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Effects of pregelatinized waxy maize starch on the physicochemical properties and stability of model low-fat oil-in-water food emulsions

Grażyna Bortnowska [a,*], Jerzy Balejko [b], Grzegorz Tokarczyk [a], Agnieszka Romanowska-Osuch [c], Natalia Krzemińska [a]

[a] Department of Food Technology, West Pomeranian University of Technology in Szczecin, Poland
[b] Department of Food Process Engineering, West Pomeranian University of Technology in Szczecin, Poland
[c] Center of Bioimmobilisation and Innovative Packaging Materials, West Pomeranian University of Technology in Szczecin, Poland

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ABSTRACT

The effects of pregelatinized waxy maize starch (WMS) concentration (0.0–5.0 wt%) on the physicochemical properties and stability of model low-fat (20.0 wt% rapeseed oil) oil-in-water emulsions, made with dried egg yolk or sodium caseinate (2.0 wt%) were explored. All samples exhibited shear-thinning flow behavior, and the detected from Herschel–Bulkley's model parameters: yield stress (τ_0), consistency coefficient (K), and flow behavior index (n) were highly affected ($p < 0.001$) by WMS addition. Oscillatory test data revealed that the structure of emulsions changed from liquid ($\leq$2 wt% WMS) to gel-like ($\geq$3 wt% WMS). The storage (G') and loss (G'') moduli were modeled as a power function of oscillatory frequency. WMS concentration had a significant ($p < 0.001$) impact on the emulsions stability with respect to creaming and fat holding capacity. Positive correlation values were found between Bohlin's and stability parameters of emulsions. The obtained results can be exploited for the development of low-fat health-oriented food emulsions.

1. Introduction

Oil-in-water (o/w) emulsions consist of small oil droplets dispersed in an aqueous medium, with each droplet being coated by a thin layer of emulsifier molecules (McClements, 2012). The commonly used food emulsions are dressings and mayonnaises (Mandala, Savvas, & Kostaropoulos, 2004). In recent years the actual nutritional trend towards low-calorie foods has increased the interest to decrease the fat content (Laverse, Mastromatteo, Frisullo, & Del Nobile, 2012). However, when the dispersed phase is reduced below 60% the emulsions become highly unstable, mainly due to the serum and droplets separation. This generally is undesirable because it would lead to consumer rejection (Dolz, Hernández, & Delegido, 2006; Heyman, Depypere, Delbaere, & Dewettinck, 2010). The physical stability of the emulsion can be extended by using a combination of various stabilizers and emulsifiers Hemar, Tamehana, Munro, & Singh, 2001; Dickinson, 2003; Bortnowska & Tokarczyk, 2009).

The usually applied food-grade emulsifiers are egg yolk (EY) and sodium caseinate (SC) (Huck-Iriart, Álvarez-Cerimedo, Candal, & Herrera, 2011; Kiosseoglou, 2003). The excellent emulsifying properties of EY are mainly related to lipoproteins which create a stable network at the oil-water interface (Peressini, Sensidoni, & de Cindio, 1998). SC is a heterogeneous mixture of caseins (α_{s1}-, α_{s2}-, β- and κ-) which are known that rapidly adsorb at the oil-water interface conferring a low interfacial tension during emulsification (Hemar et al., 2001; Huck-Iriart et al., 2011). Starch is the most commonly used hydrocolloid thickener, applied in both the native and modified forms (Saha & Bhattacharya, 2010). Physically modified (e.g. pregelatinized) starches when mixed with cold water are able to give immediate gel-like texture (Kaur, Ariffin, Bhat, & Karim, 2012). Starches from different sources vary in composition, e.g. amylose/amylopectin ratio, and thus in physicochemical and functional properties (Singh, Singh, Kaur, Sodhi, & Gill, 2003). In relation to other starches, waxy maize starch, composed mainly of highly branched amorphous amylopectin, has many specific attributes, and therefore it is a promising ingredient that can be used in many food applications (BeMiller, 2011; Copeland, Blazek, Salman, & Tang, 2009).

In general, many studies have been conducted on the stability, flow and viscoelastic properties of emulsions stabilized by EY or SC

* Corresponding author. Tel.: +48 914496526; fax: +48 91 449 6532.
E-mail address: Grazyna.Bortnowska@zut.edu.pl (G. Bortnowska).

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and thickened with different hydrocolloids (Bortnowska & Tokarczyk, 2009; Hemar et al., 2001; Laca, Sáenz, Paredes, & Díaz, 2010; Laverse et al., 2012; Liu, Xu, & Guo, 2007). However, the literature information about EY- and SC-stabilized systems supplemented with cold water swelling starch refined from waxy maize, is scarce.

The objectives of the present study were: (i) to investigate the effects of pregelatinized waxy maize starch (WMS) concentration on the particle characteristics, color, texture, rheological properties and physical stability of low-fat o/w emulsions formulated with dried egg yolk or sodium caseinate, (ii) to estimate relationships between rheological features and those describing physical stability of emulsions, and (iii) to assess the necessary WMS concentration for developing low-fat emulsions with predetermined stability, textural, and rheological properties.

2. Materials and methods

2.1. Materials

Spray-dried sodium caseinate (91.2 wt% protein, 1.8 wt% lipids, 4.8 wt% moisture) and dried egg yolk (33.1 wt% protein, 56.7 wt% total lipids having 28.4 wt% phospholipids, and 3.9 wt% moisture) were purchased from Duncean (Kamień Pomorski, Poland). Cold water swelling native waxy maize starch (99.1 wt% amylopectin) was donated by National Starch & Chemical GmbH (Hamburg, Germany). Rapeseed oil (7.0 wt% saturated, 65.0 wt% mono-unsaturated, and 28.0 wt% polyunsaturated fatty acids) was bought from a local retailer. Analytical grade: potassium sorbate, hydrochloric acid (HCl), and sodium hydroxide (NaOH) were obtained from Hartim (Szczecin, Poland). Double-distilled water was used to prepare all solutions and model emulsions. Composition of the ingredients is reported as stated by the producers.

