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Research article

Application of egg white hydrolysate (EWH) to improve frothing functionality of pasteurized liquid egg in large quantity production

Ping-Hsiu Huang [a], Sulfath Hakkim Hazeena [b], Yi-Ting Qiu [b], Jhih-Ying Ciou [c], Chang-Wei Hsieh [d,e], Ming-Kuei Shih [f], Min-Hung Chen [g], Chih-Yao Hou [b,*]

[a] *College of Food, Jiangsu Food and Pharmaceutical Science College, No. 4, Meicheng Road, Higher Education Park, Huai'an City, Jiangsu Province 223003, China*

[b] *Department of Seafood Science, College of Hydrosphere, National Kaohsiung. University of Science and Technology, Kaohsiung 81157, Taiwan, ROC*

[c] *Department of Food Science, Tunghai University, Taichung City 407, Taiwan*

[d] *Department of Food Science and Biotechnology, National Chung Hsing University, 145 Xingda Rd., South Dist., Taichung City 402, Taiwan, ROC*

[e] *Department of Medical Research, China Medical University Hospital, Taichung City 404, Taiwan, ROC*

[f] *Graduate Institute of Food Culture and Innovation, National Kaohsiung University of Hospitality and Tourism, Kaohsiung, Taiwan, ROC*

[g] *Agriculture & Food Agency Council of Agriculture Executive, Yuan Marketing & Processing Division, 54044 No. 8 Kuang-Hua Rd., Chung-Hsing New Village, Nantou City, Taiwan*

A R T I C L E I N F O

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Pasteurization
Egg white hydrolysate (EWH)
Foaming
Stability
Non-sterilized liquid egg white (NSLE)

A B S T R A C T

Sterilized Liquid Eggs (SLE) are convenient for the baking process by minimizing the food safety risks of fresh eggs. Although these advantages were encouraging, the thermal effects of the pasteurization process had a negative impact on the functionality of the egg whites, thus making them unattractive to the food industry. Therefore, our previous study found that adding 1–5% egg white hydrolysate (EWH) contributed to the foaminess and stability in SLE. This primary purpose of this study was to confirm the feasibility of applying the optimum concentration of EWH for simultaneous evaluation and shelf life for batch production of SLE. The physical characteristics of the foam were analyzed by adding 1 ± 0.2% of EWH to SLE, and it was found that the foam with 1% EWH had better stability (low drainage), better viscosity, and similar distribution of foam bubbles size in the microstructure. No *Salmonella* infection has been found during the shelf life of 7 days. In addition, the highest overall acceptability has obtained using the large quantity produced SLE with 1% EWH to produce spoon cookies, followed by sensory evaluation. The cross-sectional height of the cookie and the distribution of holes in the structure were in line with those of the non-sterilized liquid egg white (NSLE). Hence, adding 1% EWH was found to the optimum concentration, which provides good foaming performance and stability of SLE. This study conveys a positive assessment to SLE producers and potential users, as it will increase their profitability economically while meeting the market challenges.

* Corresponding author.
E-mail addresses: hugh0530@gmail.com (P.-H. Huang), sh.hazeena14@gmail.com (S.H. Hazeena), c107176201@nkust.edu.tw (Y.-T. Qiu), jyciou@thu.edu.tw (J.-Y. Ciou), welson@nchu.edu.tw (C.-W. Hsieh), mkshih@mail.nkuht.edu.tw (M.-K. Shih), cmh@mail.afa.gov.tw (M.-H. Chen), chihyaohou@gmail.com (C.-Y. Hou).

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1. Introduction

Eggs are considered an important multifunctional food component. The thickening, gelling, emulsifying, foaming, coloring, and flavoring capabilities of eggs enable the texture and sensory qualities, making them a multifunctional food ingredient. Egg whites are known to satisfy the requirements of many food formulations because of their excellent functional and nutritional properties. Its significant foaming properties (foaming ability and stability) are widely used in the food industry to produce bakery products [1–3]. For instance, ovalbumin in egg whites significantly contributes to the foaming, gelling and emulsifying properties [3–7]. In addition, these foams serve as a unique colloidal system in many food products, such as beer, coffee flavorings, dairy products, and mousses, giving unique flavors and textures to foods. Foaming is one of the most challenging processes for large quantity production of colloidal substance stabilization and control purposes as they tend to creaming, dissolve, and polymerize relatively quickly (e.g., compared to oil-water emulsions) [8].

It has been reported that solely protein molecules were not ideal candidates for a stable foaming system, probably only for plant proteins, which required to be supported by polysaccharides and gels [8,9]. Moreover, proteins have been modified with various food-grade substrates to achieve a stable foaming system [1,4,6,8]. Although many studies have reported the benefits, the foam-forming properties of the complexes do not imply that their foam stability remains consistent, and it involves a series of physicochemical indicators, including surface tension, hydrophobicity, and protein molecular structure [10,11]. In the case of products made from liquid eggs must be pasteurized to avoid microbiological risks (such as *Salmonella* and *Listeria*) [12]. As known, thermal treatment leads to denaturation and aggregation of proteins, ultimately resulting in changes of functional protein properties, such as decreased viscosity and increased surface hydrophobicity, affecting gel-forming ability and foaming properties, yet without affecting thermally induced hardness of the gel [5,12]. Additionally, some thermal aggregation of depolymerized proteins occurred under higher temperature pasteurization conditions, which has been attributed to the formation of insoluble protein aggregates [12]. It is critical to retain these functional properties, quality, and processing efficiency, contributing to the safe consumption and acceptance of liquid egg products for widespread use. Therefore, in this study, it was proposed based on the previous report on egg white hydrolysate to maintain or enhancement of the functional properties of liquid egg white such as improving foaming ability and stability. The results hopefully solve the safety concerns demanded while using the natural egg. Also, these innovations may provide a theoretical basis for liquid egg processing.

