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ScienceDirect
Colloids and Surfaces A: Physicochem. Eng. Aspects 315 (2008) 47–56
COLLOIDS AND SURFACES A
www.elsevier.com/locate/colsurfa

Effect of Arabic gum, xanthan gum and orange oil contents on ζ-potential, conductivity, stability, size index and pH of orange beverage emulsion

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Received 2 April 2007; received in revised form 1 July 2007; accepted 10 July 2007
Available online 12 July 2007

Abstract

The main and interaction effects of main emulsion components namely Arabic gum content (13–20%, w/w, x_1), xanthan gum content (0.3–0.5%, w/w, x_2) and orange oil content (10–14%, w/w, x_3) on beverage emulsion characteristics were studied using the response surface methodology (RSM). The physicochemical properties considered as response variables were: ζ-potential (Y_1), conductivity (Y_2), emulsion stability (Y_3), size index (Y_4) and pH (Y_5). The results indicated that the response surface models were significantly ($p < 0.05$) fitted for all response variables studied. In contrast with ζ-potential and pH, the independent variables had the most significant ($p < 0.05$) effect on size index. Regression models describing the variations of the responses variables showed high coefficient of determination (R^2) values ranging from 0.866 to 0.960. The main effect of Arabic gum followed by its interaction with orange oil was observed to be significant ($p < 0.05$) in most of response surface models. Therefore, the concentration of Arabic gum should be considered as a critical variable for the formulation of orange beverage emulsion in terms of the emulsion characteristics studied. The overall optimum region resulted in a desirable orange beverage emulsion was predicted to be obtained by combined level of 10.78% (w/w) Arabic gum, 0.24% (w/w) xanthan gum and 12.43% (w/w) orange oil. No significant ($p > 0.05$) difference was found between the experimental and predicted values, thus ensuring the adequacy of the response surface models employed for describing the changes in physicochemical properties as a function of main emulsion component contents.

Keywords: Arabic gum; Xanthan gum; Beverage emulsion; ζ-Potential; Conductivity; Emulsion stability

1. Introduction

The perceived quality of emulsion-based food products, such as milk, cream, sauces and beverages can be determined by the emulsion microstructure or main constituents in a food emulsion which interact with each other, either physically or chemically [1,2]. Due to the non-thermodynamic nature of emulsions, the formulation of a specific emulsion microstructure and specification of emulsion characteristics remains difficult to predict [3]. The effect of emulsion components on the physicochemical properties of emulsions has been studied by many researchers [4–6].

Beverage emulsions are oil-in-water (O/W) emulsions comprising two categories: flavor/cloud emulsions and cloud emulsions. Both types of beverage emulsions must have a significant stability in both concentrated and diluted forms in the finished emulsion-based products (soft drinks) [7]. The most common manifestations of beverage emulsions deterioration are formation of a whitish ring and/or shiny oil slick around the neck of the container. Both emulsion defects are the result of a variety of physiochemical mechanisms that occur within the beverage emulsion, including creaming, flocculation and coalescence [8].

An emulsion is traditionally defined as a dispersion of droplets of one liquid in another, the two being immiscible [2]. Emulsions and colloidal dispersions are thermodynamically unstable systems from a physicochemical point of view, rapidly or slowly separating into two immiscible phases over a period

Abbreviations: RSM, response surface methodology; CCD, central composite design; R^2, coefficient of determination; O/W, oil-in-water; DLVO, Derjaguin–Landau–Verwey–Overbeek; Min, minute; ζ-potential, zeta potential; HE, initial height of emulsion height; HC, height of cream layer; HS, height of the sedimentation phase; ES, emulsion stability index; ANOVA, analysis of variance; Eq., equation; 3D, three-dimensional

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doi:10.1016/j.colsurfa.2007.07.007

Nomenclature

w/w	weight/weight
≥	equal or more
%	percent
°C	centigrade
min	minute
MPa	mega Pascal
mV	milivolt
mS/cm	microsiemens per centimeter
:	per
cm	centimeter
nm	nanometer
<	less
>	more

of time [9] and are stabilized by improvement of their kinetic stability [10], where stability may be defined as the resistance to physical changes [11]. Stabilization is usually achieved by adding small surfactant molecules (e.g. polysorbates, phospholipids) and/or proteins (e.g. milk proteins) and/or thickening agents (gums, gelatin) to the emulsion [12]. Physical destabilization mechanisms of emulsions include the variation processes of emulsion droplet size [3]. The breakdown of an emulsion may manifest itself through the mechanisms, including: creaming, flocculation, ostwald ripening (partial) coalescence, and phase inversion [8,13].

