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This paper must be cited as:

Betoret Valls, ME.; Betoret Valls, N.; Vidal Brotons, DJ.; Fito Maupoey, P. (2011). Functional Foods Development: Trends and Technologies. Trends in Food Science and Technology. 22(9):498-508. doi:10.1016/j.tifs.2011.05.004.



The final publication is available at

<https://dx.doi.org/10.1016/j.tifs.2011.05.004>

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# Functional foods development: Trends and technologies.

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The aim of this work is to make an overview on the emerging technologies and traditionally used to develop functional foods. In this way, we classified the technologies used in three main groups and analyzed the research tendency since the year 2000 until now. Thus, while traditional techniques are the most commonly used for development of functional foods, from years 2000 until 2010 the techniques aimed towards personalized nutrition have grown greatly.

## 1. Introduction.

In the last decades consumer demands in the field of food production has changed considerably. Consumers more and more believe that foods contribute directly to their health (Mollet & Rowland, 2002). Today foods are not intended to only satisfy hunger and to provide necessary nutrients for humans but also to prevent nutrition-related diseases and improve physical and mental well-being (Takachi, Manami, Junko, Norie, Motoki, Shizuka, Hiroyasu, Yoshitaka, & Shoichiro, 2008; Nöthlings, Murphy, Wilkens, Henderson, & Kolonel, 2007). According to the World Health Organization and the Food and Agriculture Organization, several dietary patterns along with lifestyle habits constitute major modifiable risk factors in relation to the development of coronary heart disease, cancer, type 2 diabetes, obesity, osteoporosis and periodontal disease (WHO, 2003). In this regard, functional foods play an outstanding role (Figure 1). The increasing demand on such foods can be explained by the increasing cost of healthcare, the steady increase in life expectancy and the desire of older people for improved quality of their later years (Roberfroid, 2007).

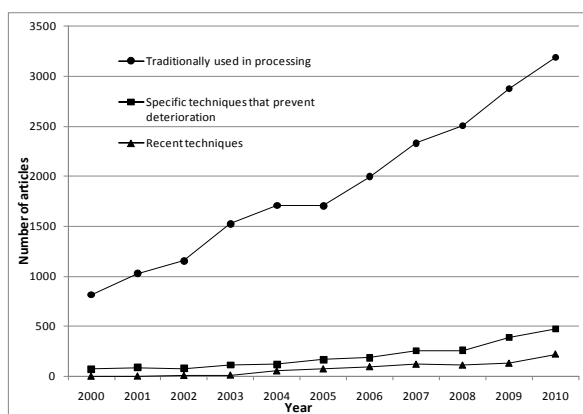
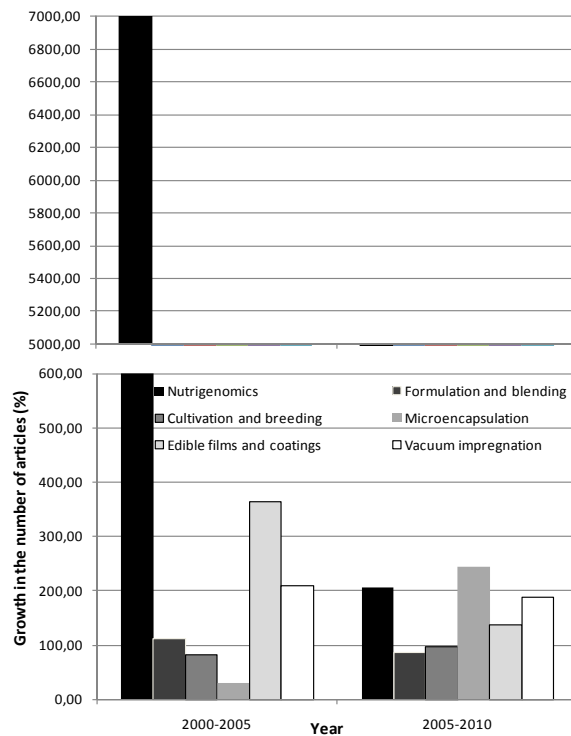


Figure 1. Tendency of the articles related to functional food with the time.

Innovation is today's business mantra. Experts proclaim daily that the only hope for business survival is the ability to continue innovating. In this context, the development of new functional food products turns out to be increasingly challenging, as it has to fulfil the consumer's expectancy for products that are simultaneously relish and healthy (Shah, 2007).

Developing a new functional food is an expensive process. Product development requires detailed knowledge of the products and the customers, which is why quantitative and qualitative marketing studies must be carried out before launching any product on the market (Beardsworth & Keil, 1992). The high reported failure rates for new international functional foods suggest a failure to manage the customer knowledge effectively, as well as a lack of knowledge management between the functional disciplines involved in the new product development process (Jousse, 2008). The methodologies that advance a firm's understanding of customer's choice motives and values, and its knowledge of management process, can increase the chances of new product success in the international market. The commercial success of functional products ultimately depends on taste, appearance, price, and health claim appeal to consumers. They need to receive a comprehensible and reasonable message about the physiological effects of food in humans, without appearing to be exaggerated; moreover, all the factors mentioned previously influence directly the consumers' attitudes toward effective purchase, which is necessary for the maintenance of industry. In summary, the food industry takes into consideration many variables to develop or reengineer functional products, such as sensory acceptance, stability, price, chemical, functional properties (Granato, Branco, & Nazzaro, 2010) and convenience. A great variability of techniques are required in order to meet needs and expectancies in the area of functional foods. The aim of this review is to make an overview on the emerging technologies and traditionally used to develop functional foods. In this way, we classified the technologies used in three main groups and analyzed the research tendency since the year 2000 until now (Figure 2). The first group is formed by the technologies traditionally used in food processing, formulation and blending and cultivation and breeding. The second group is constituted by the technologies that forming a structure try to prevent the deterioration of physiologically active compounds; microencapsulation, edible films and coatings and vacuum impregnation are part of this group. Finally, the third group we classified is formed by those technologies, recent technologies, aimed to design personalized functional foods.



**Figure 2.** Growth in the number of articles (%) over the years.

## **2. Adaptation of general technologies traditionally used in food processing.**

### *2.1 Formulation and blending.*

Formulation and blending constitutes a simply and cheap technology to develop new functional foods and has been widely used in food processing. Its use in functional food development has a long history for the successful control of deficiencies of vitamins A and D, several B vitamins (thiamine, riboflavin and niacin), iodine and iron. Salt iodization was introduced in the early 1920s in both Switzerland (Burgi, Supersaxo, & Selz, 1990) and the United States of America (Marine & Kimball, 1920) and has since expanded progressively all over the world to the extent that iodized salt is now used in most countries. From the early 1940s onwards, the fortification of cereal products with thiamine, riboflavin and niacin (Kyritsi, Tzia, & Karathanos, 2011) has become common practice. Margarine was fortified with vitamin A (FAO & WHO, 2006) in Denmark and milk with vitamin D (FAO & WHO, 2006) in the United States, then enriched with phytosterols and used by patients with high cardiovascular risk (Laforest, Moulin, Schwalm, Le Jeune, Chretien, Kitio, Massol, & Van Ganse, 2007). Folic acid fortification of wheat (Samaniego-Vaesken, Alonso-Apperte, & Varela-Moreiras, 2010) became widespread in the Americas, a strategy adopted by Canada and the United States and about 20 Latin American countries. In more recent years, the emergence of dietary compounds with health benefits offered an excellent opportunity to improve public health and thus, this category of compounds received much

attention from the scientific community, consumers and food manufacturers. The list of dietary active compounds (vitamins, probiotics, bioactive peptides, antioxidants...) is endless and the type of final products obtained is growing steadily (Wildman, 2006). From the classical enriched milks (Kim, Ko, Park, Kim, Ha, & Cho, 2010; Alzate, Pérez-Conde, Gutiérrez, & Cámara, 2010) and yogurts (Karaaslan, Ozden, Vardin, & Turkoglu, 2011; Zare, Boye, Orsat, Champagne, & Simpson, 2011) through infant formula enriched with prebiotics (Alliet, Scholtens, Raes, Hensen, Jongen, Rummens, Boehm, & Vandenplas, 2007), probiotics (Puccio, Cajozzo, Meli, Rochat, Grathwohl, & Steenhout, 2007), vitamins (Chávez-Servín, Castellote, & López-Sabater, 2008) and long chain polyunsaturated fatty acids (Chávez-Servín, Castellote, Martín, Chifré, & López-Sabater, 2009) to provide infants with the required nutrients for optimal growth and development, until juices mainly enriched with flavonoids (González-Molina, Moreno, & García-Viguera, 2009), vitamins (Rivas, Rodrigo, Company, Sampedro, & Rodrigo, 2007) and resveratrol (González-Barrio, Vidal-Guevara, Tomás-Barberán, & Espín, 2009), snacks (Da Costa, Ferraz, Ros-Polski, Quast, Collares Queiroz, & Steel, 2009), pastas rich in legumes (Petitot, Boyer, Minier, & Micard, 2010) and meats enriched with large number of bioactive compounds (Jiménez-Colmenero, Sánchez-Muniz, & Olmedilla-Alonso, 2010; Zhang, Xiao, Samaraweera, Lee, & Ahn, 2010) are being developed by formulation.