2. Materials and methods

2.1. Materials

Commercially available non-sterilization liquid eggs (NSLE) were purchased from Sheng Da Foods Co. (Kaohsiung, Taiwan). Commercially available sterilized liquid Eggs (SLE) were purchased from Jin Ding Foods Co., Ltd (Kaohsiung, Taiwan). Proteinase A purchased from Ho Jun Biotechnology Co., Ltd. (Taoyuan, Taiwan). Papain was purchased from Champion Co., Ltd. (Taipei, Taiwan).

2.2. Egg white hydrolysate (EWH) preparation

EWH was prepared according to the method previously reported by Ref. [13]. Fresh egg whites were diluted to 12.5% with distilled water and homogenized. Afterward, it was heated to 50 °C in a water bath and maintained at a constant temperature. Two-stage hydrolysis has performed by adding 0.047% of the enzyme (1:1 ratio of proteinase A to papain, 5 folds dissolved in deionized water). Specifically, hydrolysis has carried out at 50 °C for 1 h followed by 2 h at 68 °C. Following the two-stage completion, hydrolysis was performed in a water bath at 95–98 °C for 10 min. The hydrolysate has centrifuged for 5 min (4 °C, 6000×*g*). Then, the supernatant was pasteurized at 58 °C for 3.5 min to obtain the EWH and stored at 4 °C until used. EWH was added to SLE in a concentration of 0.5, 0.8, 1.0, and 1.2%, respectively. The positive control group was NSLE, while commercially available SLE has used as the negative control group.

2.3. Preparation of foaming samples and evaluation of foaming and stability characteristics

Samples had prepared as described in Section 2.2 above; each instance of 100 mL was whipped for 3–5 min until the maximum volume was foamed.

2.3.1. Drainage analysis

Drainage analysis was performed as described in Ref. [13]; with minor modifications. In brief, the foam was placed in a funnel on a beaker to collect the released liquid to determine water loss. If the weight loss was significant, meaning the foam's stability was poor, and the weight (g) of the liquid released from the foam was measured every 5 min for 30 min.

2.3.2. Measurement of viscosity during the storage period

The viscosity (mPa·s) of the samples was determined with minor modifications of the methods described by Refs. [13,14]. It was determined with a viscometer and rheometer at a shear rate of 0.1–300 s^{-1}, and it monitors the variation of viscosity (rheological properties) on days 0 and 7 during the storage period.

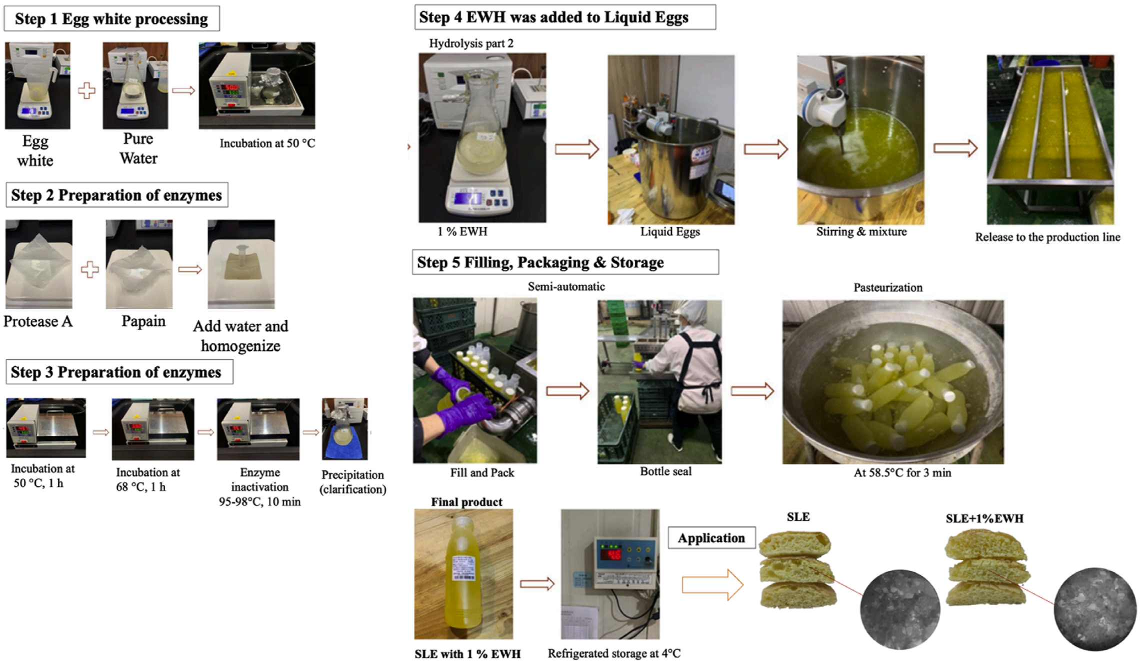

Fig. 1. Graphical Abstract. Sterilized liquid eggs (SLE) with 1% egg white hydrolysate (EWH) in large quantity production Flow.