2.2. Emulsion preparation

Dried egg yolk (DEY), sodium caseinate (SC), and pregelatinized waxy maize starch (WMS) powders were separately dispersed in double-distilled water with addition of potassium sorbate as the preservative, and then the mixtures of emulsifiers were gently stirred overnight at 22 ± 0.5 °C to ensure complete hydratation. Emulsions were produced by homogenizing (1 min, 14 000 rpm) DEY and SC solutions with rapeseed oil using a laboratory-scale MPW 302 homogenizer (Mechanika Precyzyjna, Warszawa, Poland). Then, freshly prepared emulsions were mixed with WMS suspension applying a K4555 kitchen robot (KitchenAid Inc., St. Joseph, Michigan, USA). The pH of the emulsion systems was adjusted to 7.0 with 0.1 M HCl or 0.1 M NaOH. All samples were degassed using APT Line Serie VD vacuum degasser (Binder GmbH, Tuttlingen, Germany). Finally the model emulsions contained: 20.0 wt% rapeseed oil, 2.0 wt% emulsifier (DEY or SC), 0.1 wt% potassium sorbate, and WMS ranged from 0.0 to 5.0 wt%. Samples made without WMS addition were deemed as control ones. All studies were performed on the emulsions at 22 ± 0.5 °C.

2.3. Particle size measurements

The particle size distribution (PSD) of the emulsions was measured by static light scattering using a Mastersizer 2000 with Hydro 2000MU (Malvern Instruments Ltd, Malvern, UK). The refractive indexes were 1.467 and 1.33 for emulsion particles and dispersant medium, respectively, and the Mie theory was used for analysis. The particle size measurements are reported as area-based mean diameter: $D[3,2] = \sum n_i d_i^3 / \sum n_i d_i^2$, and volume-based mean diameter: $D[4,3] = \sum n_i d_i^4 / \sum n_i d_i^3$, where: n_i, number of the particles with diameter d_i (Augusto, Ibarz, & Cristianini, 2012).

2.4. Centrifugation experiments

Centrifugation assay was applied to examine emulsion stability towards creaming (ESC), and fat holding capacity (FHC). Aliquots (~8.0 ml) of the emulsions were transferred to the 10 ml test tubes which were tightly sealed with plastic caps and then centrifuged at 2400 g for 15 min, using an MPW 350 centrifuge (Med.-Instruments, Warszawa, Poland). The ESC parameter was derived from the relation: $ESC\ (\%) = (H_C/H_T) \times 100$, where H_C, the height of the creamed layer, and H_T, the total height of emulsion (Freitas et al., 2009). Whereas, the FHC parameter was calculated as follows: $FHC\ (\%) = (V_R/V_A) \times 100$, where: V_R and V_A oil volumes remained in the emulsion system after centrifugation and added to the emulsion during its formation, respectively (Gu, Campbell, & Euston, 2009).

2.5. Color determination

Color of the emulsions was assessed using a colorimeter Hunterlab model D25-2A (Hunter Associates Laboratory Inc., Fairfax, USA) at 2° view angle. Calibration was made with a white plate ($X = 86.30$, $Y = 88.51$, $Z = 101.99$). Color coordinates were expressed as: lightness (L^*), redness/greenness (+/− a^*), and yellowness/blueness (+/− b*). The experimental data were characterized in terms of: (i) Hue angle (H°), and (ii) total color difference (ΔE) derived from equations: $H^\circ = tg^{-1}(b^*/a^*)$ and $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$, where: ΔL^*, Δa^* and Δb^* are the differences between the adequate color parameters of the containing WMS and control samples.

2.6. Texture profile analysis

The texture profile analysis (TPA) was performed using a back-extrusion (pseudo-compression) test on a Texture Analyzer model TA-XT2 (Stable Micro Systems Ltd., Surrey, UK) equipped with back extrusion cell (A/BE), 5 kg load cell, and 45 mm compression plate diameter. The TA-XT2 settings were as follows: test mode, measure force in compression; trigger type, auto at 0.05 N, and data acquisition rate, 200 pps. The acrylic cylindrical back extrusion pot (inner diameter 50 mm, height 75 mm) was filled with 100 ml of the emulsions aliquots. One cycle was applied, at a constant crosshead velocity of 1 mm s^{-1}, to a sample depth of 30 mm, and then returned. The force-time forces were analyzed using Texture Expert® for Windows® v. 1.11 equipment software and the derived textural parameters were: maximum force in compression (firmness, N), positive area of the curve (consistency, Ns), maximum negative force which indicates the resistance to withdrawal of the sample from the extrusion disc being lifted (cohesiveness, N), and negative area of the curve (adhesiveness, Ns) (Cevoli, Balestra, Ragni, & Fabbri, 2013; Ciron, Gee, Kelly, & Auty, 2010).

2.7. Rheological characterization of the emulsions

Rheological experiments were carried out with a controlled-stress AR 2000ex rheometer (TA Instruments, New Castle, DE, USA) equipped with a cone and plate geometry (40 mm cone diameter, 1° cone angle, 26 μm gap size), and a Peltier temperature controlling system. Prior the measurements, all samples were left standing on the plate for 5 min to allow structure recovery and temperature equilibration. Data were recorded with the TA Rheology Advantage Data Analysis equipment software V 5.4.7. Flow curves were determined using a steady-state flow ramp in the range of shear rate from 1.0 to 600.0 s^{-1}. The obtained data were