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Storage stability of hen egg white powders in three protein/water dough model systems

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ABSTRACT

In recent years, due to the specific health benefits associated with bioactive peptides and the reduction of protein allergenicity by enzymatic hydrolysis, the utilisation of protein hydrolysates in the intermediate-moisture food (IMF) market, such as high protein nutrition bars (HPNB), has significantly increased. Currently, no reported study is related to the storage stability of dried hen egg white (DEW) and its hydrolysates (HEW) in an IMF matrix. Therefore, three DEW/HEW dough model systems (100%HEW + 0%DEW, 75%HEW + 25%DEW and 50%HEW + 50%DEW) were established using two commercial spray-dried egg white powders to study the effect of temperature and fraction of HEW on these IMF models (water activity (a_w): ~0.8). During storage at three different temperatures (23, 35 and 45 °C) for 70 days, the selected physicochemical properties of the dough systems were compared. Overall, kinetic analysis showed an apparent zero-order model fit for the change in the colour (L^*), fluorescence intensity (FI) and hardness, as a function of time, for different dough model systems. As expected, the L^*, FI and hardness increased as a function of time mainly due to the Maillard reaction. The amount of free amino groups decreased, with an increase in rate of loss, as temperature increased in the 100%HEW + 0%DEW model. When DEW was substituted for some HEW, the regeneration of the free amino groups after loss was observed as a function of time. Furthermore, when the percentage of HEW was decreased, the incidence of mouldy samples occurred sooner, which indicates that HEW has some antimicrobial ability, especially in the 100%HEW + 0%DEW system where mould growth did not occur.

1. Introduction

Intermediate-moisture food (IMF) products are products with a moderate moisture content (10–40%, wet basis, wb) and a moderate water activity (a_w: 0.55–0.90) created to be shelf-stable without refrigeration (Karel & Heidelbaugh, 1973; Pavey & Schack, 1969; Taoukis, Elmeskine, & Labuza, 1988). Most of the commercial high protein nutrition bars (HPNB, a_w: 0.50–0.65) fit into the IMF category. HPNB is a growing segment in the sports nutrition, muscle building, health supplement, and weight reduction markets which are estimated to grow to about $3 billion in 2016 in the U.S. (Mintel., 2012b).

One major problem related to HPNB is that they generally become harder (aggregation) during storage without moisture loss, making the product unacceptable to consumers (Ahmed, 2004; Berry, 2011; Hazen, 2010; Hutchinson, 2009; Wade, 2005). One of the mechanisms is moisture-induced protein/peptide aggregation which can occur chemically (covalent interactions such as disulfide bond formation/exchange and the Maillard reaction) and/or physically (non-covalent interactions such as hydrophobic interactions), causing changes in the structure and texture of the food matrix which degrade eating quality (Liu, Zhou, Tran, & Labuza, 2009; Rao, Rocca-Smith, & Labuza, 2012; Zhou, Liu, & Labuza, 2008a; Zhou, Liu, & Labuza, 2008b; Zhu & Labuza, 2010). Moisture-induced Maillard browning would occur during storage if reducing sugars are present in any ingredients or added directly. Compared with bar hardening, the quality changes related to the Maillard reaction in HPNB are seldom noticed by consumers. The major reason is that these undesirable changes are usually masked intentionally or accidentally by other added ingredients in HPNB, such as a chocolate coating or caramel colour added.

It is well-known that the hardness of a food matrix is closely related to its glass transition temperature (T_g) (Slade & Levine, 1991). One of the impact factors of T_g is the molecular size of proteins in the food matrix (Chuy & Labuza, 1994). Due to the smaller molecular weight distribution compared with their original intact proteins, protein hydrolysates are easier to form a liquid bridge between two particles, which can effectively decrease the T_g of their powder matrix below room temperature and lead to stickiness during storage at high a_w level (Masuda, Gotoh, Higashitani, & Matsusaka, 2006; Netto, Desobry, & Labuza, 1998; Rao & Labuza,

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2012; Rao, Rocca-Smith, Schoenfuss, & Labuza, 2012). Therefore, one of the solutions for the reduction of bar hardening is to use protein hydrolysates as a humectant to decrease the T_g of the bar matrix (Taoukis & Richardson, 2007). Furthermore, the consumers can not only get the specific health benefits associated with the bioactive peptides in protein hydrolysates, but also reduce the risk of the adverse protein allergenicity (Kitts & Weiler, 2003).

Recently, through changing the moisture content, i.e., a_w (from 0.05 to 0.85), the storage stabilities of two commercial hen egg powders, spray-dried egg white powder (DEW) and its hydrolysates (HEW), were studied, respectively (Rao & Labuza, 2012; Rao et al., 2012). Overall, the physicochemical differences between the two powders during storage were closely related to their inherent characteristics. Firstly, as mentioned above, compared with DEW, the average molecular weight of HEW is smaller ($\leqslant$10 kDa) due to enzymatic hydrolysis. Therefore, at the same a_w, the T_g of HEW is much lower than that of DEW, which makes HEW subject to the results of increased molecular mobility and reaction rates. Secondly, after desugarization during product processing, both powders still contain a small amount of reducing sugar such as glucose and/or its residuals such as carbonyl groups which can react with amino compounds and result in non-enzymatic browning (Maillard reaction) (Rao & Labuza, 2012; Rao et al., 2012; Rao et al., 2012). The major difference is the existing form of reducing sugar in both powders (Rao et al., 2012). In DEW, because of the early stage Maillard reaction during dry-heat pasteurisation (60 °C for 7 days), the remaining carbonyl groups are covalently bound to the proteins (glycosylation). However, in HEW, mainly because the reaction time for glycosylation is too short during pasteurisation (60 °C for 3.5 min), non-covalently bound glucose (0.07%, g/g) can be easily detected using some commercial kits which simply extract glucose with distilled and deionized water (Rao & Labuza, 2012).