2.3.3. Evaluation of the physical properties of whipped foam

The experiment was performed with modification according to Refs. [13,15]. All foam samples had analyzed in terms of overrun (%), air phase (%), and foam density (g/cm^3). Its volumes were obtained by weighing 100 mL of whipped foams. The higher values of overrun and air phase showed lower density and better foaming performance. The equations of overrun and air phase were as follows:

$$\text{Overrun}\ (\%) = (V_f - V_1)\ /\ V_1 \times 100$$

$$\text{AirPhase}\ (\%) = \text{overrun}\ /\ (\text{overrun} + 100)$$

$$\text{Foam Density}\ (g\ /\ cm^3) = m_{100f}\ /\ m_{100H_2O}$$

where V_f as foam volume; V_1 as initial liquid volume; m_{100f} as 100 mL foam mass; m_{100H2O} as 100 mL water mass.

2.3.4. Observation of foam microstructure

According to the [13,16] method, the microstructure of all samples (liquid as 100 μL and solid as 0.5 × 0.5 cm^2) was observed with an inverted microscope (50×) to identify the foam condition or the air bubble holes in the cookie texture, followed by analysis from the photographic records.

2.4. Shelf-life assessment

The optimum concentration of EWH was added to the liquid egg white formulation for batch production (Fig. 1). The finished product was obtained via low-temperature pasteurization, which should be kept refrigerated. The above three commercial products were stored in refrigerated condition (4–7 °C), simulating the actual needs, and the shelf-life test was organized. The total plate count (TPC) determined the number of colonies in the samples have performed with the method described by Ref. [17]. The method described in Ref. [18] have used for the determination of *Salmonella* in samples. The TPC and *Salmonella* were the quality indexes followed by microbiological checks on 0, 7, and 10 days of storage. At the same time, SLE and NSLE were kept as the positive and negative control groups, respectively.

2.5. Evaluate the application of baking in spoon cookies

The above-mentioned batch-produced pasteurized liquid egg whites were produced on the theory that increased foaming properties were expected with EWH addition. Therefore, it was applied to spoon cookies, a bakery product that relies heavily on protein foaming properties. Meanwhile, NSLE and SLE were used as positive and negative control groups for comparison. The formula was modified slightly according to the recipe of [19]. In brief, the sugar (each 80 g) was added to 3 liquid egg white samples (100 mL each)

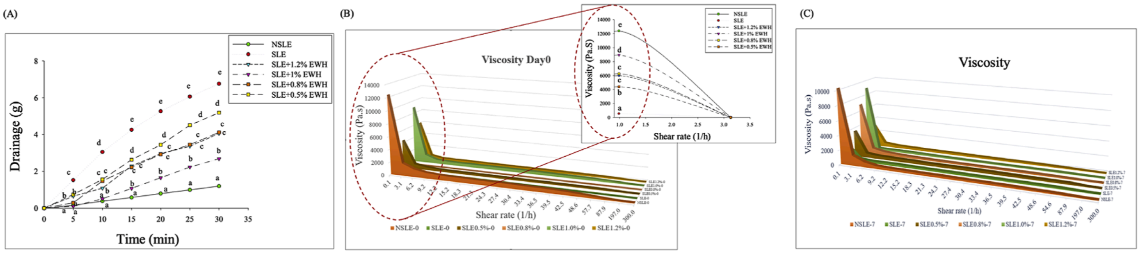

Fig. 2. Drainage of foam made by (A) non-sterilized liquid egg white (NSLE) and sterilized liquid egg white (SLE), and SLE supplemented with 0.5, 0.8, 1, and 1.2% egg white hydrolysate (EWH). (B) Viscosity analysis on day 0 of the storage period (C) on day 7. Different lowercase letters represent significant differences ($p < 0.05$).

in 2 parts, respectively, whipped to maximum volume, then added sifted powdered sugar (40 g) and low gluten flour (115 g), mixed well and fill into a laminating bag, then squeezed into a circle with about 3 cm diameter on a baking tray. Next, allow the mixture to rest at room temperature for about 30 min until the surface seems dried out and not sticky, then immediately bake in a preheated oven at 210 °C for 2–3 min. To prevent over-coloring, the temperature was reduced to 130 °C, then baked for 10 min, and the cookie was ready to serve.

2.6. *Measurement of cross-sectional height*

The spoon cookie sample has cut in half, and the rising height of the cookie was observed and measured. The more significant height was assumed to have better foaming performance.

2.7. *Sensory evaluation*

Before the sensory evaluation of this research, we provided informed consent (supplement material "Informed consent") to the participants and confirmed that these experiments were conducted according to established ethical guidelines, and informed consent was obtained from the participants, then gave them the evaluation and questionnaire (supplement material "Sensory Evaluation Form-spoon cookies").

Fifty panelists were randomly recruited as consumer assessors for sensory profile analysis in blind tests. All spoon cookie samples have been evaluated in appearance, aroma, sweetness, bitterness, texture, and overall acceptability. The evaluation approach has based on a 9-point hedonic scale test. A score of 1–9, where 1 represents weak (dislike), 5 represents the average (like), and 9 illustrates high (like very much) acceptability.

