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A “reduced-pressure distillation” method to prepare zein-based fat analogue for application in mayonnaise formulation

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ABSTRACT

In this study, the zein extracted from distillers dried grains with solubles (DDGS) is utilized to produce a fat analogue, by employing a simple ”reduced-pressure distillation microparticulation“ method. The optimal conditions for preparing the fat analogue are as follows: a zein concentration of 3 w/v% (based on 60 v/v% ethanol water), an agitator speed of 200 rpm, a xanthan gum amount of 20 wt% (based on zein mass) and a heating temperature of 50 °C. The zein-based fat analogue obtained has a volume-weighted mean diameter (D[4, 3]) of about 16 μm, which is then applied in the formulation of mayonnaise, at fat substitution ratios of 0% (full-fat), 20%, 40%, 60%, 80% and 100%, respectively. Based on the appearance, stability, total calorific value, as well as rheological, microstructure and sensory analyses, it may be concluded that the fat substitution ratio of no more than 40% is acceptable. This paper illustrates another high-value added use of zein.

1. Introduction

With the improvement of people's living standard and the popularity of “western diet”, overweight and obesity have become a severe public health problem in current China (Wang and Zhai, 2014). As fat overconsumption is a main factor causing obesity, the development of reduced-fat foods has aroused a lot of research interests (Wu et al., 2013; Zhen and Joyce, 2013; Simo et al., 2012).

As a semi-solid, oil-in-water (O/W) emulsion, mayonnaise is popular all over the world. Its main ingredients include egg yolk, vinegar, oil, salt and sugar. Though mayonnaise has a great nutritional value, the high calorific value derived from its high fat proportion (70–80%) (Shen et al., 2011) will be a great burden for human health. Therefore, some fat analogues, such as salt duck egg white gel (Wang et al., 2015), konjac gel (Li et al., 2014a), oat dextrine (Shen et al., 2011) and 4aGTase-modified rice starch (Mun et al., 2009), have been investigated to substitute the fat in mayonnaise. Nevertheless, few studies have reported about the utilization of zein-based fat analogue in mayonnaise so far.

Zein is a kind of prolamine, which can only be found in the endosperm of maize (Anderson and Lamsal, 2011; Shukla and Cheryan, 2001). Recently, it is regarded as a potential high value-added product that can be extracted from distillers dried grains with solubles (DDGS), i.e. the coproduct of dry-grind corn bioethanol process (Gu et al., 2015; Xu et al., 2007). Due to the hydrophobic nature and lack of human essential amino acid (tryptophane and lysine), zein has a poor nutritional value, which is consequently considered unacceptable in human food products (Luo and Wang, 2014). Fortunately, the disadvantages of zein mentioned above may turn into advantages in the field of fat analogue. The reasons can be concluded as follows: Firstly, as zein is inherently water-insoluble, it can be directly micronized into fat analogue without thermal denaturation process (Stark and Gross, 1991); secondly, since the calorific value of zein (4 kcal/g) is much lower than that of fat (9 kcal/g), substituting fat with zein-based fat analogue could lower people's calorie intake.

In order to imitate the taste of fat in food, zein should be micronized to achieve the similar particle size of oil drops. Heretofore, there are two main ways to produce zein-based microparticles: (1). Anti-solvent method (Stark and Gross, 1991). In this method, zein is first dissolved in the organic phase (ethanol or propylene glycol-water solution) (Chen and Zhong, 2015; Wu et al., 2012; Zhong and Jin, 2009), and then the solution is poured into the water phase at a high agitation speed. In this way, the consequent sudden decrease of the solvent concentration will lead to a rapid

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phase separation and the formation of micro-or nano-zein particles. Although anti-solvent method is easy and efficient, the concentration of zein particle is low, and freeze drying or spray-drying is needed to remove the water. Moreover, it will generate a large amount of waste water with a low ethanol content. (2). Cast-drying method (Wang and Padua, 2012). It can also be defined as the evaporated-induced self-assembled (EISA) process. During the drying process of zein-ethanol water solution, the zein particles are self-assembled under certain pH values (Zhang et al., 2011), and zein and ethanol contents (Wang and Padua, 2010). However, cast-drying is a very slow process, which limits its application in large-scale production.

Consequently, a “reduced-pressure distillation” method, which can solve the above problems, is utilized to produce zein-based fat analogue. In this method, with the vacuum distillation of ethanol, the production of fat analogue and ethanol recovery processes occur simultaneously in short order. Besides, the recycled ethanol has a high purity of >70 v/v% (the rest 30v/v% is water), enabling it to be used to dissolve zein again. This method is easy and efficient with a good industrial prospect. Then, the effect of zein concentration, shear rate, xanthan gum content and temperature are investigated in order to obtain the optimal particle size distribution of zein-based fat analogue. Finally, the effect of fat substitution ratio on appearance, stability, total caloric value, as well as rheological, microstructure and sensory properties of mayonnaise are also discussed.

