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Stability evaluation of lutein nanodispersions prepared via solvent displacement method: The effect of emulsifiers with different stabilizing mechanisms

Tai Boon Tan [a], Nor Shariffa Yussof [a], Faridah Abas [b], Hamed Mirhosseini [a], Imededdine Arbi Nehdi [c], Chin Ping Tan [a,*]

[a] Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[b] Department of Food Science, Faculty of Food Science and Technology, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[c] King Saud University, College of Science, Chemistry Department, Riyadh, Saudi Arabia

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ABSTRACT

The stability of lutein nanodispersions was evaluated during storage and when exposed to different environmental conditions. Lutein nanodispersions were prepared using Tween 80, sodium dodecyl sulfate (SDS), sodium caseinate (SC) and SDS-Tween 80 as the emulsifiers. During eight weeks of storage, all samples showed remarkable physical stability. However, only the SC-stabilized nanodispersion showed excellent chemical stability. Under different environmental conditions, the nanodispersions exhibited a varied degree of stability. All nanodispersions showed constant particle sizes at temperatures between 30 and 60 °C. However, at pH 2–8, only the SC-stabilized nanodispersion was physically unstable. The addition of NaCl (300–400 mM) only caused flocculation in nanodispersion stabilized by SDS-Tween 80. All nanodispersions were physically stable when subjected to different centrifugation speeds. Only Tween 80-stabilized nanodispersion was stable against the effect of freeze–thaw cycles (no phase separation observed). In this study, there was no particular emulsifier that was effective against all of the environmental conditions tested.

1. Introduction

Lutein is widely known as a potent nutrient which protects the human eyes. Its protective function has been proven by numerous studies over the years (Liu et al., 2015; Olmedilla, Granado, Blanco, & Vaquero, 2003) and is attributed to its capability to effectively filter the damaging, high-energy blue light from the sun and scavenge free radicals (Krinsky & Johnson, 2005; Roberts, Green, & Lewis, 2009). Although lutein is highly concentrated in the macula region of the eye, it cannot actually be synthesized endogenously by the human body and must be obtained through the metabolism of lutein-rich food (Ahmed, Lott, & Marcus, 2005). Lutein is commonly found in food such as kale, spinach, cilantro and egg yolk (Perry, Rasmussen, & Johnson, 2009). However, the absorption of lutein through food intake poses another problem because lutein is poorly soluble in water and this hinders its uptake by the human body.

Nanotechnology has been proclaimed as an efficient solution to overcome the poor bioavailability of lutein. By applying nanotechnology, nanodispersions with better bioavailability and stability can and have been widely produced. Nanodispersions are normally fabricated by using either high-energy or low-energy approaches. The high-energy approach refers to the production of nanodispersions using highly-specialized equipment capable of generating a large amount of energy, such as a combination of ultrasonic probes, a high-pressure valve homogenizer and a Microfluidizer, to break up the particles and allow the adsorption of emulsifiers onto the surface of these particles. This approach has been extensively studied and is widely used in the food industry. In contrast, the low-energy approach has only recently started to gain popularity and includes methods such as solvent displacement, emulsification–diffusion and spontaneous emulsification (Saberi, Fang, & McClements, 2013; Yang, Marshall-Breton, Leser, Sher, & McClements, 2012). Of the numerous low-energy approaches, the solvent displacement method is considered to have great potential for application on an industrial scale. The solvent displacement method is a simple and cost-effective, one-step approach for the production of ultrafine particles. Nanodispersions of bioactive compounds are highly

* Corresponding author.
E-mail address: tancp@upm.edu.my (C.P. Tan).

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sought-after and have remarkable potential for food applications. They are considerably preferable to their conventional counterpart due to their desirable properties such as better bioavailability, high kinetic stability and optical transparency (McClements, 2011).

The stability of a nanodispersion, which can be classified into physical or chemical stability, is of utmost importance. The physical stability refers to the changes in particle size and particle size distribution of a nanodispersion against time. A nanodispersion is said to be physically stable if there are no changes in its particle size or particle size distribution over a prolonged period of time. Meanwhile, chemical stability is the resistance towards any chemical changes. In the case of a lutein nanodispersion, these chemical changes refer to the oxidation or degradation of lutein particles. These chemical changes may be caused by time or external environmental conditions such as pH and temperature. The physical and chemical instabilities of a nanodispersion can be retarded or minimized by appropriate selection of emulsifiers (Schubert & Engel, 2004).