2.8. *Statistical analysis*

All statistical analyses had performed with IBM SPSS Statistics (version 12.0, IBM Inc., St. Armonk, NY, USA). The statistical significance of differences among means was evaluated using one-way ANOVA, followed by Duncan's test as a post hoc test to determine the differences between the groups with significance at $p < 0.05$. All measurements were carried out in triplicates.

3. Results and discussion

3.1. *Optimal concentration of drainage, viscosity, foaming, and stabilization properties*

Many studies showed that the stability of ovomucin in the commercial pasteurized liquid egg has reduced and caused thermal denaturation [3–5]. However, it has also been suggested that liquid eggs with precisely controlled pasteurization during the process facilitate good foaming performance. The primary factor that reduces egg whites' foaming characteristics is egg yolk contamination [20]. Moreover, it was reported that EWH with 3–5% concentration has better stability in the whipped form. The previous study has shown that SLE's stability was lower in terms of negative charge value, surface tension, and viscosity than the non-pasteurized one. However, addition of EWH raised the low ζ potential of SLE, which means it provides stability to the SLE [13]. Foaming properties were determined by the measured increase in foam volume. Foam stability was essential to maintain the desired appearance of food foam, while drainage, aggregation, and disproportionality (coarsening) were the mechanisms that caused foam instability [1]. Furthermore, several studies have shown that foam would be stabilized by the viscosity of egg whites, thereby determining the stability of the foam [13,21], and it was indicated to a certain extent the degree of protein aggregation [4]. In this regard, one may consider that the naturally stabilized egg whites play a more complex role than the traditional Pickering stabilizers [8]. Hence optimum concentration of EWH will be investigated for large quantity production to obtain the product with the best foaming properties. Therefore, for commercial cost consideration, the concentration of 1% EWH was further confirmed as the optimum concentration, and the ratio was modified to 1% ± 0.2% (0.8, 1, and 1.2%) as the final condition for large quantity production. In this study (Fig. 2A), the results of drainage analysis showed that NSLE had the best water retention capacity, with only nearly 1 g of water lost in 30 min. EWH with 1%

Table 1
The physical properties of various types of liquid egg whites.

Sample		Viscosity (mPa·s)	Overrun (%)	Air phase (%)	Foam density (g/cm^3)
NSLE		76.52 ± 0.10^{a}	350.60 ± 0.00^{a}	0.7743 ± 0.00^{a}	0.1559 ± 0.00^{f}
SLE		49.86 ± 0.24^{e}	302.00 ± 0.00^{e}	0.7512 ± 0.00^{c}	0.2007 ± 0.00^{a}
SLE + EWH	0.5%	46.84 ± 0.20^{d}	307.40 ± 0.00^{e}	0.7545 ± 0.00^{c}	0.1919 ± 0.00^{b}
	0.8%	71.20 ± 0.14^{c}	314.60 ± 0.00^{d}	0.7588 ± 0.00^{c}	0.1830 ± 0.00^{c}
	1.0%	73.92 ± 0.17^{b}	327.20 ± 0.00^{c}	0.7659 ± 0.00^{b}	0.1722 ± 0.00^{b}
	1.2%	74.93 ± 0.38^{b}	336.80 ± 0.00^{b}	0.7711 ± 0.00^{a}	0.1664 ± 0.00^{e}

*NSLE: not sterilized liquid egg; SLE: sterilized liquid egg; EWH: egg white hydrolysate.
#Values are expressed as mean ± standard deviation, and there is a significant difference between the average of different letters in the same column ($p < 0.05$).