Additionally, through studying a DEW/water dough model system (a_w: 0.95), moisture-induced aggregates were produced by two chemical reactions during storage: disulfide interaction and the Maillard reaction (Rao et al., 2012). To further study the effect of temperature and fraction of HEW on DEW/water model system, three simple DEW/HEW dough model systems (100%HEW + 0%DEW, 75%HEW + 25%DEW and 50%HEW + 50%DEW) were established in this study. During storage at three different temperatures (23, 35 and 45 °C) for 70 days, the selected physicochemical changes of the dough systems were compared.

2. Materials and methods

2.1. Materials

Two spray-dried hen egg white powders, Dried Egg Whites (DEW, H227) and Hydrolyzed Egg White (HEW, EP-1 #400) were obtained from Deb-El Food Products, LLC (Elizabeth, NJ, USA) and Henningsen Foods, Inc. (Omaha, NE, USA), respectively. Both products were kept at −20 °C until used. The partial process information and selected physicochemical properties of both products were summarized in our previous studies (Rao & Labuza, 2012; Rao et al., 2012).

2.2. Preparation of DEW/HEW dough model systems

To study the effect of temperature and fraction of HEW on DEW/water model system, three different formulations (100%HEW + 0%DEW, 75%HEW + 25%DEW and 50%HEW + 50%DEW) of DEW/HEW dough model systems were prepared. Briefly, DEW and HEW were mixed well using a powder mixer (IKA Works, Inc., Wilmington, USA) to prepare protein powder blends containing 50, 75, and 100% (g/g) of HEW, respectively. A certain amount of distilled and deionized water was then added into each powder blend to obtain about 25% moisture (wb) in the dough. After mixed until a uniform dough texture was achieved, the dough was then sealed in a plastic bag (Thermo Fisher Scientific Inc., Rockford, IL, USA) and kept at 4 °C for 2 days for moisture equilibration. Before packaging, the moisture-equilibrated dough was kept at room temperature for 2 h. The resultant dough (~10 g) was weighed and pressed into a plastic disposable sample cup (Decagon Devices, Inc., Pullman, WA, USA), and then immediately covered with the lid (Decagon Devices). All finished samples were placed in moisture barrier pouches (IMPAK Corporation, Los Angeles, CA, USA), then heat-sealed for storage. The water vapour transmission rate of the pouch is 0.009 g/m^2/24 h. The packaged samples were stored at three different temperatures (23, 35 and 45 °C) for 70 days. The samples were removed at designated time intervals and cooled at room temperature for at least 2 h before being analysed immediately or frozen at −45 °C for later analysis. The initial sample information of three DEW/HEW dough model systems is summarized in Table 1.

2.3. Physicochemical changes of DEW/HEW dough model systems

During storage, several physicochemical properties of the dough systems stored at three temperatures were analysed at designated time intervals. Firstly, the a_w of the samples was determined using the AquaLab 3TE Water Activity Meter (Decagon Devices). Secondly, the degree of hardness of the samples was analysed using the TA.XT*Plus* Texture Analyzer (Texture Technologies Corp., Scarsdale, NY, USA) fitted with a flat-ended cylinder stainless steel probe (3 mm diameter). Thirdly, the remaining free amino groups in the samples were determined using the *o*-phthalaldehyde method (Goodno, Swaisgood, & Catignani, 1981) with modifications. Fourthly, the colour (L^* value) of the samples was analysed using the Minolta Chroma Meter CR-200 (Minolta Camera Co., Osaka, Japan). Finally, the presence of fluorescent Maillard compounds in the samples was measured through the determination of fluorescence intensity (FI). All relevant methods are described in detail in our previous studies (Rao & Labuza, 2012; Rao et al., 2012). Additionally, reaction kinetics related to three dynamic parameters (L^*, FI and hardness) were analysed using an apparent zero-order model, which is described in our previous study (Rao et al., 2012). The activation energy (E_A) related to quality changes in different dough model systems was also calculated using the Arrhenius equation (Labuza & Kamman, 1983).

2.4. Statistical analysis

Each sample condition was tested at least in duplicate at each time. To compare the change in the dynamic parameters during storage, one-way ANOVA with Tukey's post test was performed. The Pearson correlation between FI and the other two dynamic parameters (L^* value and hardness) were measured. $P < 0.05$ was considered to be statistically significant. The software, GraphPad Prism for Windows (version 5.04, GraphPad Software, La Jolla, CA, USA), was used to analyse the data.

3. Results and discussion

3.1. Water activity (a_w) assessment

From Table 1, the initial moisture content in three dough systems was not significantly different ($P > 0.05$). However, their initial a_w increased slightly, but significantly ($P < 0.05$), with increasing ratio of DEW:HEW in the formulation. According to Raoult's law, the a_w of the aqueous ideal solution depends only