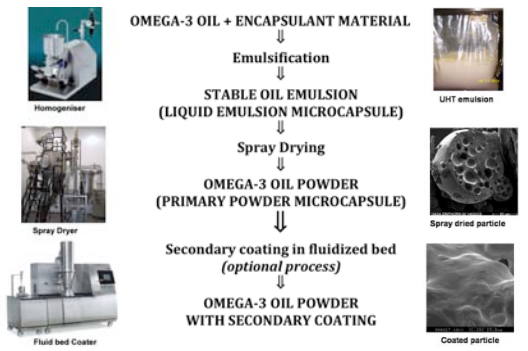

Figure 3: Standard microencapsulation process using MicroMAX® technology involving the formation of stable emulsion, which can be spray dried into powder and optionally be further coated with another layer of encapsulant material to tailor the release characteristics of the final microcapsule.

MicroMAX® has been used in the commercial manufacture of stable omega-3 oil products. MicroMAX® spray dried powders have high oil loading (>50% oil), low surface oil (<1% surface oil) and long shelf-life (>24 months) at 25-35°C storage. MicroMAX® UHT emulsions have high oil loading (25% oil), and are stable to high heat and high shear processes making them ideal for UHT product applications. In addition, they are stable for up to 12 months shelf-life. First generation MicroMAX® formulation is proven in the marketplace for delivery of omega-3 in infant formula due to its long shelf-life. The 2nd generation MicroMAX® formulations are more robust and versatile omega-3 ingredients can been added to a much wider range of food products, such as yogurt, beverage, UHT drinks, canned products, meat and fish products, bread and bakery products, and processed cheese (Figure 4). The technology can be used to convert liquid oils into powders. The oil powders can then be used as alternative fat and oil ingredients in dry mixes to make, for example, ice cream, dairy desserts, creamers, soup bases, as well as filled dairy products and bakery applications. CSIRO researchers have extensive experience with oil and oil-soluble bioactives, including commercialisation of omega-3 microcapsules. They also have experience in the microencapsulation of resveratrol and probiotics, and are currently developing their expertise in microencapsulation of phytochemicals.

Figure 4: Examples of functional food products containing microencapsulated omega-3 oils using MicroMAX®.

MicroMAX® is a platform technology that can be applied and tailored to protect and deliver probiotic bacteria (MicroMAX-Pro), potentially to specific regions of the GIT. MicroMAX®-Pro offers significant improvement in probiotics survival during storage at non-refrigerated and intermediate humidity conditions, as well as during in vitro digestion (Figure 5).

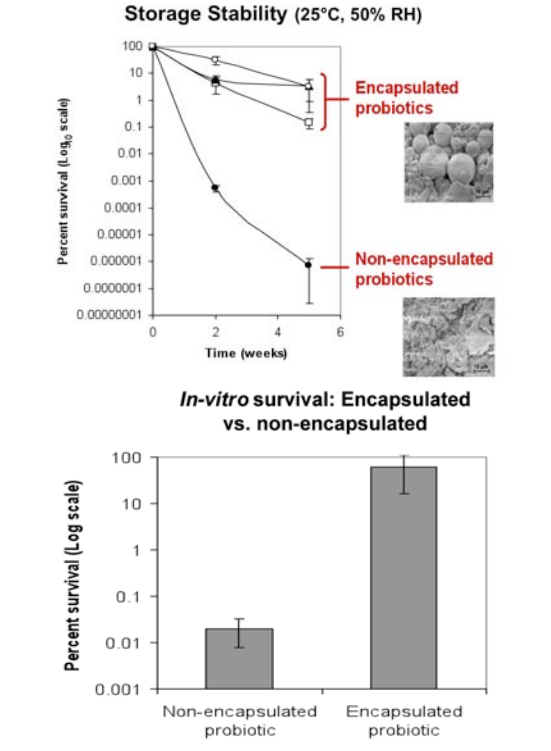

Figure 5: Comparison of the survival of a Lactobacillus sp during storage at 25°C and aw~0.5 (50% relative humidity), and when exposed to in vitro digestion for encapsulated using MicroMAX® versus nonencapsulated bacteria.

