

Comparison of techno-functional and sensory properties of meringue with egg white and blood plasma for substituting egg allergen and developing functional food

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ABSTRACT

The problem of egg substitution to produce a sensory equivalent to egg products in foods where the colloidal properties of egg white are predominant has not yet been solved. The similarity of the proteins in blood plasma makes it a good natural substitute for egg white. To investigate the substitutability, it is practical to use as simple a matrix as possible, which is a solid foam-based food – meringue – in this study. Important techno-functional – texture (fracture force), colour, dry matter content, baking loss – and sensory properties were measured to compare the effect of blood plasma and egg white with a variable protein sugar ratios (protein source : sugar ratio: 1:1, 1:1.5; 1:2, 1:2.5, 1:3). The findings highlight blood plasma as an effective egg white substitute in foam-based food products showing similar effect on texture, colour and baking loss. Sensory evaluations revealed a slight preference for egg white meringues, although blood plasma meringues could be equally acceptable to consumers with egg allergies.

KEYWORDS

animal blood, by-product, blood plasma, egg, functional food, sustainability, meringues

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1. INTRODUCTION

Egg allergy is a symptomatic overreaction by the immune system to normally harmless *Gallus gallus* (chicken) egg proteins. 9% of children have egg allergy worldwide. This IgE-associated allergy, like other food allergies, can even lead to an immune reaction of death. Allergens are substances, which prompts an immune response upon contact with the immune system of the allergic humans. The egg allergens are the following: 1.) ovomucoid (11% of egg white), which is the most allergic, 2.) ovalbumin (54% of egg white), which is the most abundant, 3.) ovotransferrin (12% of egg white), 4.) lysozyme (3.4% of egg white), 5.) α -livetin (from egg yolk), 6.) YGP42 (from egg yolk) (Dona and Suphioglu, 2020). The blood plasma proteins (albumins, α -, β - and γ -globulins, fibrinogen) have very good solubility, emulsifying capacity, foaming capacity and very good gelling properties. These properties make plasma proteins a suitable substitute for egg proteins in foods (Álvarez et al., 2009). Since the *Bos taurus* (cow) milk is also one of the main food allergens, it is mainly *Sus scrofa domestica* (pork) blood plasma that can substitute the egg allergen.

Animal blood is usually treated as hazardous waste in slaughterhouses, however, it can be a useful raw material in food industry. Animal blood is an ideal raw material for common and functional food development and production (Duarte et al., 1999; Csurka et al., 2023; Hsieh and Ofori, 2011; Ofori and Hsieh, 2012; Toldrá et al., 2012; Bah et al., 2013), and it is also suitable for allergen replacement (Csurka et al., 2021a,b, 2022; Csurka, 2022).

Blood for human consumption in the European Union is obtained directly from the blood ducts of mammalian animals during the bleeding process, without contact with the environment, and then collected and treated in a closed system. After inhibiting the blood coagulation and keeping the blood refrigerated, the blood is separated, as the haemoglobin, which remains in the red blood cell fraction, gives undesirable properties when used as an ingredient in most foods. Separated plasma has a very short shelf life, so it is spray-dried and is usually commercially available as a powder (Csurka et al., 2021c).

Egg white is difficult to substitute in bakery products due to its heat coagulation, solubility, emulsifying and foaming properties (Shepherd and Yoel, 1976). Animal blood plasma was used in bakery products and in similar forms and quantities to egg white has similar effects on the texture and appearance of bakery products (Johnson et al., 1979; Lee et al., 1991). Plasma proteins are composed mainly of globular proteins: about 60 g (100 g)⁻¹ albumin and 40 g (100 g)⁻¹ globulins, and besides the globular proteins about 3–4 g (100 g)⁻¹ fibrinogen (Putnam, 2012). According to other research, raw bovine plasma contains an average of 7.9 g (100 g)⁻¹ of protein, of which 4.2 g (100 g)⁻¹ immunoglobulin, 3.3 g (100 g)⁻¹ albumin and 0.4 g (100 g)⁻¹ fibrinogen (Makara et al., 2016). Recent studies have shown that they are more suitable for forming binding agents than meat powders, gelatine, wheat gluten, isolated soy proteins and calcium carbonate sodium alginate (Lu and Chen, 1999). Also, other blood protein fractions (globulins, serum albumin, haemoglobin) are better emulsifiers than egg (Caldironi and Ockerman, 1982). The egg white proteins contain 54–55 g (100 g)⁻¹ albumin and egg yolk proteins contain 14 g (100 g)⁻¹ serum albumin, 41 g (100 g)⁻¹ glycoprotein and 45 g (100 g)⁻¹ immunoglobulin (Jolivet et al., 2008). Egg white mainly consists of 88 g (100 g)⁻¹ water, 11 g (100 g)⁻¹ protein and 1 g (100 g)⁻¹ carbohydrates, ash, and trace amounts of lipids. Egg white proteins have outstanding foaming properties: foaming capacity and stability (Gharbi and Labbafi, 2019). Therefore, egg white proteins play a key role in many liquid foam and rigid foam foods:

meringues, cakes, biscuits, soufflés, nougats, bavarois, whipped creams, chocolates, mousses, and leavened bakery products. Investigating the effect of blood proteins on texture is important, since it can replace egg as allergenic ingredients and can enhance development of a better, firmer texture. Utilisation of blood is important from sustainability aspect as well due to elimination of a high-volume waste material in slaughterhouses (Csurka et al., 2022).

Meringue is a simple, homogeneous food matrix that is easy to investigate (Vega and Sanghvi, 2012). It is based on a two-element suspension (sugar crystals in the egg white), but after whipping it becomes a foam-type lysol, and after baking it becomes a solid foam-type xerosol. In all cases, it is a dispersion colloid in terms of the continuity of the medium. Proteins have both hydrophilic and hydrophobic groups towards the air phase (Gharbi and Labbafi, 2019). After the whipping, hydrophilic groups are oriented towards the water phase and hydrophobic groups are oriented towards the gas phase. Numerous studies used a 1:1 egg white : sugar ratio (Alavi et al., 2020; Özler and Ağan, 2021; O'Charoen et al., 2014), while others used a higher sugar ratio (Licciardello et al., 2012; Yüceer and Caner, 2021; Yüceer and Asik, 2020). Since the meringue has only a few components, the effect of protein substitution on the techno-functional and sensory properties can be investigated well.

A further aim was to determine acceptance of plasma products by consumers. Data were collected on how the flavour is detected and to what degree any disturbing or off-taste sensation may be eliminated by increasing the sugar content. The objective was to examine the impact of these factors – protein source and protein source: sugar ratio — – on various techno-functional and sensory properties of meringue. The main aim of the study was to support the development of a product benefited by consumers suffering from egg allergies consuming and preferring animal products to vegetable or other alternatives. The primary aim of the sensory evaluation, which complements instrumental analyses, was to assess consumer acceptance of plasma-based products, the perceived intensity of their taste, and whether this was considered less favourable when compared to the typical egg white flavour. The secondary aim was to investigate whether increasing the sugar content could alleviate the potentially unpleasant taste experience associated with the plasma-based meringues.

2. MATERIAL AND METHODS

2.1. Materials

2.1.1. Subject of the investigation. The effect on the techno-functional and organoleptic properties of meringues was investigated by substituting egg white with animal blood plasma in a full factorial experimental design at different sugar-protein source ratios. For comparability, since raw animal blood plasma is not commercially available, only blood plasma powder, rediluted egg white from egg white powder (RDE) and rediluted blood plasma from blood plasma powder (RDP) were used in the experiments. At the same time, in a third sample group, meringues made from liquid egg white (LEW) were also examined at varying sugar egg white ratios aiming to conclude what would happen if fresh blood plasma was used directly instead of blood plasma powder. Moreover, information was collected whether meringues made from LEW and RDE differ.

2.1.2. Protein sources. The determinative protein sources used in this investigation were the followings:

- Plasma powder 70B (Sonac Burgum B.V., Netherlands)
- Egg white powder (Capriovus Ltd., Hungary)
- Pasteurised liquid egg white (Capriovus Ltd., Hungary)

100 g of pasteurised liquid egg white contained 10 g of protein, according to the product specification. Thus, for comparability, the egg white powder and the plasma powder were diluted with tap water until all three liquids had the same water content. According to the specifications, 100 g of egg white powder contained 83 g of protein and 100 g of 70B blood plasma powder contained 69 g of protein.