## *2.2 Cultivation and animal breeding techniques.*

Agriculture and livestock provide the primary source of the nutrients required by human. There is a general consensus among nutritionist that the best way to tackle micronutrient deficiency is through diversification in diet to include vegetables, fruits, meat and fish (FAO & WHO, 2001). However, this is not always possible. Agriculture and livestock have been traditionally presented a way to obtain products with high nutrients. In cases where agronomic and breeding approaches cannot achieve significant improvement of food products, biotechnology offers a useful alternative (Zhao & Shewry, 2011).

Biotechnology has been practised in crops and animal breeding since the beginning of human history. The evaluation and selection of different breeds started with the domestication of animal and plant species around 12.000 years ago, which was led by the wish to obtain desired traits, dictated by social, nutritional and environmental needs with no understanding of the molecular processes involved (National Research Council, 1989).

Going not so far in time, with the use of molecular biology tools and the development of genetically modified seeds, the biotechnology turned into a modern technique which offers an additional way to modify composition of foods. The most known enriched crop product is the Golden Rice (Ye, Al-Babili, Klott, Zhang, Lucca, Beyer, & Potrykus, 2000) that has 1.6 µg/g total carotenoids in the rice endosperm. The second generation of Golden Rice (Golden Rice 2) (Paine,

Shipton, Chaggar, Howells, Kennedy, Vernon, Wright, Hinchliffe, Adams, Silverstone, & Drake, 2005) contains up to 37 µg/g of total carotenoids. A recent clinical trial shows that the Golden Rice 2 is an effective source of vitamin A for humans, with a b-carotene to retinol conversion efficiency (Tang, Qin, Dolnikowski, Russell, & Grusak, 2009), and locally adapted varieties of Golden rice are expected to reach the market in 2012 (Potrykus, 2010). The fortification of vitamin A has been carried out also in other food crops like potato (Tanumihardjo, Bouis, Hotz, Meenakshi, & McClafferty, 2008) and maize (Zhu, Naqvi, Breitenbach, Sandmann, Christou, & Capell, 2008). Tomato (De La Garza, Gregory, & Hanson, 2007) and rice grain (Storozhenko, De Brouwer, Volckaert, Navarrete, Blancquaert, Zhang, Lambert, & Van der Straeten, 2007) have been fortified in folates and corn seeds and soybean seeds (Karunanandaa, Qi, Hao, Baszis, Jensen, Wong, Jiang, Venkatramesh, Gruys, Moshiri, Post-Beittermiller, Weiss, & Valentin, 2005) in vitamin E. Furthermore, an attractive alternative is to synthesise LC-PUFAs in plants, notably in oilseeds to replace the fatty acids which are usually stored on triacylglycerol (reviewed by Venegas-Caleron, Sayanova, & Napier, 2010).

Animal breeding also offers the possibility to obtain improved food products. In this way, a lot of studies have been done to examine the sources of nutrients available for inclusion in animal diets and their subsequent transfer into products obtained. Matsushita, Tazinafo, Padre, Oliveira, Souza, Visentainer, Macedo, & Ribas, (2007) carried out a study in which characterized the fatty acids profiles and physico-chemical parameters of milk samples from Saanen goats fed diets enriched with 3% of three different vegetable oils (soybean, canola and sunflower). The milks obtained presented different concentration of conjugated linoleic acid (CLA) depending on the vegetable oil added to animal feed. In addition (Laible, 2009), many other milk modifications have been suggested to improve the nutritional quality of milk and its processing into dairy products. Woods & Fearon in 2009 examined in a review the sources of fatty acids available for inclusion in animal diets and their subsequent transfer into meat, eggs or milk. Juniper, Phipps, Ramos-Morales, & Bertin, (2009) determined the concentration of total selenium and the proportion of total (Se) comprised as selenomethionine and selenocysteine, as well as meat quality of lambs offered diets with an increasing dose rate of selenized enriched yeast or sodium selenite.

### **3. Specific technologies for the manufacture of functional food that prevent the deterioration of physiologically active compounds.**

#### *3.1 Microencapsulation.*

Microencapsulation is the envelopment of small solid particles, liquid droplets or gases in a coating (Thies, 1987). Microencapsulation is based on the embedding effect of a polymeric matrix, which creates a microenvironment in the capsule able to control the interactions between the internal part and the external one

(Borgogna, Bellich, Zorzin, Lapasin, & Cesàro, 2010). Microencapsulation allows the protection of a wide range of materials of biological interest, from small molecules and protein (enzymes, hormones,...) to cells of bacterial, yeast and animal origin (Thies, 2005). For this reason such versatile technology is widely studied and exploited in the high technological fields of biomedicine and biopharmaceutics, for application ranging from cell therapy to drug delivery (Smidsrød & Skjak-Braek, 1990). The same characteristics make microencapsulation suitable for food industry applications, in particular for the production of high value aliments and nutraceuticals.

Many encapsulation procedures have been proposed but none of them can be considered as a universally applicable procedure for bioactive food components. This is caused by the fact that individual bioactive food components have their own characteristic molecular structure (Augustin & Hemar, 2009). However compatibility with the bioactives is not the only requirement an encapsulation procedure has to meet. It also should have specific characteristics to withstand influences from the environment (Augustin and Hemar, 2009).

An important requirement is that the encapsulation system has to protect the bioactive component from chemical degradation (e.g., oxidation or hydrolysis) to keep the bioactive component fully functional. A major obstacle in the efficacious delivery of bioactive food components is not only the hazardous events that occur during passage through the gastrointestinal tract but also the deleterious circumstances during storage in the product that serves as vehicle for the bioactive components (de Vos, Faas, Spasojevic, & Sikkema, 2010). Many food components may interfere with the bioactivity of the added bioactive food component. It is therefore mandatory that the encapsulation procedure protects the bioactive component during the whole period of processing, storage, and transport (Gibbs, Kermasha, Alli, & Mulligan, 1999). Another requirement is that the encapsulation system allows an efficient package load (McClements, Decker, & Park, 2009a; McClements, Decker, Park, & Weiss, 2009b). How 'efficient' this package load should be depends on the type of molecule that is desired as bioactive component and the specific product that serves as vehicle. Administration of large structures such as probiotics will require a higher efficiency of package than molecular structures such as vitamins. When choosing an encapsulation system with high package efficiency, it is always essential to choose a system that can be easily incorporated into the food without interfering with the texture and taste of the food. And, last but certainly not least, it might be necessary to design the encapsulation system as such that the bioactive component is released in a specific site of the gastrointestinal tract (de Vos et al., 2010).

The studies addresses a broad array of questions and challenges related to microencapsulation in four main research directions:

- Microencapsulating materials
- Wall (matrix) materials for microencapsulation.
- Processes for microencapsulation.

- Properties and functionality of encapsulated systems.