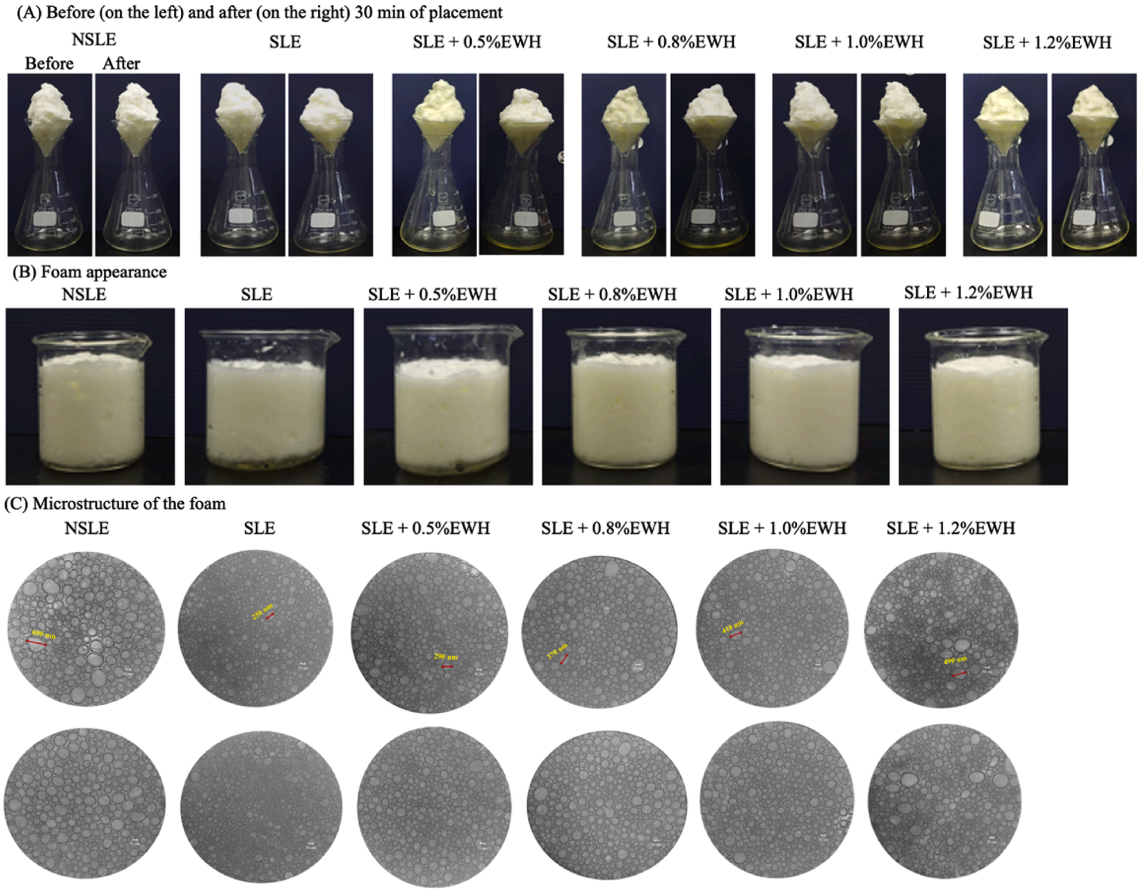

Fig. 3. Foam of different liquid egg white whipping: (A) the appearance of foam draining for 30 min before and after (B) the appearance of foam (C) the microstructure of foam. NSLE: not sterilized liquid egg; SLE: sterilized liquid egg; EWH: egg white hydrolysate.

(2.2 g) was the second, and the others were 1.2, 0.8, and 0.5% in order. The most water released was SLE (6.3 g). Therefore, the lower the concentration of EWS added, the more drainage after frothing. At the same time, it cannot significantly stabilize the structure of foaming protein. Interestingly, the drainage results were comparable to 0.8% EWH with the highest concentration of 1.2% EWH added (both about 4 g) and were significantly different ($p < 0.05$) from the 1%. In addition, the thermal treatment in the pasteurization process caused a decrease in the stability of the ovalbumin, lysozyme, or ovomucin due to thermal denaturation, which clearly showed a significant difference with the results of the NSLE and SLE groups ($p < 0.05$), similar to previous studies [13]. Furthermore, the adverse effects caused by pasteurization were mostly reported on foam foaming characteristics and stability [14,22,23].

Notably, a study reported that the high surface tension value of egg whites in the absence of lysozyme was detrimental to the adsorption, stretching, and rearrangement of egg white molecules at the interface [7]. Since ovotransferrin, the second most abundant protein in the egg white, is heat-liable [1], it is assumed that the remaining foaming capacity of SLE was attributable to it. Hence, by adding 1% of EWH, it might be possible to have better stability of whipping.

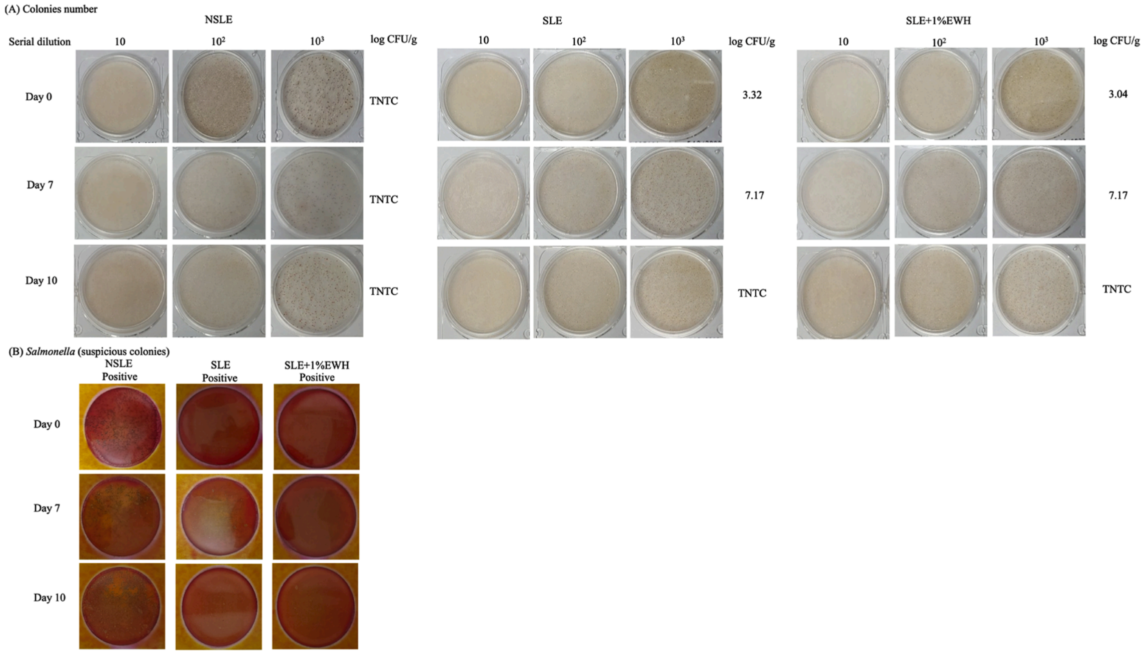

Fig. 4. The detection of microorganisms on days 0, 7, and 10 of the storage periods for different liquid egg whites: (A) colonies number; (B) Salmonella. NSLE: not sterilized liquid egg; SLE: sterilized liquid egg; EWH: egg white hydrolysate.

