Bioencapsulation and agrifood related (bio)technologies: achievements and prospects

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INTRODUCTION

Biotechnology, the specific technology based on biology-related sciences, use intensively bioengineering and bioprocessing as tools to modify organisms, to improve their performances, with/without genetic engineering. The traditional agrifood related biotechnology, uses microorganisms for the manufacture of food products (beer, wine technology and milk fermented products). Nowadays, biotechnology has general applications in four major areas, such as agrifood-related areas, biomedicine, industrial non-food uses of crops (e.g. biodegradable plastics, biofuels), and environmental uses, including the waste management, bioremediation and biological weapons to replace chemicals. **Biotechnological engineering or biological engineering** includes different disciplines such as biochemical engineering, biomedical engineering, bio-process engineering, biosystem engineering. It is an integrated approach of fundamental biological sciences and traditional engineering principles.

A series of derived terms and colors are used to identify several branches of biotechnology **(Fig.1). Green biotechnology** is specifically applied to agriculture and derived-processes (e.g. selection and domestication of plants via micropropagation, designing of transgenic plants to grow under specific environmental conditions with/without chemicals. Whether or not the green biotechnology products (GM crops) are ultimately more environmentally friendly is a topic of considerable debate. **Red biotechnology** is applied to medical processes (microoorganisms to produce antibiotics, engineering of genetic cures through genomic manipulation) and finds promising applications in drug production and pharmacogenomics. **White biotechnology** is applied to industrial processes (designing organisms to produce useful chemicals, use of enzymes as industrial catalysts to produce valuable chemicals or to destroy pollutants). **Blue biotechnology** describe the marine and aquatic applications of biotechnology, but its use is still rare. **Bioinformatics** and **bioeconomy** bring also new nuances to these "colored" biotechnologies, as interdisciplinary fields.

During the 1990s the *red/green* distinction of biotechnology dominated the media debates, public perceptions and EU regulations. By 1999, medical biotechnology (*red*) was treated much more favorably than agri-food biotechnology (*green*).
We intend to review some relevant achievements and some prospects of using bioencapsulation in agrifood-related (bio)technologies.

MATERIALS AND METHODS APPLIED IN BIO(MICRO)ENCAPSULATION

Bioencapsulation technology applied in "green" areas. The encapsulation of a target molecule which originate from a natural source or is designed to be active in a living organism is nominated as "bioencapsulation" , combined or not with micro- or nano- prefix , which refers to the dimension of capsules. Concerning the involvement of bioencapsulation in "green" areas, we should discriminate between the "technological applications in green biology"(1) and "green biotechnology"(2). Many data regarding bioencapsulation refers more to first, agrifood technological

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applications, than to 2nd one, being focused on different steps of food product development (food chain)(Fig.2). Micro- or nano-encapsulation, as technique, is therefore may be achieved by multiple procedures based on different materials (unique molecules natural or synthetic) introduced in specific matrices (natural or synthetic), dependent on the application purposes. The processes involved are either chemical (coacervation, interfacial and In situ polymerization, extrusion through nozzles), mechanical or physical processes, such as spray drying, fluid bed drying and coating, rotational suspension separation, or the spinning disk method. Different biomolecules can be encapsulated or immobilized on natural, compatible material (matrix) to form microcapsules (as core, coating or wall material) stable and with a controlled release or diffusion, for a specific period of time, under controlled external conditions to trigger the capsule rupture, melting or dissolving.

Informations about the protocols and procedures are well documented, being presented at yearly BRG and COST 865 meetings (between 2006-2009). We assist to a rapid growth of published scientific articles and patents, e.g. by a factor of 3 the last 10 years (from 800 to 2500) comparing with a factor of 2,5 in 20 years (1979-1999) (Boh, 2003). Updated systematic presentations regarding materials, methods and delivery systems are available (Weiss and Vladisavljevic, 2005; Benita, 2005; Poncelet, 2006, 2008).

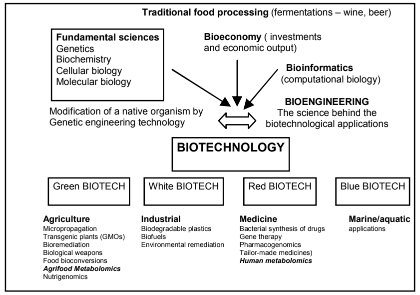

Figure 1 : Colors of Biotechnology and their application fields.

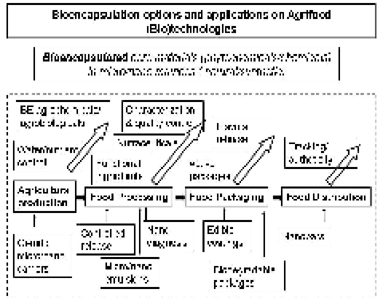

Figure2: Applications of Bioencapsulation in Agrifood (Bio)technologies in the food chain

ACHIEVEMENTS (RESULTS AND APPLICATIONS)

There are almost limitless applications for microencapsulated materials used in agriculture & food areas, biotechnology, medicine, recently reviewed (de Vos, 2009). Plant- or food-derived bioactive molecules (antioxidants, pigments, phenolics, sterols,etc.) are generally labile and need encapsulation for a better protection, stability improvement and their controlled release, at best, efficient concentrations (Socaciu, 2008). Many examples of their bioencapsulation can be cited from literature (see also other COST meetings and BRG workshops).
The market for microencapsulation technologies has enlarged continuously in the last years, the most significant drivers of this development being the technical innovations from industry. Different companies are interested on developers and manufacturers of microcapsules, producers and distributors of equipments for microencapsulation, users and processors of microcapsules.
Table 1. includes some important applications in agrifood related areas.