2.1.3. Preparation of meringue. The meringue samples consisted of two ingredients: crystal sugar (Magyar Cukor Zrt., Hungary) and a protein source. The protein source : sugar ratios in the different sample groups were the following:

- 1:1
- 1:1.5
- 1:2
- 1:2.5
- 1:3

For each sample group, sugar was added gradually while the protein source was continuously stirred using the second of five speeds of a 300 W mixer. After adding the sugar, the two ingredients were mixed on the fourth (maximal) speed until 10 min of mixing time was completed. The foam was filled into a foam bag and shaped into 3 cm diameter flattened balls from a 1.5 cm diameter tube onto baking paper. The meringues were dried in a bottom-up oven at 80 °C for 2 h.

After preparation, the meringues were stored at room temperature for 12 h under the same conditions before testing.

2.2. Method

2.2.1. Experimental design. The results are presented in a 5×3 full factorial experimental design, to compare the effects of five different protein source : sugar ratios (1:1, 1:1.5, 1:2, 1:2.5 and 1:3) and three different protein sources (blood plasma powder, egg white powder and liquid egg white), each containing the same protein quantity.

2.2.2. Measurement of baking loss. Following dosing and formatting, pre-baking weight of each sample was recorded using a KERN GAB 12K0.1N balance (KERN & SOHN, Germany). After low-temperature hot air drying, the meringues were allowed to cool to room temperature (25 °C), which was achieved within 10 min, then the weight of the baked samples was measured. The difference between the pre- and post-baking weights, expressed as a percentage, represented the baking loss. This loss corresponded to the amount of water evaporated from the protein source material during heat treatment (see detailed sample preparation in Materials).

2.2.3. Measurement of dry matter content. A sample weighing 3–5 g was accurately measured using a Kern ABJ-NM/ABS-N analytical balance (Kern & Sohn GmbH, Germany) and placed into an open Petri dish. The samples were subsequently dried at 120 °C in a laboratory drying oven (Labor Műszeripari Művek, Hungary) until achieving a constant weight. Following the drying process, the samples were cooled in a desiccator, and their residual mass was determined using the same analytical balance (Visy et al., 2021).

2.2.4. Texture analysis. The texture of the meringue samples was examined using a Stable Micro Systems (SMS) TA.XT Plus texture analyser (Stable Microsystems, United Kingdom) equipped with an HDP/3PB three-point bend rig probe. This probe is specifically designed for evaluation of the breaking and bending characteristics (Csurka et al., 2022). A fracture test was performed, during which the fracture force, defined as the peak force (Newton), was measured.

The peak force was recorded at the point of fracture when the meringue sample was split. For meringues with a hard crust, the peak force was determined at the point of crust breakage, rather than at the fracture of the entire meringue. The probe was placed on the surface of the sample and moved across it at a speed of 1 mm s⁻¹. Three replicate measurements were taken for each sample. The probe's penetration into the sample up to the point of fracture, the work performed by the probe up to fracture, and the adhesion of the sample were all evaluated.

2.2.5. Colour measurement. A Minolta CR-400 chromameter (Konica Minolta, Inc., Japan) was used to assess the reflected colour of the meringues. The CIE Lab colour characteristics were qualified by the chromameter, where the ratio of three distinct wavelengths of light is represented in a coordinate system referred to as the CIE Lab colour space. The colour measurements are provided as numerical values by the device (Horváth-Mezőfi et al., 2024).

The instrument was calibrated using a standard white etalon (No: 15033034; L* = 93.7, a* = 0.3131, b* = 0.3191). Each sample was measured three times placed at different points on a white plate, ensuring uniform illumination. The attributes measured included redness/greenness (a*), yellowness/blueness (b*), and brightness (L*).