Some studies have reported the success on some microencapsulation materials. Several biopolymers, such as starch, hydrocolloids, whey proteins, gelatins and maltodextrins, have already been tested as encapsulating materials by spray drying (Gharsallaoui, Roudaut, Chambin, Voilley, & Saurel, 2007). Proteins have a potential role as substrates for the development of delivery systems due to their good functional properties and high nutritional value (Chen, Remondetto, & Subirade, 2006). Proteins from soy bean have been used in the microencapsulation of orange oil emulsion by spray drying, being effective in the retention and protection against oxidation, due to its emulsification activity (Kim & Morr, 1996). Rodrigues Pereira, Saraiva, Carvalho, Andrade, Pedrosa, & Pierucci, (2009) have been able to obtain microparticles of ascorbic acid by spray drying using protein isolates of green pea and cowpea. Also by spray drying technique Sansone, Picerno, Mencherini, Villecco, D'Ursi, Aquino, & Lauro, (2011) produced naringerin and quercetin particles using a combination of cellulose acetate phthalate (CAP) as coating gastro resistant polymer and swelling or surfactant agents as enhancers of dissolution rate. Presence of a combination of CAP and surfactants or swelling agents in the formulation produced microparticles with good resistance at low pH of the gastric fluid and complete flavonoids release in the intestinal environment. The microencapsulation improved the technological characteristics of the powders such as morphology and size, gave long-lasting storage stability and reserved the antioxidant properties.

Some studies have reported the success on encapsulating bioactive compounds. The most commonly applied bioactive food molecules that are already encapsulated in industrial applications are lipids, proteins, and carbohydrates (Augustin and Hemar, 2009). Lipids include fatty acids, phospholipids, carotenoids, and oil-soluble vitamins (Hämäläinen, Nieminen, Vuorela, Heinonen, & Moilanen, 2007; McClements et al., 2009a,b). They cannot be easily solved in food products because of their extreme low solubility in water and poly-unsaturated fatty acids, which are highly susceptible to oxidation, and are now widely applied in powdered products thanks to encapsulation processes that form an effective barrier for oxygen (de Vos et al., 2010). Therefore many different approaches of encapsulation have been proposed for encapsulation of lipids in order to be able to apply them in a large variety of food products (McClements et al., 2009a,b). Bioactive proteins also might require encapsulation. Many food derived peptides act as growth factor, anti-hypertensive agent, antioxidant or immune regulatory factor (Hartmann & Meisel, 2007; McClements et al., 2009a,b). Some of these proteins have to reach the site of uptake in the small bowel in an intact conformation in order to exert a beneficial health effect (de Vos et al., 2010). Most peptides even require hydrolysis in the stomach and small intestine in order to release specific bioactive peptides or amino acids (McClements et al., 2009a,b). Thus whether encapsulation for proteins has to be considered depends on the type of protein, its envisioned health effect and the product that serves as vehicle for the bioactive protein (de Vos et al.,



2010). Carbohydrates that can benefit from microencapsulation are mainly bioactive carbohydrates that are found in dietary fibers (Redgwell & Fischer, 2005). The fibers or its components that would benefit most from encapsulation are the soluble non-digestible polysaccharides. These fibers have been included for cholesterol reduction, reduction of glycemic fluctuations, prevention of constipation, prebiotic effects, and even for the prevention of cancer (McClements et al., 2009a,b; Redgwell and Fischer, 2005). The main challenge in this area is not to target the fibers to specific parts of the gut but to increase the amount of fibers in food in order to achieve the aforementioned health benefits (de Vos et al., 2010). The major encapsulation effort in this area is therefore improving the food load of fibers by packing enough fibers in capsules without interfering with the product quality such as changes in texture, mouth feel, or flavour (de Vos et al., 2010).

Encapsulation methods have been also widely applied to enhance viability of probiotic bacteria in commercial products.

Several authors studied the probiotic strain survival under simulated gastrointestinal conditions (Mokarram, Mortazavi, Habibi Najafi, & Shahidi, 2009) and similarly for liquidbased products such as dairy products (Kailasapathy, 2006). Hou, Lin, Wang, & Tzen, in 2003 developed a technique to protect *Lactobacillus delbrueckii ssp. bulgaricus* by encapsulation of bacterial cells within artificial sesame oil emulsions. In 2004, Krasaekoopt, Bhandari, & Deeth, evaluated the influence of coating materials on some properties of alginate beads and survivability of microencapsulated probiotic bacteria. In the same way, Ross, Gusils, & Gonzalez, (2008) improved a microencapsulating method using non fat milk cell suspension mixed with sodium alginate solution to increase a strain survival. Mokarram et al., (2009) studied the influence of multi stage coating on the properties of alginated beads and the survivability of microencapsulated *Lactobacillus* bacteria in the beads coated with one or two layers of alginate. In 2010, Weinbreck, Bodnár, & Marco, evaluated the use of microencapsulation to maintain probiotic *Lactobacillus rhamnosus GG (LGG)* viability during exposure to detrimentally high levels of water activity in order to lengthen the shelf-life of probiotic bacteria in dry products such as infant formula powder.

Even if microencapsulation would be able to enhance the survival rate of probiotics this would not immediately imply that we will increase functional survival (de Vos et al., 2010). During recent years it has become clearer that probiotic effects are determined by the presence of specific bioactive molecules or effector molecules in the cell envelope of probiotic bacteria (van Baarlen, Troost, van Hemert, van der Meer, de Vos, de Groot, Hooiveld, Brummer, & Kleerebezem, 2009; Kleerebezem & Vaughan, 2009; Konstantinov, Smidt, de Vos, Bruijns, Singh, Valence, Molle, Lortal, Altermann, Klaenhammer, & van Kooyk, 2008). These effector molecules are (glyco) proteins and have to be preserved in order to achieve functional effects (Konstantinov et al., 2008). The survival of these effector molecules in the product and during passage in the gastrointestinal tract is even more important than the survival of numbers of probiotics. The effector molecules

that are presently identified (Konstantinov et al., 2008) are susceptible for the acidic circumstances and digestive enzymes in the stomach at beginning of the small bowel. Preserving and protecting these effector molecules will be a major challenge in the near future (Ledeboer, Nauta, Sikkema, Laudund, Niederberger, & Sijbesma, 2006).

### *3.2 Edible films and coatings.*

Any type of material used for enrobing (i.e. coating or wrapping) various food to extend shelf life of the product that may be eaten together with food with or without further removal is considered an edible film or coating (Pavlath & Orts, 2009). Edible films and coatings are applied on many products to control moisture transfer, gas exchange or oxidation processes. For film-forming materials dispersed in aqueous solutions, solvent removal is required to achieve solid film formation and control of its properties (Hernández-Izquierdo & Krochta, 2008). Edible films can be formed via two main processes: a “wet process” in which biopolymers are dispersed or solubilised in a film-forming solution (solution casting) followed by the evaporation of the solvent, and a “dry process” which relies on the thermoplastic behaviour exhibited by some proteins and polysaccharides at low moisture levels in compression moulding and extrusion (Liu, Kerry, & Kerry, 2006).

One major advantage of using edible films and coatings is that they have a high potential to carry active ingredients such as antibrowning agents, colorants, flavours, nutrients, spices and antimicrobial compounds that can extend product shelf-life, reduce the risk of pathogen growth on food surfaces and provide specific nutrients that affect beneficially one or more functions of the body.

Some studies have reported the effect of the addition of active compounds in the functionality of edible films. For instance, Mei & Zhao (2003) evaluated the feasibility of milk protein-based edible films to carry high concentrations of calcium (5 or 10% w/v) and vitamin E (0.1% or 0.2% w/v). In contrast, Park & Zhao (2004) reported that the water barrier property of the chitosan-based films was improved by increasing the concentration of mineral (5-20% w/v zinc lactate) or vitamin E in the film matrix. Nevertheless, the tensile strength of the films was affected by the incorporation of high concentrations of calcium or vitamin E. Gómez-Estaca, Montero, Giménez, & Gómez-Guillén, (2007) studied the effect of functional edible film enriched with oregano or rosemary extract, a gelatine-chitosan film-coating and/or high pressure processing on the microbiological and oxidative stability of cold-smoked sardine. Films enriched with oregano or rosemary extract were able to slow lipid oxidation, but they failed to slow microbial growth. Gómez-Guillén, Ihl, Bifani, Silva, & Montero, (2007) obtained edible films based on tuna-fish gelatine with extracts of two murta ecotypes leaves (*Ugni molinae* Turcz). The edible films of tuna-fish gelatine were transparent and showed acceptable mechanical properties and barrier properties to water vapour

and UV light. In the case of films with Soloyo Grande ecotypes, it was possible to increase significantly the antioxidant properties of the film, when natural extracts with high polyphenols content were added, producing only minor modifications of the film properties. When using an extract with a bigger content of polyphenols, like the Soloyo Chico ecotype, the antioxidant capacity of the film was increased, but the mechanical properties were decreased, due to a greater interaction between polyphenols and proteins.