The stability of an emulsion is also governed by the relative magnitude of attractive e.g. van der Waals force and repulsive (e.g. electrostatic, steric, and hydration forces) interactions between the emulsion droplets [8]. Oil-in-water emulsions are usually stabilized by means of electrostatic repulsion between similarly charged oil droplets as predicted by Derjaguin–Landau–Verwey–Overbeek (DLVO) theory [14]. However, the DLVO theory takes into account only two kinds of molecular interactions: electrostatic and van der Waals [15]. The repulsive electrostatic interactions between similarly charged emulsion droplets do not allow them to get as close together as uncharged droplet and the cloud of counterions surrounding a droplet moves less slowly than the droplet itself [16]. The ζ-potential can be used as a measure of the electrostatic repulsive forces, which can give an indication of the potential stability of the colloidal system.

Despite a large number of studies performed on flavor/cloud emulsion, there is a lack of sufficient knowledge on the formulation of a desirable orange beverage emulsion in terms of the critical physicochemical properties. The present study was conducted to investigate the effect of proportion of main emulsion components (namely Arabic gum, xanthan gum and orange oil) on physicochemical properties of orange beverage emulsion. In the present study, response surface methodology (RSM) was applied for modeling the possible relationships between the response and independent variables. Response surface analysis can provide the response regression models for rapidly estimating the overall variation of physicochemical emulsion properties as a function of main emulsion components in a relatively short time. In addition, the present study was conducted to optimize a desirable formulation for the orange beverage emulsion without using the unhealthy synthetic compounds such as weighting agents. The main objective of present study was to determine an optimum level of independent variables resulting in (1) maximum emulsion stability, (2) minimum conductivity and size index, (3) the largest magnitude of ζ-potential and (4) a suitable pH value depending on the other response goals. Therefore, a three-factor central composite design (CCD) was used to study the effect of three independent variables namely Arabic gum content (13–20%, w/w), xanthan gum content (0.3–0.5%, w/w) and orange oil content (10–14%, w/w) on the response variables studied. It should be noted that other critical parameters such as turbidity, average droplet size, polydispersity index, absorbance, viscosity, flow behavior, density and flavor release of orange beverage emulsion have also been investigated in our other studies.

2. Materials and methods

2.1. Materials

Arabic gum was provided by Colloides Naturels International Co. (Rouen, France). Xanthan gum was donated by CP Kelco (Chicago, USA). Citric acid, sodium benzoate and potassium sorbate (≥95%) were purchased from Fisher Scientific (Pittsburgh, PA). Valencia cold pressed orange oil was provided by Danisco (Danisco Cultor, Aarhus, Denmark).

2.2. Preparation of orange beverage emulsion

As shown in Table 2, 20 orange beverage emulsions that composed of gum Arabic (13–20%, w/w), xanthan gum (0.3–0.5%, w/w), orange oil (10–14%, w/w), sodium benzoate (0.1%, w/w), potassium sorbate (0.1%, w/w), citric acid (0.4%, w/w) and deionized water were prepared for the optimization procedure based on a three factor CCD. As mentioned in our previous study [17,18]. To prepare the water phase, sodium benzoate, potassium sorbate and citric acid were dispersed in deionized water (60 °C) using a high speed blender (Waring blender 32BL80, New Hartford, CO, USA). While mixing the mixture, Arabic gum was gradually added to the deionized water (60 °C) and mixed for 3 min to facilitate hydration. The Arabic gum solution was kept overnight at room temperature to fully hydrate. Xanthan gum solution was prepared separately by dissolving xanthan gum in deionized water and then mixed with Arabic gum solution by using a high speed blender. While mixing the water phase, the cold pressed orange oil was gradually added into water phase to provide an initial coarse emulsion [17–19]. Fine emulsification (i.e. small average droplet size of <1 μm with narrow particle size distribution) was achieved by subjecting the pre-emulsions to pre-homogenization using a high shear blender (Silverson L4R, Buckinghamshire, UK) for 1 min and then passed through a high pressure homogenizer (APV, Crawley, U.K.) for three passes (30, 28 and 25 MPa) [17–19].