Table 1. Micro- and nanotechnologies applied in Agrifood-related areas.

Sector	Application	Method or Material	Details
Agriculture	Agrochemicals delivery	Microcapsules Nanoparticles	Efficient, controlled delivery of pesticides, fertilizers and other agrichemicals
	Alternative energy production	Nanodetection	Single molecule detection for enzyme/ substrate interactions (e.g. cellulases in ethanol production).
	Animal Production	Nanoparticle chips (nanochips)	Preservation, tracking & controlled delivery of growth hormones
	Animal or Plant Health	Biosensors	Pathogens early detection
	Veterinary Medicine	Micro/Nanoparticles	Delivery of animal vaccines
	Plant Production	Micro/Nanoparticles	DNA delivery to plant target tissues (i.e. targeted genetic engineering).
Food	Sensing	Nanosensors	Detection of chemicals or foodborne pathogens. Control of temperature & moisture
	Safety	Nanoparticles	Selectively bind and remove chemicals or pathogens.
	Packaging	Nanoclays & nanofilms	Prevention and treatment of spoilage (contaminants or pathogens).
	Healthy Food	Microemulsions, nanoparticles	Improved availability and dispersion of nutrients, nutraceuticals or additives.

PROSPECTS : GREEN BIOTECHNOLOGY NEEDS BIOENCAPSULATION

Beside the above-mentioned applications, some prospective directions about the usefulness of bioencapsulation in green biotechnology need to be noticed.

Improved crop yields and reduced vulnerability of crops to environmental stress. By modern biotechnology techniques, one or two genes may be transferred to a highly developed crop variety to impart a new character that would increase its yield. But many of the associated genetic characteristics are controlled by a large number of genes, cumulating their individual effects on the overall yield. Crops containing genes that enable resistance to biotic and abiotic stress may be developed or selected from plants which cope with extreme conditions in order to find the responsible genes for resistance and eventually transferring these genes to more desirable crops. Significant scientific work need to be done in this area, where bioencapsulation may contribute by using specific vehicles for gene transfer and expression.

Increased nutritional qualities &quantity of food. Proteins in foods may be modified or encapsulated to increase their stability and nutritional qualities, as well many phytochemicals needed for a balanced diet, see the results obtained by **Golden rice** (Beyer, 2002). Biotechnology can be also used to slow down the spoilage of fruits which can ripe longer on the plant and then be transported to the consumer with a reasonable shelf life. In cheese production, the enzymes produced by micro-organisms may be stabilized and used, as alternative to animal rennet, for cheese makers, providing comparable quality, at lower price. Addition of maltogenic amylases to the flour induces longer shelf life of bread and a significant economy on flour consumption.

Reduced dependence on fertilizers, pesticides and other agrochemicals. Current commercial applications aim the reduction of farmers' dependence on **agrochemicals**, using agrobiologicals

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(e.g. ***Bacillus thuringiensis*** (Bt) as a soil bacterium with insecticidal qualities. Some interesting results are yet obtained applying microencapsulation (Patel, 2009). Some crops (soybean, corn and cotton), have also been genetically engineered to acquire tolerance to broad-spectrum herbicides to control weed species, but also detrimental to agronomic crops. Transgenic crops that express tolerance to glyphosate and bromoxynil are developed, so herbicides can now be sprayed on such transgenic crops without inflicting damage on the crops. Microencapsulation can be a good solution to protect their detrimental side-effects.

Production of novel molecules by crops, for non-food applications. Oily seeds can be modified to produce certain fatty acids used for detergents, or to substitute fuels and petrochemicals. Potatoes, tomatoes, lettuce, safflowers, and other plants have been genetically-engineered to produce insulin and certain vaccines, being grown locally and cheaply, avoiding logistical and economic problems. In the case of insulin grown in transgenic plants, it might be produced at significantly cheaper than insulin produced in bioreactors. Microencapsulation can offer better stability and efficacy at even lower costs.

Bioremediation and biodegradation include sustainable ways to clean-up contaminated environments by the elimination of a wide range of pollutants and wastes from the environment. Especially marine environments are especially vulnerable by direct pollution through human activities or from natural seepages. Biotechnology is taking advantage of the catabolic versatility of microorganisms to degrade/convert such compounds. Recently, the hydrocarbonoclastic bacteria (HCCB) showed hydrocarbon-degrading activities, with good prospects for future investigations and applications. Specific vehicles to encapsulate pollutants and the use of microencapsulated forms to preserve microorganisms activity at lower costs, can contribute to environment bioremediation.

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