Unlike the pharmaceutical industry, the stringent standards and regulations set for the food sector to ensure food safety have severely limited the choice of emulsifiers which can be used in food products. Nevertheless, there is still a variety of emulsifiers which can be applied to stabilize nanodispersion systems. The selection of emulsifiers to be used in a food application is normally determined by the functionality, practicality and cost factors. Emulsifiers work by adsorbing to the surface of the dispersed particles and forming a protective barrier to prevent aggregation or coalescence (Jafari, Assadpoor, He, & Bhandari, 2008). Suitable emulsifiers are chosen based on their capability to produce the smallest particle size using the lowest concentration and ability to withstand stresses caused by environmental conditions such as temperature, pH and ionic strength (McClements, 2007). These emulsifiers can be generally categorized according to their stabilizing mechanisms, i.e., steric, electrostatic, electrosteric and electrostatic-steric (Fig. 1). Since each category of emulsifiers has its own advantages and disadvantages, it would be interesting to observe and compare the efficiency of these emulsifiers in stabilizing nanodispersions. Many researchers have employed a wide variety of emulsifiers in order to stabilize nanodispersions containing their compounds of interest. However, to the best of our knowledge, no study has been done to fundamentally compare the effects of emulsifiers with different stabilizing mechanisms on the stability of nanodispersions, especially for those prepared by using low-energy emulsification methods. For these low-energy approaches, most researchers have employed the same category of emulsifiers (for example, Tween emulsifiers) which have essentially the same steric-stabilizing mechanism (Guttoff, Saberi, & McClements, 2015; Saberi et al., 2013). Thus, in this study, we prepared lutein nanodispersions by using emulsifiers with different stabilizing mechanisms via the solvent displacement method. The processing parameters and the type and concentration of emulsifiers used in this study were decided based on the findings of our previous work (Tan et al., 2016). All of the emulsifiers used were classed as suitable for food usage and frequently utilized by other research groups in their works on food-based emulsion and dispersion systems (Qian & McClements, 2011; Teeranachaideekul, Junyaprasert, Souto, & Müller, 2008; Yang, Leser, Sher, & McClements, 2013). The objective of the current study was to evaluate the stability of these resulting nanodispersions during storage and also when exposed to the various environmental conditions (such as pH, temperature, ionic strength, centrifugal force and freeze–thaw cycle) commonly encountered when they are applied to different foods and beverages.

2. Materials and methods

2.1. Materials

Lutein (>90%) was purchased from Rui Heng Industry Co. Limited (Hefei City, China). Tween 80 and HPLC grade acetone were purchased from Merck (Darmstadt, Germany). Sodium dodecyl sulfate (SDS) and sodium caseinate were purchased from Fisher Scientific (Fair Lawn, NJ). The deionized water used in the preparation of all nanodispersions was produced using a Sartorius Stedim Biotech Arium 611DI system (Goettingen, Germany).

2.2. Preparation of lutein nanodispersions

Lutein nanodispersions were prepared using the solvent displacement method. The organic phase was prepared by dissolving 0.1% (w/w) lutein in acetone, and the aqueous phase was prepared by dissolving 0.1% emulsifier (Tween 80, SDS, sodium caseinate or SDS-Tween 80) in deionized water. The organic phase was then added dropwise (6 ml/min) to the aqueous phase at an organic-phase-to-aqueous-phase volume ratio of 1:9, under continuous magnetic stirring at 750 rpm for 15 min. Finally, the resulting nanodispersion was subjected to rotary evaporation (Eyela NE-1101, Tokyo Rikakikai Co. Ltd., Tokyo, Japan) at a temperature of 40 °C under reduced pressure (0.25 bar) to remove the organic solvent

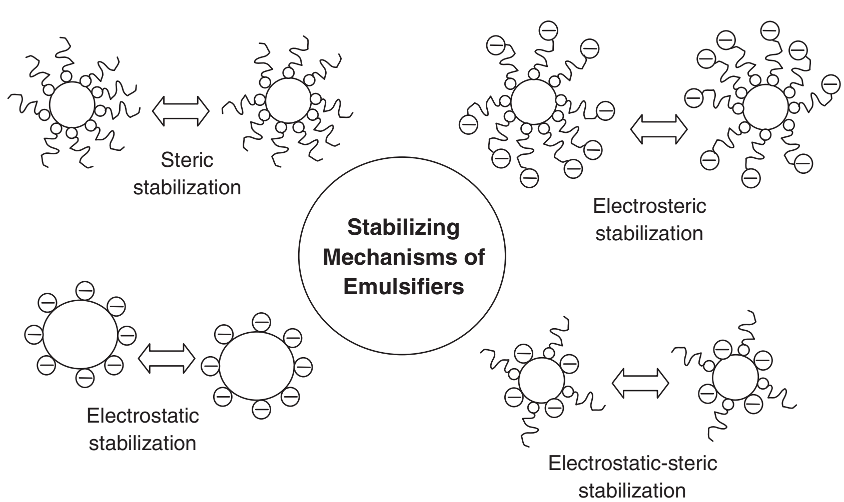

Fig. 1. The different stabilizing mechanisms of emulsifiers.