Several researchers have endeavoured to incorporate minerals, vitamins and fatty acids into edible film and coating formulations to enhance the nutritional value of some fruits and vegetables, where these micronutrients are present in low quantities. Tapia, Rojas-Graü, Carmona, Rodríguez, Soliva-Fortuny, & Martin-Belloso, (2008) reported that the addition of ascorbic (1% w/v) to the alginate and gellan-based edible coatings helped to preserve the natural ascorbic acid content in fresh-cut papaya, thus helping to maintain its nutritional quality throughout storage. Han, (2002) indicate that chitosan-based coatings had capability to hold high concentrations of calcium or vitamin E, thus significantly increasing their content in fresh and frozen strawberries and red raspberries. Similarly, Hernández-Muñoz, Almenar, Ocio, & Gavara, (2006) observed that chitosan-coated strawberries retained more calcium gluconate (3079 g/kg dry matter) than strawberries dipped into calcium solutions (2340 g/kg).

The addition of probiotics to obtain functional edible films and coatings has been scarcely studied. Tapia, Rojas-Graü, Rodríguez, Ramírez, Carmona, & Martin-Belloso, (2007) developed the first edible films for probiotic coatings on fresh-cut apple and papaya, observing that both fruits were successfully coated with alginate or gellan film-forming solutions containing viable  $10^6$  cfu/g bifidobacteria.

### *3.3 Vacuum impregnation.*

Vacuum impregnation has been considered as a useful way to introduce desirable solutes into the porous structure of foods, conveniently modify their original composition as an implement for development of new products. Physiologically active compounds may be introduced into fruit and vegetable products using this technique without modifying their integrity. This so-called 'direct-formulation' distinguishes it from other processing methods (Mavroudis, Gekas, & Sjöholm, 1998a,b; Torreggiani, 1993).

The use of vacuum impregnation to develop functional foods can be orientated in two ways. On one hand, several studies use the vacuum impregnation technique to modify desirable the original composition of one porous food. Fito, Chiralt, Betoret, Gras, Cháfer, Martínez-Monzó, Andrés, & Vidal, (2001) first evaluated the feasibility of using vacuum impregnation for mineral fortification of fruits and vegetables from an engineering point of view. Mathematical models were developed to determine the concentration of different minerals in impregnation solutions required to achieve a 20–25% dietary reference intake (DRI) fortification

in 200g of samples. Following the modelling prediction, experimental validation confirmed that VI could be an effective method for the enrichment of fruits and vegetables with minerals, vitamins or other physiologically active components. Gras, Vidal, Betoret, Chiralt, & Fito, (2003) evaluated calcium fortification of eggplants, carrots, and oyster mushroom using VI with sucrose solutions, and found that raw material variability induces significant differences in the final impregnation level. Xie & Zhao (2003a,b) studied calcium and zinc fortification of fruits using VI processing of high fructose corn syrup solution containing calcium and/or zinc in fresh-cut apples, strawberry slices, and whole marionberry. Cortés, Osorio, & García, (2007) developed apple products enriched with Vitamin E (100% IDR/200g fresh apple) and evaluated the shelf life of the products after drying at 40°C in function of colour, texture and stability of vitamin E at different storage conditions. Anino, Salvatori, & Alzamora, (2006) analyzed the ability of apple matrix for calcium incorporation by two different impregnation techniques (in vacuum or at atmospheric pressure) and determined the effect of these treatments on material compression behaviour. Some authors studied the effect of the mineral fortification of fruits on posterior osmotic dehydration operation (Barrera, Betoret, & Fito, 2004; Barrera, Betoret, Corell, & Fito, 2009; Moraga, Moraga, Fito, & Martínez-Navarrete, 2009).

Betoret, Puente, Diaz, Pagán, García, Gras, Marto, & Fito, (2003) developed probiotic-enriched dried fruits using VI technique by applying VI process either with commercial apple juice containing *Saccharomyces cerevisiae*, or with whole milk or apple juice containing  $10^7$  or  $10^8$  cfu/ml of *Lactobacillus casei* (*spp. rhamnosus*). It was reported that dried apple samples could contain about  $10^6$  cfu/g *Lactobacillus casei* (*spp. rhamnosus*), a similar level to that in commercial dairy products.

More recently, some studies are focused on the protection this technology can provide to the active compounds. Watanabe, Yoshimoto, Okada, & Nomura, (2011) studied the effect of impregnation using sucrose solution on stability of anthocyanin in strawberry jam. Strawberry jam mixed with or produced from strawberry impregnated with sucrose from 0.29 to 1.46 mol/L was prepared, and the stability of anthocyanin in the jam was evaluated. Results obtained suggested that the impregnation of sucrose in advance of the jam preparation stabilized the anthocyanin in the jam more strongly than the mere addition of sucrose during the preparation.

#### **4. Recent technologies that contribute to a custom designed functional foods: Nutrigenomics.**

While a number of formal definitions exist; in essence nutrigenomics (sometimes called nutritional genomics) considers the interactions between foods or dietary supplements and an individual's genome, and the consequent downstream effects on their phenotype. It recognizes that appropriate dietary

advice for one individual may be inappropriate, or actual harmful, to another. The field has the potential to provide tailored nutritional advice or develop specialist food products for population or for individuals and is still considered as an emerging science (Ferguson, Philpott, & Barnett, 2010).

The key steps involve the following considerations:

1. Ferguson, 2009:
  - Evidence for bioactivity.
  - Mechanism of action.
  - Enhancing levels via diet.
  - Influence of genotype on bioactivity.
2. Ferguson et al., 2010:
  - Identification of a genetic component to the disorder.
  - Size of the component in relation to other causes of diseases susceptibility.
  - Identification of the gene(s) associated with the effect.
  - Functional variants in those genes.
  - Interaction of those variants with diet and/or other environmental factors to cause the phenotype.

Sutton, (2007) demonstrated that aqueous extracts of kiwifruit and avocado had very low cytotoxicity and high anti-inflammatory activity in a Crohn's gene-specific assay. Non-aqueous extracts of kiwifruit, blueberry, avocado and broccoli had similarly high anti-inflammatory activity, albeit with slightly higher cytotoxicity than the aqueous extracts. Also Sutton, in 2007 has used functional snack bar products to deliver targeted glycaemic impacts.

Fenech, Baghurst, Luderer, Turner, Record, Ceppi, & Bonassi, (2005) carried out a study in which illustrate the strong impact of nine micronutrients and their interactions on genome damage depending on level of intake. The micronutrients were vitamin E, calcium, folate, retinol, nicotin acid, B-carotene, riboflavin, pantothenic acid and biotin.

Ferguson et al., (2010) studies aimed to understand how different foods or food components might interact with a particular genotype to cause the chronic intestinal inflammation which is a hallmark of Crohn's disease. The model Interleukin-10 Gene-Deficient (IL10<sup>-/-</sup>) Mouse has been used to test the efficacy of potential food components including polyunsaturated fatty acids (Knoch, Barnett, McNabb, Park-Ng, Zhu, Nones, Dommels, Knowles, & Roy, 2009), fish oils (Hegazi, Saad, Mady, Matarese, O'Keefe, & Kandil, 2006), flaxseed oil (Cohen, Moore, & Ward, 2005), and some probiotics (McCarthy, O'Mahony, O'Callaghan, Sheil, Vaughan, Fitzimons, Fitzgibbon, O'Sullivan, Kiely, Collins, & Shanahan, 2003). The Multidrug Resistance Gene-Deficient (mrd1a<sup>-/-</sup>) Mouse model is another tool (Ferguson et al., 2010) used to understand the development of intestinal inflammation (Dommels, Butts, Zhu, Davy, Martell, Hedderly, Barnett, Broadley, & Roy, 2007), and to test the efficacy of food components such as curcumin and rutin (Nones, Dommels, Martell, Butts, McNabb, Park-Ng, Zhu, Hedderley, Barnett, & Roy,

2009) and green tea (Nones, Dommels, Martell, Butts, McNabb, Park-Ng, Barnett, Zhu, Hedderley, & Roy, 2008) on the prevention of this phenotype.