2.2.6. Sensory evaluation. A questionnaire-based sensory evaluation was carried out in a controlled laboratory environment, free from confounding factors, with panel members separated either temporally or spatially. Six sample groups were selected for the sensory analysis, as the quality of the evaluation is notably diminished when more than six samples are presented (Lawless et al., 1999). The samples used in this evaluation corresponded to the minimum and maximum values of the protein source: sugar ratio from the analytical samples:

- Liquid egg white : sugar = 1:1
- Liquid egg white : sugar = 1:3
- Rediluted egg white from egg white powder : sugar = 1:1
- Rediluted egg white from egg white powder : sugar = 1:3
- Rediluted blood plasma from blood plasma powder : sugar = 1:1
- Rediluted blood plasma from blood plasma powder : sugar = 1:3

Panel members were informed that the meringues may contain animal blood plasma. The tasting was voluntary and panellists were informed that they could stop testing at any time. The information was given verbally, but all the necessary information was included in the

evaluation form. The panel consisted of 16 members. They were also made aware that they would be tasting six different samples, each assigned a random three-digit code. The six samples were presented to each panel member in ascending order of sugar content. To minimise the effect of successive tasting, the meringues containing three different protein sources were presented in a randomised order, as the preceding sample could influence the perception of the subsequent one. Panel members were provided with water to cleanse their palates between samples. The panellists were consumers, rather than experts.

Panellists were asked to assess and rank the following attributes of the samples: flavour preference, smell preference, texture preference, hardness, and sweet taste intensity. These attributes were evaluated on a five-point scale in a descriptive test, with rankings ranging from one to five. Panel members were also asked to provide comments on the samples and to rank them according to their preferences.

2.2.7. Statistical analysis. Measurement results were evaluated by IBM SPSS statistic v28 (IBM Corp., Armonk, NY) and presented by Microsoft Excel 365 version: 2010 (build: 13328.20356) software. To detect the effect of protein raw material and protein source : sugar ratio on texture, colour, dry matter content, baking loss and sensory attributes, different statistical analysis methods were used in case of different dependent variants. Depending on the number of dependent variables, univariate or multivariate analysis of variance (ANOVA or MANOVA) was carried out to compare the means of different sample groups of related variables (Huberty and Olejnik, 2006).

The normality of residuals was checked by Shapiro-Wilk test (Shapiro and Wilk, 1965) in case of texture, colour, dry matter content and baking loss, and D'Agostino's K-squared test (D'Agostino, 1970) was used in case of sensory attributes. Normality of residuals for sensory attributes was not completely adequate for MANOVA, but in order to evaluate the results, MANOVA was carried out for all of the three attribute groups.

Homogeneity of variances were checked by Levene's test (Levene, 1960). MANOVA is robust enough to fit equality of covariance matrices, so in case of sensory attributes, with no adequate homogeneous covariance matrices, according to the results of Levene's test, Box's M test (Box, 1949) was carried out. MANOVA was used in case of each dependent variant group (texture, colour, dry matter content, baking loss, sensory attributes). The value of the unexplained variance rate (Wilks's lambda) was evaluated. The homogeneous groups were separated by Tukey HSD post hoc test.

3. RESULTS AND DISCUSSION

3.1. Baking loss

The dry matter content results presented the following already predicted baking loss results it was observed in the following subchapter that each sample group had similar dry matter content after baking. Water content of the protein sources used was nearly the same. For this reason, it was expected that samples with a lower sugar content and therefore higher water content would lose more water during the baking. Baking meringues is basically a hot drying process. This explains that, according to the Tukey post hoc test, while the values of the sample groups

with different protein sources did not differ significantly, the values of the sample groups with different protein source : sugar ratios showed significant difference ($P = 0.05$).

As shown in Fig. 1, samples with 1:1; 1:1.5; 1:2; 1:2.5; and 1:3 protein source : sugar ratio had $42.20\% \pm 0.56\%$; $33.97\% \pm 0.51\%$; $27.57\% \pm 0.71\%$; $23.70\% \pm 0.64\%$; $20.72\% \pm 0.64\%$ baking loss per whole original mass, respectively. and baking loss, samples with 1:1.5 protein. It would not be appropriate to give mean values for sample groups prepared with different protein sources, because the absolute standard deviation of 8.19–8.93% of the baking loss depending on the protein source means a relative standard deviation of 27.60–30.07%. These results suggested that meringue baking was practically a drying to a constant weight, since all meringues were baked/dried to nearly the same dry matter content. It is important to note that this was independent of whether RDE or LEW was used. In addition, samples with blood plasma behaved the same way and showed similar baking loss as samples with egg white. Therefore,