2. Materials and methods

2.1. Materials

Distillers Dried Grains with Solubles (DDGS) and Corn germ oil are donated by Jilin Fuel Alcohol Co., Ltd (China). Chicken egg, white vinegar, sugar and salt were purchased from the supermarket of East China University of Science and Technology (China). Ethanol of analytically pure is purchased from Shanghai Titan Chemical Co., Ltd (China). Xanthan gum of USP grade is purchased from Aladdin Industrial Inc (China).

2.2. Zein extraction

Zein is extracted from DDGS using the semi-continuous method (Gu et al., 2015). As the obtained zein is applied in food production, the activated carbon is used to decolor the zein, instead of the H_2O_2. As a result, the yield of zein is about 20% (based on protein content in DDGS), and the zein has a protein content of 90.8%, reaching the purity of commercial product (Xu et al., 2007).

2.3. Preparation of zein-based fat analogue

A simple microparticulation apparatus is used to produce zein-based fat analogue, and it's a standard laboratory reduced-pressure distillation device consisting of a round bottom flask fitted with condenser and a conical flask to receive the condensate, meanwhile, the conical flask is connected to a vacuum pump. In this method, the pH value of zein solution is 6 and the ethanol concentration is 60v/v% (the minimum concentration to dissolve zein). Firstly, in the 100 mL round-bottomed flask, 0.6 g zein is dissolved in 20 mL 60v/v% ethanol water solution, with a concentration of 3w/v%. Secondly, 0.12 g xanthan gum (20 wt%, based on zein) is carefully dispersed in the solution. Thirdly, the PTFE impeller is put into the flask with an O-Ring to keep the apparatus in a sealed state. Finally, the round flask is heated to 50 °C and the vacuum pump is opened to distill the ethanol from the zein solution (vacuum degree: 0.085Mpa). Meanwhile, the impeller is stirred in the flask, with a fixed rotate speed of 200 rpm. As a result, the ethanol is distilled away and collected in the receiving flask, and the remaining substances in the flask form the semi-solid, glossy zein-based fat analogue.

2.4. Particle size measurement of zein-based fat analogue

The particle size distribution of zein-based fat analogue is tested by a laser particle analyzer (Type: Mastersizer 2000, Malvern Instruments Ltd, UK).Where d (x) means that about 100x% of particles in sample are less than d (x) (x = 0.1, 0.5 and 0.9, respectively), and the D[4, 3] is the volume-weighted mean diameter of the sample.

2.5. Morphology of zein-based fat analogue

The fat analogue is dried and tested by FE-SEM (Nova Nano 450, FEI Co.), and the sample should be sputter-coated with platinum before observation.

2.6. Preparation of mayonnaise

As a kind of O/W emulsion, the mayonnaise could be divided into the water phase (25 wt%) and oil phase (75 wt%). Water phase: egg yolk (40 wt%), white vinegar (40 wt%), salt (11 wt%), sugar (8.5 wt%) and potassium sorbate (0.5 wt%) are mixed by a high-speed homogeneous device of 2000 rpm. Then the corn oil is slowly mixed with the water phase, forming the controlled mayonnaise sample. Besides, the zein-based fat analogue is added to substitute the corn oil, with the levels of 0% (Z(0)), 20% (Z(20)), 40% (Z(40)), 60% (Z(60)), 80% (Z(80)) and 100% (Z(100)), respectively.

2.7. Whiteness measurement of mayonnaise

The blue-ray whiteness of mayonnaise is measured by a whiteness meter with the 20 mm testing area and d/0 detection mode (Type: WSB-VI, Hangzhou Daji Photoelectric Instrument Co., LTD, China).

2.8. Stability test

The stability test is made refer to the method of Mun et al., 2009. 5 g mayonnaise sample (a) is put into the 10 ml plastic tube and centrifuged for 10 min at 3000 rpm to remove the top oil layer. After the centrifugation, the mass of the precipitated layer is measured (b), and the emulsion stability is calculated as: (b/a) × 100(%).

2.9. Rheological measurement

2.9.1. Dynamic behavior

The viscoelastic behaviors of mayonnaise are tested by a rotational rheometer (Type: MCR101, Anton Paar, Austria) with a 25 mm parallel-plate rotor and 1 mm gap. Then the dynamic frequency sweep is carried out in a constant stain of 0.1% (in the linear viscoelastic region), with the frequency ranging between 0.1 and 2 Hz at 25 °C. The data are fitted with Gabriele model (Gabriele et al., 2001):

$$G^{*}(\omega) = \sqrt{G'(\omega) + G''(\omega)} = A\omega^{1/z} \quad (1)$$

In this equation, the $G^{*}(\omega)$, $G'(\omega)$ and $G''(\omega)$ are the complex modulus (Pa), elastic modulus (Pa) and viscous modulus (Pa), respectively, ω is the frequency (Hz), z is the coordination number