While nutrigenomics can suppose a wide window of opportunities in the area of functional foods the field itself is still in its infancy and there are some aspects not well clarified yet. For example Ronteltap, van Trijp, Renes, & Frewer, (2007) affirmed the nutrigenomics area is not well demarcated yet. Also, Ronteltap et al., (2007) showed that there is no unanimity among experts concerning the definition of nutrigenomics, its development over time and the critical factors that determine its success or failure. Furthermore, by its very nature, nutrigenomics gives rise to a number of ethical and legal issues. Experts recognize this as a critical factor for its development (Chadwick, 2004; Penders, Horstman, Saris, & Vos, 2007).

Being more accurate in practical problem science has, Ferguson et al., (2010) affirmed the Nutrigenomics New Zealand model provides an approach towards personalized, genotype-based nutrition that has the potential to provide food products and personalized advice to benefit health at the individual or population level. There is convincing evidence that SNPs (Single Nucleotide Polymorphisms) in certain genes may profoundly influence the biological response to nutrients. However, effects of single-gene variants on risk or risk factor levels of a complex disease tend to be small and inconsistent. Increased sensitivity of current biological measurements, plus methods of integrating information on combinations of relevant SNPs or CNVs (Copy Number Variations) in different genes, will become necessary to move the field to a higher dimension. Many of the challenges are in bioinformatics, especially in relation to reducing the complexity of multidimensional data sets (Kaput & Dawson, 2007). To date, there are only sporadic examples of clinical trials utilizing these technologies, and we have not investigated potential adverse effects of a genotype-derived dietary intervention. There are a considerable number of issues to be addressed before genomic approaches can become an acceptable method to guide food development or nutritional recommendations.

## **5. Conclusions.**

There is no doubt that functional food development has a great interest from consumers, industries, governments and universities. From the research and development point of view functional foods represent an opportunity to obtain innovative products that satisfy considerably this demand that already exists. The technologies mainly used as it is possible to see in the figure 2, has changed considerably over the years. Thus, while traditional techniques are the most commonly used for development of functional foods, from years 2000 until 2010 the techniques aimed towards personalized nutrition have grown greatly.

There is a group of technologies, which have grown significantly, that form a structure aimed to prevent the deterioration of physiologically active compounds. In this way, it is important to note the importance of the relationship “structure-

property". The functional effect of a food or food component depends on the active component gaining access to the functional target site. However, foods are mostly complex mixtures of macro- and micro- components that can trap active compound, modulate its release or inhibit its activity (Chen, Remondetto, & Subirade, 2006; Chen & Subirade, 2007). Thus, the food matrix both in its raw state, after storage or culinary preparation can have a significant influence on the activity or release on the key components. Selection and development of an appropriate food vehicle that maintain the active molecular form until the time of consumption, and deliver this form to the physiological target within the organism, is an important step to the success of a functional food. As an example, it has been demonstrated that plant sterol efficacy differs across various matrices, the milk matrix being almost three times more effective than in bread or cereal (Jones & Jew, 2007).

## 6. Acknowledgments.

The authors acknowledge the Ministerio de Ciencia e Innovación for its contribution throughout the projects AGL2009-09905 and PET2008\_0015.

## 7. References.

- Alliet, P., Scholtens, P., Raes, M., Hensen, K., Jongen, H., Rummens, J-L., Boehm, G., & Vandenplas, Y. (2007). Effect of prebiotic galacto-oligosaccharide, long-chain fructooligosaccharide infant formula on serum cholesterol and triacylglycerol levels. *Nutrition*, *23*, 719-723.
- Alzate, A., Pérez-Conde, M. C., Gutiérrez, A. M., & Cámara, C. (2010). Selenium-enriched fermented milk: A suitable dairy product to improve selenium intake in humans. *International Dairy Journal*, *20*, 761-769.
- Anino, S. V., Salvatori, D. M., & Alzamora, S. M. (2006). Changes in calcium level and mechanical properties of apple tissue due to impregnation with calcium salts. *Food Research International*, *39*, 154-164.
- Augustin, M. A., & Hemar, Y. (2009). Nano- and micro-structured assemblies for encapsulation of food ingredients. *Chemical Society Reviews*, *38*, 902-912.
- Barrera, C., Betoret, N., Corell, P., & Fito, P. (2009). Effect of osmotic dehydration on the stabilization of calcium-fortified apple slices (var. Granny Smith): Influence of operating variables on process kinetics and compositional changes. *Journal of Food Engineering*, *92*, 416-424.
- Barrera, C., Betoret, N., & Fito, P. (2004). Ca<sup>2+</sup> and Fe<sup>2+</sup> influence on the osmotic dehydration kinetics of apple slices (var. Granny Smith). *Journal of Food Engineering*, *65*, 9-14.
- Beardsworth, A. D., & Keil, E. T. (1992). The vegetarian option: varieties, conversions, motives and careers. *The Sociological Review*, *40*, 255.

- Betoret, N., Puente, L., Diaz, M. J., Pagán, M. J., García, M. J., Gras, M. L., Marto, J., & Fito, P. (2003). Development of probiotic enriched dried fruits by vacuum impregnation. *Journal of Food Engineering*, *56*(2-3), 273-277.
- Borgogna, M., Bellich, B., Zorzín, L., Lapasin, R., & Cesàro, A. (2010). Food microencapsulation of bioactive compounds: Rheological and thermal characterisation of non-conventional gelling system. *Food Chemistry*, *122*, 416-423.
- Burgi, H., Supersaxo, Z., & Selz, B. (1990). Iodine deficiency diseases in Switzerland one hundred years after Theodor Kocher's survey: a historical review with some new goitre prevalence data. *Acta Endocrinologica*, *123*, 577-590.
- Chadwick, R. (2004). Nutrigenomics, individualism and public health. *Proceedings of the Nutrition Society*, *63*, 161-166.
- Chávez-Servín, J. L., Castellote, A. I., & López-Sabater, M. C. (2008). Vitamins A and E content in infant milk-based powdered formulae after opening the packet. *Food Chemistry*, *106*, 299-309.
- Chávez-Servín, J. L., Castellote, A. I., Martín, M., Chifré, R., & López-Sabater, M. C. (2009). Stability during storage of LC-PUFA-supplemented infant formula containing single cell oil or egg yolk. *Food Chemistry*, *113*, 484-492.
- Chen, L., Remondetto, G.E., & Subirade, M. (2006). Food protein-based materials as nutraceutical delivery systems. *Trends in Food Science and Technology*, *17*(5), 272-283.
- Chen, L., & Subirade, M. (2007). Effect of preparation conditions on the nutrient release properties of alginate/whey protein granular microspheres. *European Journal of Pharmaceutics and Biopharmaceutics*, *65*, 354-362.
- Cohen, S. L., Moore, A. M., & Ward, W. E. (2005). Flaxseed oil and inflammation-associated bone abnormalities in interleukin-10 knockout mice. *The Journal of Nutritional Biochemistry*, *16*, 368-374.
- Cortés, M., Osorio, A., & García, E. (2007). Air dried apple fortified with vitamin e using matrix engineering. *VITAE, Revista de la Facultad de Química Farmacéutica*, *14*(2), 17-26.
- Da Costa, P. F. P., Ferraz, M. B. M., Ros-Polski, V., Quast, E., Collares Queiroz, F. P., & Steel, C. J. (2009) Functional extruded snacks with lycopene and soy protein. *Ciência e Tecnologia de Alimentos*. Campinas ISSN 0101-2061.
- de La Garza, R. I. D., Gregory, J. F., & Hanson, A. D. (2007). Folate biofortification of tomato fruit. *Proceedings of the National Academy of Sciences of the United States of America*, *104*, 4218-4222.
- de Vos, P., Faas, M. M., Spasojevic, M., & Sikkema, J. (2010). Encapsulation for preservation of functionality and targeted delivery of bioactive food components. *International Dairy Journal*, *20*, 292-302.
- Dommels, Y. E., Butts, C., Zhu, S. T., Davy, M., Martell, S., Hedderly, D., Barnett, M. P., Broadley, K., & Roy, N. C. (2007). Characterization of inflammation in mdr1a -/- mice and identification of related gene expression changes in colonic epithelial cells. *Genes and Nutrition*, *2*, 209-223.