One of the primary reasons for the excellent egg white foam stability was the high-viscosity osmolyte-lyase complex [1]. The sample's rheology and viscosity characteristics were analyzed at a shear rate of 0.1–300 (S^{-1}) (Fig. 2B and Table 1). The Viscosity (mPa·s) results were maximum for NSLE (76.52), followed by 1.2%, and other groups in the order of 1, 0.8, 0.5%, and SLE. The above results showed significant differences ($p < 0.05$). However, there was no significant difference between the 1 and 1.2% groups. In addition, the 0.5% EWH addition showed that its low concentration could not significantly improve the viscosity. Additionally 1 and 1.2% had the most similar results compared to the commercially available non-pasteurized liquid eggs (NSLE group). Therefore, the result showed that the addition of EWH might improve the viscosity of the pasteurized liquid protein. It has been reported that the hydrolysis of egg whites results in the formation of lower molecular weight (10 KDa) hydrolysates which can diffuse and adsorb rapidly at the interface with more surface activity than the unmodified egg whites [1,24]. However, it was assumed that the possible reason for the higher viscosity of EWH might be attributed to the small molecules of amino acids and peptides that fill the bridges of the otherwise heat-damaged proteins, thus leading to a higher viscosity with better stability. Moreover, previous studies have shown a progressive decrease in viscosity as the concentration of EWH increased [13]. The viscosity analysis on storage day 7 showed the same result (Fig. 2C); the effect of EWH was not affected by the storage time. Notably, the viscosity could not be significantly improved by the low concentration of 0.5 and 0.8% EWH, and the 1.2% was caused by the formation of continuous phase liquid, leading to low viscosity. In theory, enlargement of the viscosity of the continuous phase (such as an increase in the concentration) probably leads to the reduction of the bubble size distribution and a decrease in the drainage rate [21,25]. It has been reported that the increase in viscosity of the liquid phase probably reduced the drainage speed, probably due to the reduction of foam rearrangement and growth [1]. Meanwhile, it aggravates the effect of Laplace pressure difference [8]. In this study, where the high EWH concentration contributed to the drainage increase (Fig. 2A), and the bubble size was more significant than the low concentration (Fig. 3A–C). Hence, the most suitable concentration would be 1% EWH.

In terms of foaming characteristics, the appearance of the foam showed the maximum volume of foam with NSLE, while the three groups with 0.8, 1.0, and 1.2% were similar to NSLE. SLE has the same reason as above, caused by the effect of thermal treatment led to a decrease in foaming capacity; and low concentration (0.5% EWH) was unable to provide good foaming capacity. Foam is a dynamic process in which the air/water interface develops and breaks down in a short period with high shear. Gravitational force, density differences, and other gels interaction effects cause the drainage of the liquid, and then the volume of the air bubble gradually decreased due to polymerization and disproportionality [1,4,15,21]. In such cases, minimizing liquid drainage and gas diffusion while enhancing the stability of the foam towards polymerization would be sufficient to produce food foams with satisfactory stability and texture, typically by strengthening the viscoelastic interface and increasing the viscosity of the continuous aqueous phase [21,25]. The foaming efficiency of the samples can be determined by physical properties (including overrun, air phase, and foam density) according to Refs. [13,16], in which the higher values of overrun and air phase indicate the lower density of the foam produced. The overrun and air phase were measured with different proportions of EWH added and whipped into foam (Fig. 3A and B). Compared with the SLE group, the values of overrun and air phase were significantly increased with the concentration. Whereas the foam density values decreased with the increasing EWH concentration. The results of the above physical properties were significantly different ($p < 0.05$).

