The Use of Emulsion Technology for Bioactive Delivery in Foods

By: Dr. Lisa Zychowski

Emulsion-based delivery systems for bioactives are often employed in both the food and pharmaceutical industry. Emulsions, especially oil-in-water (o/w) emulsions, can improve the bioaccessibility and dispersibility of a compound within different matrices (McClements, Decker, & Weiss, 2007). For example, lipophilic bioactive compounds, such as phytosterols, carotenoids and antioxidants, are not soluble in hydrophilic environments. Functional foods need to be consumed in high doses and, thus, large portions of oil-based foods are not always desirable due to the accompanying high-calorie content. Hence, foods with a higher water content are often utilised in functional food matrices, such as yoghurts, orange juice, or milk and, by utilising an o/w emulsion, enrichment of these matrices is possible (Torre & Pinho, 2015).

Several different types of bioactive-enriched emulsions can be employed, which should be selected based on the intended matrix and bioactive (Fig. 1). The most common type is the conventional o/w emulsion, as discussed above, which consists of an oil phase surrounded by an interfacial layer, dispersed in an aqueous phase. Conventional o/w emulsions offer several advantages as they can easily incorporate bioactive compounds if the bioactive is added prior to homogenisation. For example, if the bioactive is an omega-3 oil, incorporation into the oil phase involves simple mixing but, in the case of bioactives with higher melting points, i.e. phytosterols, carotenoids, resveratrol ect., the oil phase is first combined with the bioactive and then must heated beyond the melting point of the bioactive. After heating, the emulsion is usually subjected to homogenisation or another form of shear before the bioactive has the opportunity to re-crystallise (McClements & Li, 2010). Typical o/w emulsions are also usually low in cost when compared to other more sophisticated systems as discussed below, as they require less research and development and usually use less expensive, easy to source food-grade ingredients. They are also customisable, as they can be tailor designed to release at pre-determined stages of digestion.

Conventional o/w emulsions have been able to successfully incorporate many different types of bioactive compounds, such as lycopene, β-carotene, astaxanthin and phytosterols (Tyssandier, Lyan, & Borel, 2001; Yuan, Gao, Zhao, & Mao, 2008). However, there are disadvantages to using simpler o/w emulsions, as sometimes the bioactive components can

degrade. For example, in a study by Clark et al. (2000), stable o/w emulsions with the β-carotene were created using soy bean polysaccharides; however, they were susceptible to β-carotene oxidation. Chitosan was added to create a multilayer emulsion system, which decreased β-carotene oxidation in the emulsion. Multiple layer emulsions can be useful in other similar situations when the bioactive requires extra protection but are difficult to prepare, as flocculation can easily occur when adding polyelectrolytes to an emulsion surface (McClements, Decker, & Weiss, 2007). Spray-drying multiple layer emulsions has also been proven effective to slow bioactive degradation, as work by Lim et al. (2016) has shown that carotenoid retention improved significantly in multiple layer spray-dried emulsion made with trehalose and WPI, as opposed to single layer emulsions.

Another option for bioactive encapsulation is multiple emulsion systems such as w/o/w. These emulsions are perhaps the most difficult to make but can be beneficial in novel applications, such as controlled release, to protect bioactives/oil matrices that are very susceptible to degradation, or in systems with encapsulated bioactives with different hydrophilicities. For example w/o/w have been used to encapsulate polyunsaturated fatty acid, docosahexaenoic acid (DHA; oil phase) and insulin (aqueous inner phase) to improve insulin absorption in the intestinal membrane (Onuki, Morishita, Watanabe, Chiba, Tokiwa, Takayama, et al., 2003).

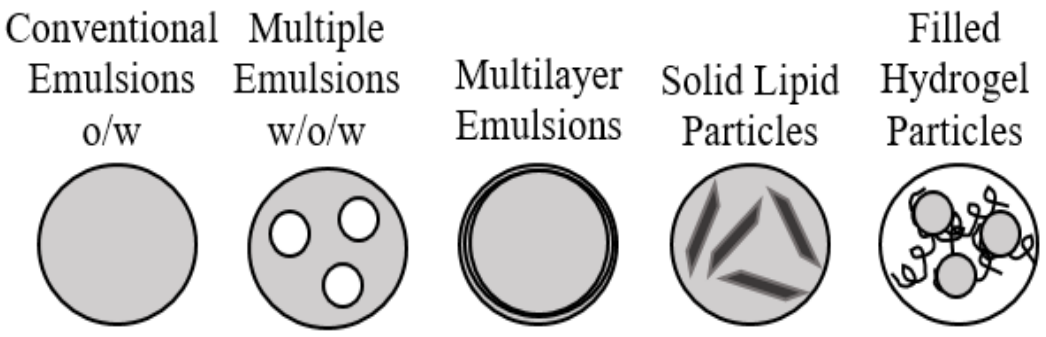

Figure 1 *Different types of possible emulsion system adapted from McClements et al. (2007).*

Filled hydrogels are another emulsion type that can be used for bioactive delivery. These emulsions are used extensively in the pharmaceutical industry and consist of bioactive-enriched oil droplets which are confined by hydrogel particles, dispersed in an aqueous continuous phase (Ahmed, 2015; McClements, Decker, & Weiss, 2007). Hydrogels have been successful in encapsulating compounds such as drug compounds (i.e., 4-vinylpyridine and *N*-(3-

aminopropyl), ω-3 fatty acids, and flavour oils (McClements, Decker, & Weiss, 2007; Xinming, Yingde, Lloyd, Mikhalovsky, Sandeman, Howel, et al., 2008). However, hydrogels are more difficult to prepare than the more basic o/w or multiple layer emulsions and have not been used extensively in food (Shewan & Stokes, 2013).

Another type of emulsion matrix that is used commonly in the pharmaceutical industry is the solid lipid particles (SLP) emulsion. In these emulsions, a fully or semi-solid lipid matrix is chosen to encapsulate a bioactive compound. This matrix can be a disordered or ordered crystalline matrix, which will in turn stop bioactive crystallisation or limit bioactive crystal growth. Preventing bioactive crystal growth in emulsion systems is important, as it can lead to emulsion destabilisation and possibly decrease the bioactivity of the active component (McClements, 2012; Ostlund, Spilburg, & Stenson, 1999). The solid lipid matrix can also improve bioactive stability, as radicals and other compounds have limited mobility in the matrix. For example, milk fat-based emulsions (semi-solid lipid participles) with β-carotene were found to have less bioactive degradation than similar emulsions made with corn oil (Zhang, Hayes, Chen, & Zhong, 2013). Sometimes just the addition of a solid lipid, such as monoacylglycerols (MAG), can sufficiently immobilise a compound. In soybean emulsions MAG added at 0.5% into the lipid phase had significantly higher flavour retention than emulsions with no added MAG. Increasing the MAG to 2% in the lipid phase, further decreased flavour loss demonstrating the ability of solid lipid particles to confine encapsulated compounds (Mao, Roos, & Miao, 2014).

Thus, when choosing a bioactive-enriched emulsion system, several factors should be considered for emulsion and bioactive stability. Firstly, it is crucial to understand and manage the mechanism of chemical degradation of the bioactive (i.e., hydrolysis or oxidation). Also, the loading capacity of the system is important, as excessively high bioactive addition could result in emulsion destabilisation and bioactive degradation in the aqueous phase. The delivery mechanism needs to also be considered as some bioactives might degrade in the stomach and must be released in the intestine. Finally, the bioactive must be compatible in the food material and bioaccessible (McClements, Decker, & Weiss, 2007).

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