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Review

Potential applications of multiple emulsions in the development of healthy and functional foods

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A B S T R A C T

Recent advances in food and nutrition sciences have highlighted the possibility of modulating some specific physiological functions in the organism through food intake. The beneficial effects of functional foods derive from dietary active compounds, and therefore the design and development of these foods require strategies to control their presence. Thanks to their characteristics, multiple emulsions can be used to induce qualitative and quantitative changes in food composition. This review provides an overview of the specific developments and food applications of multiple emulsions ($W_1/O/W_2$) as a technological strategy to modulate the presence of active dietary compounds for the development of healthier foods including functional foods. It discusses food-grade $W_1/O/W_2$ emulsion applications to: a) improve fat content, both by reducing fat (calories) content and providing healthier fatty acid profiles; b) encapsulate (protect) bioactive compounds such as minerals, carotenoids, vitamins, microorganisms, lactoferrin, phenolic compounds, amino acids and oils; and c) reduce sodium content.

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1. Introduction

The role of dietary active compounds in human nutrition is one of the most important areas of concern and investigation in the field of nutritional science. The findings of research on this subject have

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wide-ranging implications for consumers, health-care providers and nutrition educators as well as food producers, processors and distributors (FAO, 2007). New scientific evidence concerning the benefits and risks associated with particular aspects of dietary compounds is constantly emerging. The potential effects of nutrients and other components in the diet has led to the realization that it is possible to create food items with specific characteristics that are capable of influencing body function over and above meeting basic nutrition needs. Foods that have been satisfactorily shown to improve the state of health and wellbeing and/or to reduce the risk of disease, are denominated functional foods (Diplock et al., 1999); in fact they are currently an expanding market and one of the chief factors driving the development of new products. With consumers increasingly looking for healthy foods with added value, the most successful products are those which are able to claim an added health benefit.

Since the beneficial effects of functional foods derive from dietary active compounds (functional components), the design and development of these foods require strategies for defining/optimizing their presence, either by increasing the proportion of those that exhibit beneficial effects, or else limiting the content of others that have negative implications for health. Different strategies (technological or biotechnological) for production systems (raw materials from animal or vegetal sources), and for preparation, storage, and distribution or consumption processes, can be implemented to induce qualitative and quantitative changes in food composition and to optimize beneficial properties. With these strategies it is possible to introduce changes in the amounts and types of functional components with different potential implications for human health. Among the technological strategies used to design and develop functional foods are those based on changes in food transformation systems. The greatest versatility in the modification of a food's composition can be achieved thanks to the wide range of options for changing the ingredients used in their preparation, and consequently the presence of different bioactive compounds. With this strategy a number of approaches can be used to remove, reduce, increase, add and/or replace different components with physiological activity (Jiménez-Colmenero, 2007). The modification of the food formulation process also makes it possible to use traditional ingredients, and other ingredients specifically designed with certain attributes (nature or composition) that confer healthy properties. In this context the use of multiple (double) emulsions looks especially promising.

Multiple emulsions are multi-compartmentalized systems in which oil-in-water (O/W) and water-in-oil (W/O) coexist, where the globules of the dispersed phase themselves contain even smaller dispersed droplets (Garti, 1997). The most common forms are water-in-oil-in-water (W/O/W), but oil-in-water-in-oil (O/W/O) emulsions can also be used in specific applications. Water-in-oil-in-water emulsions consist of minute water particles (W_1) dispersed inside fat globules (O), which are dispersed in turn in a continuous aqueous phase (W_2) (Fig. 1). What we have, then, is a system ($W_1/O/W_2$) comprising three phases, two aqueous (one inner and another outer, generally with different compositions) and a lipid phase located between them and separated by two types of interphases which are stabilized by means of hydrophilic and lipophilic surfactants.

Potentially, W/O/W emulsions have some advantages over conventional O/W emulsions such as delivery systems for bioactive lipids and for encapsulation, protection and release of hydrophilic components (McClements, Decker, & Weiss, 2007). Because of their properties, among these is the ability to trap and protect various substances and control their release from inside one phase to another, these emulsions have been used as a means of micro-encapsulation in pharmacology (carriers for anti-cancer agents, hormones, steroids, etc.), cosmetics (easy application of creams with encapsulated compounds) and other industrial uses (Benichou, Aserin, & Garti, 2004; Kukizaki & Goto, 2007; Muschiolik, 2007). Double emulsions offer a means of preparing micro- and nano-capsulates (in solid or semi-solid form) containing hydrophilic and lipophilic compounds (Benichou et al., 2004). Multiple emulsions may offer some advantages for food applications, since it has been found to be a potentially useful strategy for producing low calorie and reduced fat products, masking flavors, preventing oxidation, and improving sensory characteristics of foods, or controlling the release of and protecting labile ingredients during eating and digestion (Benichou et al., 2004; Dickinson, 2011; McClements et al., 2007; Muschiolik, 2007). Since multiple emulsions offer the opportunity to enclose nutritional and bioactive compounds, and these emulsions could be used as food ingredients, they offer an interesting approach among the technological strategies used to optimize dietary active components in new food systems such as functional foods.

Numerous research articles have highlighted the potential for applying multiple emulsions in new food systems. However, most of the research has focused on the design, formation, structure and properties of the actual emulsion as affected by different variables associated with composition and preparation procedure, in an attempt to overcome the problems associated with the production of stable multiple emulsions. In the context of development of healthier foods (including functional foods), multiple emulsions have been reviewed as part of a wide variety of structured delivery systems mainly for the encapsulation of functional components (McClements, Decker, Park, & Weiss, 2009; McClements et al., 2007), with less attention to specific food applications. This article offers a detailed review of the specific possibilities and food applications of multiple emulsions as a technological strategy to incorporate dietary active compounds for the development of healthier foods, including functional foods. It discusses food-grade $W_1/O/W_2$ emulsion applications to improve fat content, to encapsulate bioactive compounds, and to reduce sodium content. This review does not deal with studies focusing on emulsification technology or the properties, stabilization and transport

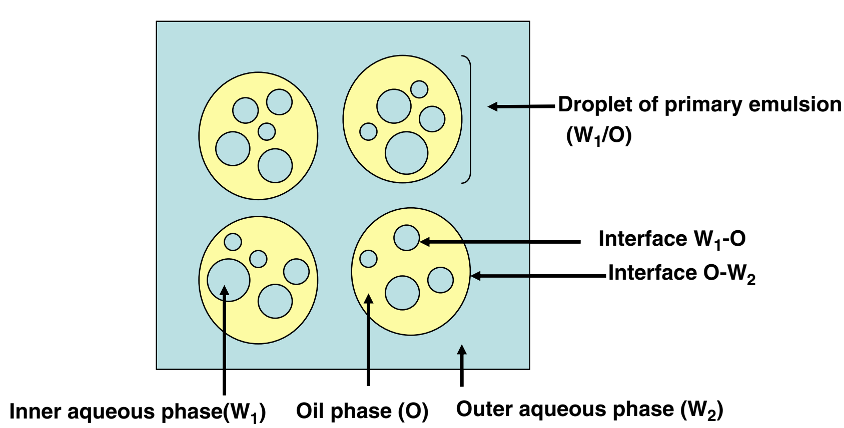

Fig. 1. Schematic representation of multiple emulsions ($W_1/O/W_2$).