- FAO, WHO. (2001). *Human Vitamin and Mineral Requirements*. Report of a Joint FAO/WHO Expert Consultation, Bangkok, Thailand. Food and Nutrition Division, FAO Rome.
- FAO, WHO. (2006). *Guidelines on food fortification with micronutrients*. Geneva: WHO Press.
- Fenech, M., Baghurst, P., Luderer, W., Turner, J., Record, S., Ceppi, M., & Bonassi, S. (2005). Low intake of calcium, folate, nicotinic acid, vitamin E, retinol, b-carotene and high intake of pantothenic acid, biotin and riboflavin are significantly associated with increased genome instability results from a dietary intake and micronucleus index survey in South Australia. *Carcinogenesis*, *26*(5), 991-999.
- Ferguson, L. R. (2009). Nutrigenomics Approaches to Functional Foods. *Journal of the American Dietetic Association*, *109*, 452-458.
- Ferguson, L. R., Philpott, M., & Barnett, M. P. G. (2010). Nutrigenomics: Integrating Genomic Approaches into Nutrition Research. *Molecular Diagnostics*, 347-363
- Fito, P., Chiralt, A., Betoret, N., Gras, M., Chafer, M., Martinez-Monzó, J., Andrés, A., & Vidal, D. (2001). Vacuum impregnation and osmotic dehydration in matrix engineering application in functional fresh food development. *Journal of Food Engineering*, *49*, 175-183.
- Gharsallaoui, A., Roudaut, G., Chambin, O., Voilley, A., & Saurel, R. (2007). Applications of spray-drying in microencapsulation of food ingredients: An overview. *Food Research International*, *40*(9), 1107-1121.
- Gibbs, B. F., Kermasha, S., Alli, I., & Mulligan, C. N. (1999). Encapsulation in the food industry: a review. *International Journal of Food Science and Nutrition*, *50*, 213-224.
- Gómez-Estaca, J., Montero, P., Giménez, B., & Gómez-Guillén, M. C. (2007). Effect of functional edible films and high pressure processing on microbial and oxidative spoilage in cold-smoked sardine (*Sardina pilchardus*). *Food Chemistry*, *105*, 511-520.
- Gómez-Guillén, M. C., Ihl, M., Bifani, V., Silva, A., & Montero, P. (2007). Edible films made from tuna-fish gelatin with antioxidant extracts of two different murta ecotypes leaves (*Ugni molinae* Turcz). *Food Hydrocolloids*, *21*, 1133-1143.
- González-Barrio, R., Vidal-Guevara, M. L., Tomás-Barberán, F. A., & Espín, J. C. (2009). Preparation of a resveratrol-enriched grape juice based on ultraviolet C-treated berries. *Innovative Food Science and Emerging Technologies*, *10*, 374-382.
- González-Molina, E., Moreno, D. A., & García-Viguera, C. (2009). A new drink rich in healthy bioactives combining lemon and pomegranate juices. *Food Chemistry*, *115*, 1364-1372.
- Granato, D., Branco, G. F., & Nazzaro, F. (2010). Functional Foods and Nondairy Probiotic Food Development: Trends, Concepts and Products. *Comprehensive Reviews in Food Science and Food Safety*, *9*, 292-302.

- Gras, M. L., Vidal, D., Betoret, N., Chiralt, A., & Fito, P. (2003). Calcium fortification of vegetables by vacuum impregnation. *Journal of Food Engineering*, 56(2-3), 279-284.
- Hämäläinen, M., Nieminen, R., Vuorela, P., Heinonen, M., & Moilanen, E. (2007). Anti-inflammatory effects of flavonoids: genistein, kaempferol, quercetin, and daidzein inhibit STAT-1 and NF-kappaB activations, whereas flavone, isorhamnetin, naringenin, and pelargonidin inhibit only NF-kappaB activation along with their inhibitory effect on iNOS expression and NO production in activated macrophages. *Mediators of Inflammation*, 2007, Article ID 45673.
- Han, J. (2002). *Protein-based edible films and coatings carrying antimicrobial agents*. In A. Gennadios (Ed.), *Protein-based films and coatings* (pp. 485-498). Florida: CRC Press.
- Hartmann, R., & Meisel, H. (2007) Food-derived peptides with biological activity: from research to food applications. *Current Opinion in Biotechnology*, 18, 163-169.
- Hegazi, R. A., Saad, R. S., Mady, H., Matarese, L. E., O'Keefe, S., & Kandil, H. M. (2006). Dietary fatty acids modulate chronic colitis, colitis-associated colon neoplasia and COX-2 expression in IL-10 knockout mice. *Nutrition*, 22, 275-282.
- Hernandez-Izquierdo, V. M., & Krochta, J. M. (2008). Thermoplastic Processing of Proteins for Film Formation-A Review. *Journal of Food Science*, 73(2), R30-R39.
- Hernández-Muñoz, P., Almenar, E., Ocio, M. J., & Gavara, R. (2006). Effect of calcium dips and chitosan coatings on postharvest life of strawberries (*Fragaria ananassa*). *Postharvest Biology and Technology*, 39, 247-253.
- Hou, R. C. W., Lin, M. Y., Wang, M. M. C., & Tzen, J. T. C. (2003). Increase of Viability of Entrapped Cells of *Lactobacillus delbrueckii* ssp. *Bulgaricus* in Artificial Sesame Oil Emulsions. *Journal of Dairy Science*, 86, 424-428.
- Jiménez-Colmenero, F., Sánchez-Muniz, F. J., & Olmedilla-Alonso, B. (2010). Design and development of meat-based functional foods with walnut: Technological, nutritional and health impact. *Food Chemistry*, 123, 959-967.
- Jones, P. J., & Jew, S. (2007). Functional food development: concept to reality. *Trends in Food Science and Technology*, 18, 387-390.
- Jousse, F. (2008). Modeling to improve the efficiency of product and process development. *Comprehensive Reviews in Food Science and Food Safety*, 7, 175-181.
- Juniper, D. T., Phipps, R. H., Ramos-Morales, E., & Bertin, G. (2009). Effects of dietary supplementation with selenium enriched yeast or sodium selenite on selenium tissue distribution and meat quality in lambs. *Animal Feed Science and Technology*, 149, 228-239.