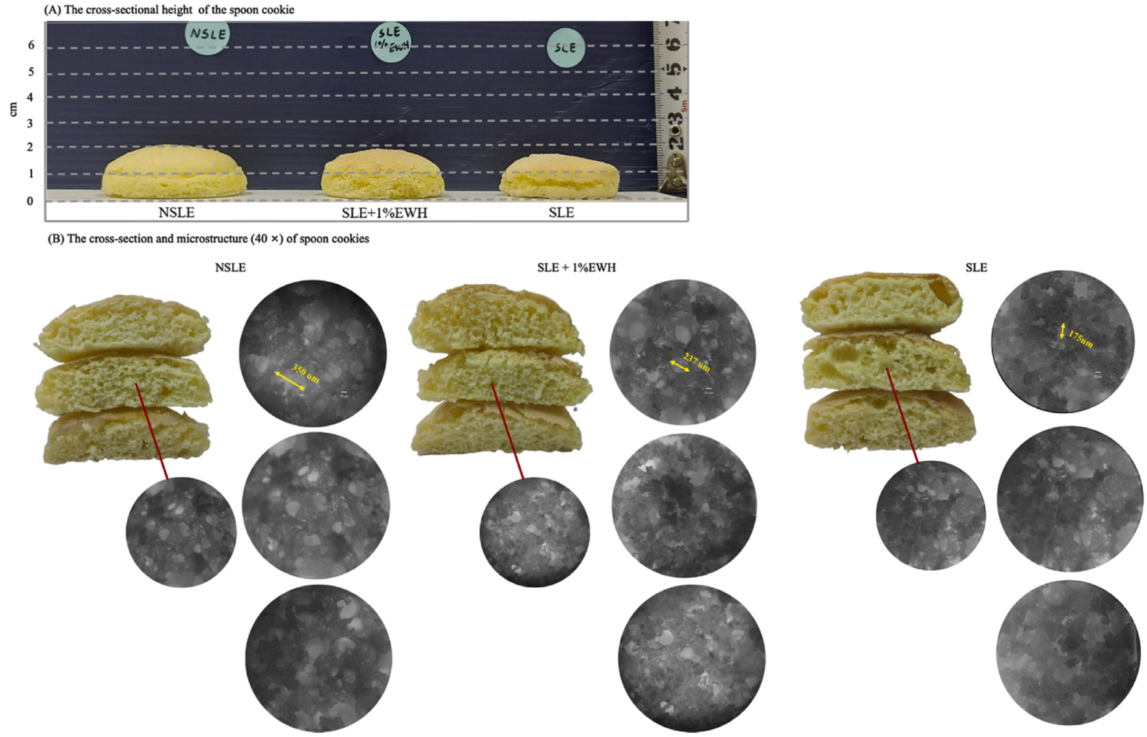

Fig. 5. The spoon cookie production with different liquid egg whites: (A) the cross-sectional height of the spoon cookie; (B) the cross-section and microstructure (40×) of spoon cookie. NSLE: not sterilized liquid egg; SLE: sterilized liquid egg; EWH: egg white hydrolysate.

The results showed that EWH significantly improved of the foaming characteristics of the pasteurized liquid protein, and it increased with the increasing concentration. The foaming characteristics of the NSLE group and the concentration of 1 and 1.2% EWH added groups were similar. Even though, 1.2% EWH has better foaming ability, the stability was not the best.

The spoon cookie microstructure has been observed to analyze the bubble size performance in the foam. The larger the bubble represents, the better foaming characteristics. The results showed (Fig. 3C) that the foam developed was increased with EWH concentration. The foam size and distribution were similar with EWH at 0.8 (370 μm) and 1% (410 μm). On the contrary, with 1.2% of EWH (490 μm), the foaming characteristics were closest to those of NSLE (690 μm). The foam density, size, and distribution of the 1% EWH group are uniform, and the structure of the baked product has improved. Similar to the results in this study, Sun et al. described the effect of added sugar on the impact of foam bubble size, with a decrease in the number of large bubbles (ranging from 250 to 400 μm) and an increase in the number of tiny bubbles (ranging from 100 to 200 μm) [11].

Moreover, the drainage measured by the whipping was low which states that adding 1% of EWH is the most suitable concentration. These results evidenced the weak stability of liquid eggs have increased with pasteurization and 1% EWH addition. In contrast, the stability of liquid eggs had reduced when the EWH concentration increased even further. Hence, the best stability was achieved by adding 1% EWH to liquid eggs.

3.2. The growth of microorganisms during the shelf life

Following the addition of EWH (1%) to the liquid egg white for the batch production, all samples were kept under refrigeration for 0, 7, and 10 days of shelf-life period with random sampling for microbiological measurements (TPC and *Salmonella*). The results in Fig. 4(A and B) showed the TPC of SLE in which 1% EWH added was 3.32 and 7.17 log CFU/g on day 0. In contrast, no obvious changes were observed after 7 days of storage, 3.04 and 7.17 log CFU/g, respectively, and there were too numerous to count (TNTC) after day 10. However, NSLE has not been pasteurized. Thus, the results of colonies numbers have always shown TNTC. Although it has been reported that reduced foaming characteristics occur in liquid whole eggs, mainly due to yolk contamination [20], no such cases were found in this study. Egg whites were inevitably contaminated by egg yolk during the egg breaking and separation process due to various reasons such as poor egg quality, the fragility of egg shells, and manual errors in actual processing and production [2]. Noteworthy that there was no growth of *Salmonella* in all groups during the refrigerated period. Although the results for TPC in NSLE were mostly TNTC, in the future, it was necessary to control the chance of microbial contamination in whole production chain.

Table 2
Sensory evaluation of spoon cookies made from various liquid egg whites.

Sample	Acceptability					
	Appearance	Aroma	Sweetness	Bitterenss	Texture	Overall
NSLE	7.30 ± 0.18[b]	7.28 ± 0.16[b]	7.46 ± 0.15[a]	9.00 ± 0.00	7.22 ± 0.41[b]	7.44 ± 0.52[b]
SLE	6.18 ± 0.18[c]	6.54 ± 0.07[c]	6.68 ± 0.08[b]	9.00 ± 0.00	5.80 ± 0.87[c]	6.42 ± 1.00[c]
SLE + 1.0% EWH	7.67 ± 0.00[a]	7.73 ± 0.17[a]	7.60 ± 0.59[a]	9.00 ± 0.00	7.73 ± 0.59[a]	7.90 ± 0.52[a]

*NSLE: not sterilized liquid egg; SLE: sterilized liquid egg; EWH: egg white hydrolysate.
#Values are expressed as mean ± standard deviation, and there is a significant difference between the average of different letters in the same column ($p < 0.05$), the study was conducted with 50 consumer-based assessors for sensory evaluation ($n = 50$).