CSIRO is currently seeking commercial partners and investors to further exploit the MicroMAX® suite of technologies for development of microencapsulated ingredients other than omega-3 for a range of applications.

CSIRO's capability in microencapsulation and delivery systems

- **Food grade encapsulant material design**. CSIRO has strong capability in the development of new food grade encapsulant materials, via physical modification of natural food ingredients using emerging technologies and processes and food-safe processes and formulations to protect and deliver bioactives to target sites along the GIT.
- **Characterisation of microcapsules and delivery systems**. CSIRO has strong material characterisation and analytical capabilities for testing and characterising new materials and microencapsulated bioactives; understanding the release of microencapsulated bioactives in various food matrices and understanding the impact of bioactives on gut health.
- **Formulations and process development**. CSIRO's multidisciplinary team assist commercial clients in the formulation and processing of functional foods containing microencapsulated bioactives from 'proof-of-concept' at lab-scale, to pilot- to commercial-scale manufacture. They provide strategies and solutions to solve problems in micro-encapsulation of food ingredients.
- **Powder technology**. CSIRO has strong capability in powder technology including spray drying and developing capability in fluid bed processing.

Collaborations

CSIRO's microencapsulation and delivery team collaborates with Australian and international universities and research groups with interest in delivery systems, functional foods and preventative health. Research collaborations are in the form of joint student supervision (undergraduate and post graduate interns), industrial trainees, research fellowships and visiting scientists. We also collaborate with commercial companies in technology evaluations, product development and applications. CSIRO is interested in forming further collaborations with both academic and commercial research group in pre-competitive research topics.

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Luz Sanguansri is the Research Team Leader for Delivery Systems at CSIRO Food and Nutritional Sciences (CFNS). Luz and her team are developing new materials, processes and formulations to protect and deliver bioactive and nutraceutical ingredients into functional foods, and to target the site of release in the gastrointestinal tract. Luz has more than 18 years experience in leading and managing teams in a wide range of research and commercial projects relating to process development, process evaluation, process design, product formulation, shelf-life evaluation, pilot scale production trial, commercial scale-up and technology transfer. (http://www.csiro.au/people/luz.sanguansri.html)

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Find below a quick selection of articles published in 2011, on microencapsulation for food applications, showing that, on this quite specific subject, it is publihed probably more 30 articles per months

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Interfacial engineering for optimisation of the functionality of microcapsules

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Introduction

As reviewed by several authors [1] a variety of microencapsulation techniques exist, which can nowadays be considered as well established in the food industry. The different techniques can be classified depending on the nature of the process (physical, chemical, physicochemical techniques) as it was done by Kunz et al. [2] or the functionality, the working principle and the corresponding type of carrier matrix [3]. In the early phase of technological transfer and adoption of microencapsulation techniques in the food industry, the inclusion of food ingredients to protect them from unfavourable environmental conditions and to overcome incompatibilities between food ingredients or a food ingredient and the food itself has been the aim.

Nowadays the growing sector of functional foods is the major driving force behind innovation in microencapsulation techniques. Frequently, functional food ingredients are isolated ingredients derived from plant or animal tissue. These ingredients need to be stabilised during storage prior to their use in food production. Furthermore a protection and controlled release during gastrointestinal transit is desirable.

As shown by Ubbink et al. [3] each microencapsulation technique has unique advantages, but also limitations. Therefore, recent developments focused on the combination of different microencapsulation techniques to develop more complex multiple capsule structures to take advantage of the individual properties of different materials and techniques. One example is a multiple shell encapsulation using a sequence of coacervation and agglomeration steps to produce gelatine-based microcapsules with a very high microencapsulation efficiency and good oxygen barrier properties [4]. Bouquerand et al. [5] e.g. combine complex coacervation and extrusion in order to provide a coacervate encapsulated in a glassy matrix, which does not release the core material before its arrival in the gastro-intestinal tract.