- Kailasapathy, K. (2006). Survival of free and encapsulated probiotic bacteria and their effect on the sensory properties of yoghurt. *LWT-Food Science and Technology*, *39*, 1221-1227.
- Kaput, J., & Dawson, K. (2007). Complexity of type 2 diabetes mellitus data sets emerging from nutrigenomic research: a case for dimensionality reduction?. *Mutation Research*, *622*, 19-32.
- Karaaslan, M., Ozden, M., Vardin, H., & Turkoglu, H. (2011). Phenolic fortification of yogurt using grape and callus extracts. *LWT - Food Science and Technology*, *44*, 1065-1072.
- Karunanandaa, B., Qi, Q. G., Hao, M., Baszis, S. R., Jensen, P. K., Wong, Y. H. H., Jiang, J., Venkatramesh, M., Gruys, K. J., Moshiri, F., Post-Beittermiller, D., Weiss, J. D., & Valentin, H. E. (2005). Metabolically engineered oilseed crops with enhanced seed tocopherol. *Metabolic Engineering*, *7*, 384-400.
- Kim, J., Ko, Y., Park, Y-K., Kim, N-I., Ha, W-K., & Cho, Y. (2010). Dietary effect of lactoferrin-enriched fermented milk on skin surface lipid and clinical improvement of acne vulgaris. *Nutrition*, *26*, 902-909.
- Kim, Y. D., & Morr, C. V. (1996). Microencapsulation properties of gum arabic and several food proteins: Spray dried orange oil emulsion particles. *Journal of Agriculture and Food Chemistry*, *44*(5), 1314-1320.
- Kleerebezem, M., & Vaughan, E. E. (2009). Probiotic and gut lactobacilli and bifidobacteria: molecular approaches to study diversity and activity. *Annual Reviews of Microbiology*, *63*, 269-290.
- Knoch, B., Barnett, M., McNabb, W., Park-Ng, Z., Zhu, S., Nones, K., Dommels, Y., Knowles, S., & Roy, N. (2009). Genome-wide analysis of genes involved in eicosapentaenoic acid-induced modulation of colonic inflammation. *Journal of Nutrigenetics and Nutrigenomics*, *2*(1), 9-28.
- Konstantinov, S. R., Smidt, H., de Vos, W. M., Bruijns, S. C., Singh, S. K., Valence, F., Molle, D., Lortal, S., Altermann, E., Klaenhammer, T. R., & van Kooyk, Y. (2008). S layer protein A of *Lactobacillus acidophilus* NCFM regulates immature dendritic cell and T cell functions. *Proceedings of the National Academy of Sciences of the United States of America*, *105*, 19474-19479.
- Krasaekoopt, W., Bhandari, B., & Deeth, H. (2004). The influence of coating materials on some properties of alginate beads and survivability of microencapsulated probiotic bacteria. *International Dairy Journal*, *14*, 737-743
- Kyritsi, A., Tzia, C., & Karathanos, V. T. (2011). Vitamin fortified rice grain using spraying and soaking methods. *LWT - Food Science and Technology*, *44*, 312-320.
- Laforest, L., Moulin, P., Schwalm, M. S., Le Jeune, P., Chretien, S., Kitio, B., Massol, J., & Van Ganse, E. (2007). Use of margarine enriched in phytosterols by patients at high cardiovascular risk and treated by hypolipidemic drugs. *Nutrition, Metabolism & Cardiovascular Diseases*, *17*, 657-665.

- Laible, G. (2009). Enhancing livestock through genetic engineering - Recent advances and future prospects. *Comparative immunology, Microbiology and infectious diseases*, 32, 123-137.
- Ledeboer, A. M., Nauta, A., Sikkema, J., Laulund, E., Niederberger, P., & Sijbesma, W. (2006). Survival of probiotics. *European Dairy Magazine*, 4, 31-32.
- Liu, L., Kerry, J. F., & Kerry, J. P. (2006). Effect of food ingredients and selected lipids on the physical properties of extruded edible films/casings. *International Journal of Food Science and Technology*, 41, 295-302.
- Marine, D., & Kimball, O. P. (1920). Prevention of simple goiter in man. *Archives of Internal Medicine*, 25, 661-672.
- Matsushita, M., Tazinafo, N. M., Padre, R. G., Oliveira, C. C., Souza, N. E., Visentainer, J. V., Macedo, F. A. F., & Ribas, N. P. (2007). Fatty acid profile of milk from Saanen goats fed a diet enriched with three vegetable oils. *Small Ruminant Research*, 72, 127-132.
- Mavroudis, N. E., Gekas, V., & Sjöholm, I. (1998b). Osmotic dehydration of apples— Shrinkage phenomena and the significance of initial structure on mass transfer rates. *Journal of Food Engineering*, 38, 101-123.
- Mavroudis, N. E., Gekas, V., & Sjöholm, I. (1998a). Osmotic dehydration of apples— Effects of agitation and raw material characteristics. *Journal of Food Engineering*, 35, 191-209.
- McCarthy, J., O'Mahony, L., O'Callaghan, L., Sheil, B., Vaughan, E. E., Fitzsimons, N., Fitzgibbon, J., O'Sullivan, G. C., Kiely, B., Collins, J. K., & Shanahan, F. (2003). Double blind, placebo controlled trial of two probiotic strains in interleukin 10 knockout mice and mechanistic link with cytokine balance. *Gut*, 52, 975-980.
- McClements, D. J., Decker, E. A., & Park, Y. (2009a). Controlling lipid bioavailability through physicochemical and structural approaches. *Critical Reviews in Food Science and Nutrition*, 49, 48-67.
- McClements, D. J., Decker, E. A., Park, Y., & Weiss, J. (2009b). Structural design principles for delivery of bioactive components in nutraceuticals and functional foods. *Critical Reviews in Food Science and Nutrition*, 49, 577-606.
- Mei, Y., & Zhao, Y. (2003). Barrier and mechanical properties of milk protein-based edible films incorporated with nutraceuticals. *Journal of Agricultural and Food Chemistry*, 51, 1914-1918.
- Mokarram, R. R., Mortazavi, S. A., Habibi Najafi, M. B., & Shahidi, F. (2009). The influence of multi stage alginate coating on survivability of potential probiotic bacteria in simulated gastric and intestinal juice. *Food Research International*, 42, 1040-1045
- Mollet, B., & Rowland, I. (2002). Functional foods: At the frontier between food and pharma. *Current Opinion in Biotechnology*, 13, 483-485.
- Moraga, M. J., Moraga, G., Fito, P. J., & Martínez-Navarrete, N. (2009). Effect of vacuum impregnation with calcium lactate on the osmotic dehydration

- kinetics and quality of osmodehydrated grapefruit. *Journal of Food Engineering*, 90, 372-379.
- National Research Council. (1989). *Past experience with genetic modification of plants and their introduction into the environment* (pp. 16-36). Washington DC: National Academy Press.
- Nones, K., Dommels, Y., Martell, S., Butts, C., McNabb, W., Park-Ng, Z., Zhu, S., Hedderley, D., Barnett, M., & Roy, N. (2009). The effects of dietary curcumin and rutin on colon inflammation and gene expression in *mdr1a* *-/-* mice, a model of inflammatory bowel diseases. *British Journal of Nutrition*, 101, 169-181.
- Nones, K., Dommels, Y., Martell, S., Butts, C., McNabb, W., Park-Ng, Z., Barnett, M., Zhu, S. T., Hedderley, D., & Roy, N. (2008). Effect of green tea extract on colon inflammation and gene expression in *mdr1a* *-/-* mice. *Journal of Nutrigenetics and Nutrigenomics*, 1, 82.
- Nöthlings, U., Murphy, S. P., Wilkens, L. R., Henderson, B. E., & Kolonel, L. N. (2007). Flavonols and pancreatic cancer risk – The multiethnic cohort study. *American Journal of Epidemiology*, 166 (8), 924-931.
- Paine, J. A., Shipton, C. A., Chaggar, S., Howells, R. M., Kennedy, M. J., Vernon, G., Wright, S. Y., Hinchliffe, E., Adams, J. L., Silverstone, A. L., & Drake, R., (2005). Improving the nutritional value of Golden Rice through increased provitamin A content. *Nature Biotechnology*, 23, 482-487.
- Park, S., & Zhao, Y. (2004). Incorporation of a high concentration of mineral or vitamin into chitosan-based films. *Journal of Agricultural and Food Chemistry*, 52, 1933-1939.
- Pavlath, A. E., & Orts, W. (2009). *Edible Films and Coatings: Why, What, and How?*. Embuscado, M. E., Huber K. C. (Eds.) *Edible Films and Coatings for Food Applications* (pp. 1-23). New York: Springer. (Chapter 1).
- Penders, B., Horstman, K., Saris, W. H. M., & Vos, R. (2007). From individuals to groups: a review of the meaning of 'personalized' in nutrigenomics. *Trends in Food Science & Technology*, 18, 333-338
- Petitot, M., Boyer L., Minier, C., & Micard, V. (2010). Fortification of pasta with split pea and faba bean flours: Pasta processing and quality evaluation. *Food Research International*, 43, 634-641.
- Potrykus, I. (2010). Regulation must be revolutionized. *Nature*, 466, 561.
- Puccio, G., Cajozzo, C., Meli, F., Rochat, F., Grathwohl, D., & Steenhout, P. (2007). Clinical evaluation of a new starter formula for infants containing live *Bifidobacterium longum* BL999 and prebiotics. *Nutrition*, 23, 1-8.
- Redgwell, R. J., & Fischer, M. (2005). Dietary fiber as a versatile food component: an industrial perspective. *Molecular Nutrition and Food Research*, 49, 521-535.
- Rivas, A., Rodrigo, D., Company, B., Sampedro, F., & Rodrigo, M. (2007). Effects of pulsed electric fields on water-soluble vitamins and ACE inhibitory peptides added to a mixed orange juice and milk beverage. *Food Chemistry*, 104, 1550-1559.