3.3. The application of baking in spoon cookies

According to some studies, foam is commonly defined as a two-phase system in which a continuous phase (such as water) covers a dispersed phase (such as air) [2,21,26]. In structural terms, foams eventually grow in size by filling with massive amounts of air and generating bubbles [9]. Interestingly, frothing initiated as tiny bubbles changed to larger ones. More giant bubbles in the foam indicated a better ability to froth characteristics [27]. Additionally, the foaming characteristics of bakery products that require foaming were analyzed by observing the pores in the tissue concerning the height of expansion. Therefore, the more significant the air bubble pores, the higher the volume expansion height of the product, which indicates better foaming characteristics [28]. According to previous studies, the 5% EWH had the best foaming performance, but unfortunately, the bubbles did not spread evenly, which caused the cake to collapse. Otherwise, the 1% EWH preserved the volume of the cake for good stability [13].

In this study, consideration has been given to avoiding the effects of other food ingredients, and the spoon cookies with only egg whites, sugar and low gluten flour were selected to evaluate the physical properties and serviceability of the SLE with the addition of 1% EWH. Its original name is biscuits à la cuillère (in French) (or finger cookies, French-style biscuits). Still, the original meaning is spoon cookies molded with a spoon directly, with a crispy exterior and a wonderful fluffy interior. The recipe that has been improved by bakers worldwide and now resembles a macaroon. It is not only a dessert, a delicacy, combined with the texture and taste of the structure provided by the foaminess of the egg whites.

The results for cross-sectional height (Fig. 5A) showed that the SLE group had a significantly lower cross-sectional height than the NSLE group cookies. A previous study showed that the volume expansion was significantly higher compared to the sterilized group when baked cakes with various percentages of EWH in the fixed protein solution [13]. In addition, it has been found that 1% EWH added SLE was effective with improved foaming characteristics and thus improved the expansion, which increased the cross-sectional height significantly, similar to NSL.

In terms of microstructure (Fig. 5B), a comparison of the three groups of baked spoon cookies, NSLE, SLE, and with 1% EWH-SLE, showed that the pores in the NSLE group and the 1% EWH-SLE have evenly distributed and consistent. On the contrary, SLE showed an uneven distribution of pores with different sizes. In summary, the 1% EWH-SLE showed a better performance in uniform air bubble hole size distribution, both in the whipped foam and in the spoon cookies.

3.4. Sensory evaluation

For future application in the baking industry and acceptability to general consumers, this study was conducted by a consumer-oriented assessment for sensory evaluation. Overall, a nine-point hedonic scale was used to evaluate the appearance, aroma, sweetness, bitterness, texture, and overall acceptability of the spoon biscuits. The bitterness acceptability occurs because of the known possibility of bitter amino acids or peptides (such as lysine with hydrophobic groups, valine, leucine, proline, phenylalanine, tyrosine, isoleucine, and tryptophan) produced by the enzyme hydrolysis [29–32]. The results showed in Table 2 that the spoon cookies with SLE had the lowest acceptability scores. It confirms that commercial SLE has not been favored by the bakery and food processing industry to be widely used, and the previous study reported a similar case in cake production [13]. The spoon cookies made using SLE with 1% EWH were significantly better accepted in all evaluation items than NSLE. Notably, the group with 1% EWH had the highest overall acceptance score in all three groups. Nevertheless, throughout the evaluation process, the consumer assessors had no feedback on the bitterness of the products. Therefore, presumably, the reason might be that such assessors have no training and that the evaluation scale assumed a high preference for acceptability means higher scores were accorded, combined with the fact that no bitterness was detected, the maximum score of 9 was used for the evaluation.

Furthermore, all three samples had identical bitterness acceptability scores, which confirmed this point. In summary, according to the above results, adding 1% EWH to SLE has the dual benefits of enhancing the physical and sensory characteristics of the product. The promotion of industrial use in the future can achieve an effective reduction of process time, operability, and quality improvement, in line with the direction of this study.

4. Conclusions

In this study, the foams whipped by adding 1% of EWH to SLE had better stability (minor drainage), and the physical properties of the foams were consistent in size and evenly distributed. There was no growth of *Salmonella* during the shelf life of the finished products in batch production. In the sensory evaluation of the spoon cookies, the overall acceptability of 1% EWH with SLE was the best. The cross-sectional height and microstructure of the cookies were similar to that of NSLE. However, this study involved the determination of foaming ability enhancement, and identifying the critical components were helpful for future research. In general, a potential method to help the foaming and stability of SLE with 1% EWH might be provided by this study. Addition of EWH would regard as an excellent method for efficient and superior egg white sustainment in expectation of contributing to the improvement of pasteurized liquid egg white for its development in the bakery food industry.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.heliyon.2022.e12697.

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