Another opportunity to develop more sophisticated structures is a target-oriented modification of the materials themselves and the design of structured interfaces during the process of microencapsulation to change the functionality of the resulting microcapsules. Figure 1 gives an overview on the possibilities for interfacial engineering in matrix capsules and microcapsules.

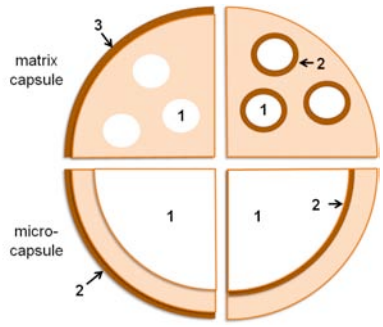

Figure 1: Strategies for interfacial engineering during production of matrix capsules and microcapsules through surface accumulation of surface –active materials (3), multi-layer formation and chemical modification of materials on the surface of the encapsulant (2); (1) encapsulant

Multi-layer formation and chemical modification on the surface of the encapsulant

An internal interface may result from a physical incompatibility of the encapsulant and the surrounding continuous phase of the carrier matrix as it e.g. occurs in microencapsulation of lipophilic food ingredients. This interface is usually occupied by a surface active food grade constituent, which lowers surface tension and thus stabilises the multi-phase system. Microcapsules can be prepared by solvent removal from the system. One possibility for modification of the

interface is cross-linking of the surface-active material. In the scientific literature cross-linking of proteins with transglutaminase is described [6, 7], which can result in a retardation of core material release in vivo. Crosslinking also affects interfacial properties [8-11], but a systematic investigation on the impact on microencapsulation properties and functionality is missing.

A second possibility for interfacial engineering is the deposition of multiple layers of oppositely charged polymers on the surface of the dispersed core material [12]. It has been described that e.g. the stability of polyunsaturated fatty acids in emulsions is increased when the droplets are surrounded with a thick interface with positive net charge [13]. If slowly digestible or non-digestible polymers are used during deposition the release of the core material can be modified. As recently reviewed [14] the preparation of triple emulsions (water-in-oil-in-water) with polymer deposition and aggregation to allow multiple microencapsulation by interfacial polymerization has been patented by Casana et al. [15]. It is assumed that multilayer formation affects interfacial elasticity and thus the behaviour of the dispersed system during the microencapsulation process. However, the preservation of the integrity of the modified interface during processing is a key requirement to maintain the functionality.

Surface modification of solid microcapsule systems

A key issue for evaluation of the success of an encapsulation process and for the stability of the encapsulant is the microencapsulation efficiency. It has been emphasized that very low amounts of non-encapsulated core material may significantly affect the quality, and thus functionality, of a microencapsulated food ingredient [16]. A traditional approach to increase the microencapsulation efficiency is coating of a primary particle e.g. by fluidised bed coating. In multi stage drying it is possible to cover drying droplets with powderous compounds like e.g. starch [17, 18].

In microencapsulation applications, which involve the use of surface active materials, excess surface active material may be used to modify the surface composition of microcapsules. The surface-active material accumulates on the surface of e.g. droplets and remains there during solvent evaporation. This concept of surface accumulation has successfully been applied to increase the microencapsulation efficiency during encapsulation of proteins by spray-drying [19]. It has also been shown that redispersibility of food powders can be improved through surface accumulation of lecithin [20]. Proteins and protein hydrolysates may be used for surface modification in food and feed applications. With respect to functional ingredients it might be of interest to investigate e.g. the surface accumulation of mucoadhesive and physiologically active compounds in microcapsules to precisely define the release of the core material. In this context food materials science aspects need to be considered and suitable analytical techniques need to be developed.

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