- Roberfroid, M. B. (2007). Concepts and strategy of functional food science: the European perspective. *The American Journal of Clinical Nutrition*, *71*, 1660-1664.
- Rodrigues Pereira, H. V., Saraiva, K. P., Carvalho, L. M. J., Andrade, L. R., Pedrosa, C., & Pierucci, A. P. T. R. (2009). Legumes seeds protein isolates in the production of ascorbic acid microparticles. *Food Research International*, *42*, 115-121.
- Ronteltap, A., van Trijp, J. C. M., Renes, R. J., & Frewer, L. J. (2007). Consumer acceptance of technology-based food innovations: Lessons for the future of nutrigenomics. *Appetite*, *49*, 1-17.
- Ross, G. R., Gusils, C., & Gonzalez, S. N. (2008). Microencapsulation of Probiotic Strains for Swine Feeding. *Biological & Pharmaceutical Bulletin*, *31*(11), 2121-2125.
- Samaniego-Vaesken, M. L., Alonso-Aperte, E., & Varela-Moreiras, G. (2010). Analysis and evaluation of voluntary folic acid fortification of breakfast cereals in the Spanish market. *Journal of Food Composition and Analysis*, *23*, 419-423.
- Sansone, F., Picerno, P., Mencherini, T., Vilecco, F., D'Ursi, A. M., Aquino, R. P., & Lauro, M. R. (2011). Flavonoid microparticles by spray-drying: Influence of enhancers of the dissolution rate on properties and stability. *Journal of Food Engineering*, *103*, 188-196.
- Shah, N. P. (2007). Functional cultures and health benefits. *International Dairy Journal*, *17*, 1262-1277.
- Smidsrød, O., & Skjak-Braek, G. (1990). Alginate as immobilization matrix for cells. *Trends in Biotechnology*, *8*, 71-78.
- Storozhenko, S., De Brouwer, V., Volckaert, M., Navarrete, O., Blancquaert, D., Zhang, G. F., Lambert, W., & Van der Straeten, D. (2007). Folate fortification of rice by metabolic engineering. *Nature Biotechnology*, *25*, 1277-1279.
- Sutton, K. H. (2007) Considerations for the successful development and launch of personalised nutrigenomic foods. *Mutation Research*, *622*, 117-121.
- Takachi, R., Manami, I., Junko, I., Norie, K., Motoki, I., Shizuka, S., Hiroyasu, I., Yoshitaka, T., & Shoichiro, T. (2008). Fruit and Vegetable intake and risk of total cancer and cardiovascular disease – Japan public health center-based prospective study. *American Journal of Epidemiology*, *167* (1), 59-70.
- Tang, G. W., Qin, J., Dolnikowski, G. G., Russell, R. M., & Grusak, M. A. (2009). Golden Rice is an effective source of vitamin A. *American Journal of Clinical Nutrition*, *89*, 1776-1783.
- Tanumihardjo, S. A., Bouis, H., Hotz, C., Meenakshi, J. V., & McClafferty, B. (2008). Biofortification of staple crops: An emerging strategy to combat hidden hunger. *Comprehensive Reviews in Food Science and Food Safety*, *7*, 329-334.
- Tapia, M. S., Rojas-Grau, M. A., Carmona, A., Rodriguez, F. J., Soliva-Fortuny, R., & Martin-Belloso, O. (2008). Use of alginate and gellan-based coatings for

- improving barrier, texture and nutritional properties of fresh-cut papaya. *Food Hydrocolloids*, 22, 1493-1503.
- Tapia, M. S., Rojas-Graü, M. A., Rodríguez, F. J., Ramírez, J., Carmona, A., & Martín-Belloso, O. (2007). Alginate- and gellanbased edible films for probiotic coatings on fresh-cut fruits. *Journal of Food Science*, 72, E190-E196.
- Thies, C. (1987). *Microencapsulation*. In *Encyclopedia of Polymer Science and Engineering* (pp. 724-745). Mark, H. F., Bikales, N. M., Overberger, C. G., Menges, G. & Kroschwitz, J.I., (Eds.). New York: John Wiley & Sons.
- Thies, C. (2005). *A survey of microencapsulation processes*. In *Microencapsulation* (pp. 1-20) Benita, S. (Ed.). New York: Marcel Dekker Inc.
- Torreggiani, D. (1993). Osmotic dehydration in fruit and vegetable processing. *Food Research International*, 26, 59-68.
- Van Baarlen, P., Troost, F. J., van Hemert, S., van der Meer, C., de Vos, W. M., de Groot, P. J., Hooiveld, G. J., Brummer, R. J., & Kleerebezem, M. (2009). Differential NF- $\kappa$ B pathways induction by *Lactobacillus plantarum* in the duodenum of healthy humans correlating with immune tolerance. *Proceedings of the National Academy of Sciences of the United States of America*, 106, 2371-2376.
- Venegas-Caleron, M., Sayanova, O., & Napier, J. A. (2010). An alternative to fish oils: Metabolic engineering of oil-seed crops to produce omega-3 long chain polyunsaturated fatty acids. *Progress in Lipid Research*, 49, 108-119.
- Watanabe, Y., Yoshimoto, K., Okada, Y., & Nomura, M. (2011). Effect of impregnation using sucrose solution on stability of anthocyanin in strawberry jam. *LWT - Food Science and Technology*, 44, 891-895.
- Weinbreck, F., Bodnár, I., & Marco, M. L. (2010). Can encapsulation lengthen the shelf-life of probiotic bacteria in dry products?. *International Journal of Food Microbiology*, 136, (2010) 364-367
- WHO (2003). Diet, nutrition and the prevention of chronic diseases. WHO technical report series 916. Geneva, Switzerland.  
<http://www.fao.org/docrep/005/AC911E/AC911E00.HTM#Contents>  
Accessed 14.01.2011.
- Wildman, R. E. C. (2006). *Classifying nutraceuticals*. In *Handbook of Nutraceuticals and Functional Foods*, (2nd ed.), Wildman Ed., CRC Publisher, 13-31.
- Woods, V. B., & Fearon, A. M. (2009). Dietary sources of unsaturated fatty acids for animals and their transfer into meat, milk and eggs: A review. *Livestock Science*, 126, 1-20.
- Xie, J., & Zhao, Y. (2003a). Nutritional enrichment of fresh apple (Royal Gala) by vacuum impregnation. *International Journal of Food Science and Nutrition*, 54, 387-398.
- Xie, J., & Zhao, Y. (2003b). Improvement of physicochemical and nutritional qualities of frozen Marionberry by vacuum impregnation pretreatment with cryoprotectants and minerals. *Journal of Horticultural Science and Biotechnology*, 78, 248-253.

- Ye, X. D., Al-Babili, S., Klott, A., Zhang, J., Lucca, P., Beyer, P., & Potrykus, I. (2000). Engineering the provitamin A (beta-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. *Science*, *287*, 303–305.
- Zare, F., Boye, J. I., Orsat, V., Champagne, C., & Simpson, B. K. (2011). Microbial, physical and sensory properties of yogurt supplemented with lentil flour. *Food Research International*, doi:10.1016/j.foodres.2011.01.002
- Zhang, W., Xiao, S., Samaraweera, H., Lee, E. J., & Ahn, D. U. (2010). Improving functional value of meat products. *Meat Science*, *86*, 15-31.
- Zhao, F-J., & Shewry, P. R. (2011). Recent developments in modifying crops and agronomic practices to improve human health. *Food Policy*, *36*, S94–S10.
- Zhu, C. F., Naqvi, S., Breitenbach, J., Sandmann, G., Christou, P., & Capell, T. (2008). Combinatorial genetic transformation generates a library of metabolic phenotypes for the carotenoid pathway in maize. *Proceedings of the National Academy of Sciences of the United States of America*, *105*, 18232-18237.