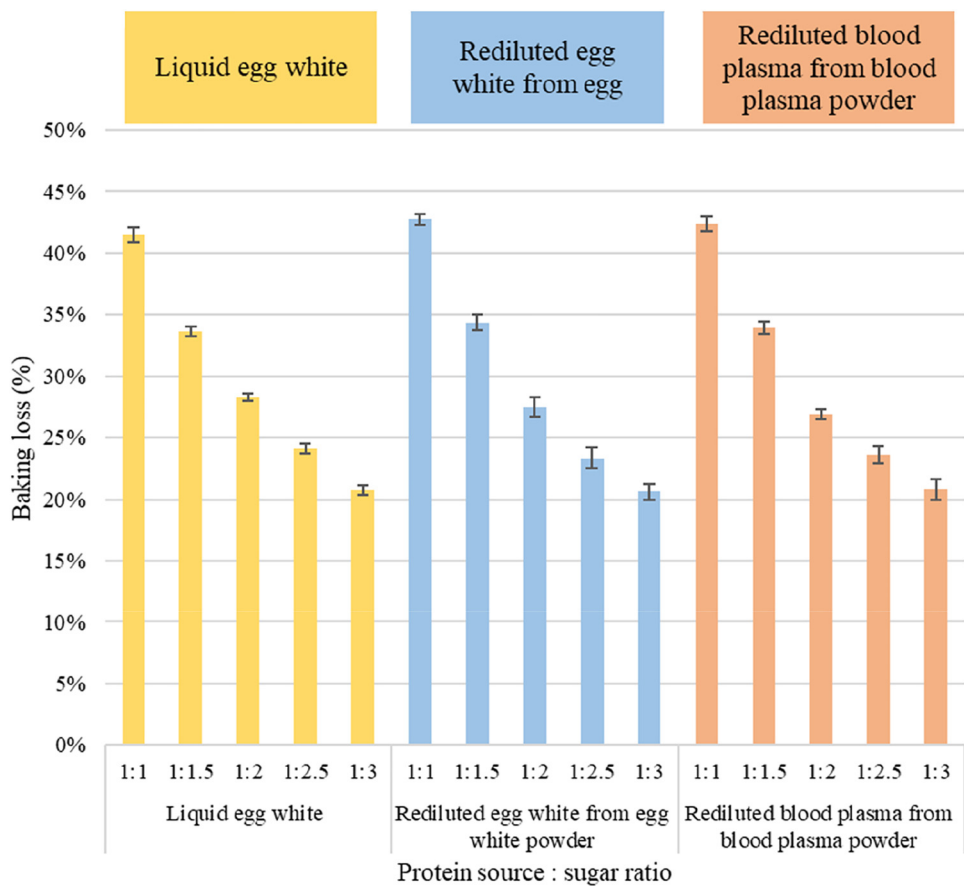


Fig. 1. Baking loss [%] per original mass results of meringue sample groups made with different protein sources (liquid egg white, rediluted egg white from egg white powder, rediluted blood plasma from blood plasma powder) and different protein source: sugar ratios (1:1, 1:1.5, 1:2, 1:2.5, 1:3)

it can be concluded that, from baking aspect, the proteins in egg whites and blood plasma bind water and dry similarly under the baking conditions used in the experiment.

It is worth mentioning that if instead of starting with samples of the same mass, we start with a protein source of the same mass, to which we add different masses of sugar per sample group, the absolute value of the baking loss will be similar for each sample group. The baking loss for all sample groups was 0.83 g per 1 g of protein source and 1–3 g of sugar. The standard deviation of the mean of the sample groups was 0.01 g. However, this average of 0.83 g, which was typical for all sample groups, already showed a significantly different value in weight percentage of the original sample weight.

According to the results of ANOVA the effect of protein source : sugar ratio on the baking loss was very strong [$F(4, 30) = 3449.156, P < 0.01$], but the effect of protein source on baking loss was very low and not significant [$F(2, 30) < 0.01, P = 0.859$]. Thus, it is worthwhile to describe the values of the samples prepared with different protein : source sugar ratios to describe the results of the baking loss measurement.

3.2. Dry matter content

Average dry matter content of all samples was between $0.96 \text{ g (100 g)}^{-1}$ and $0.99 \text{ g (100 g)}^{-1}$. Nominal differences between sample groups were minimal. This means that all the meringue sample groups had a similar dry matter content, so they dried to near constant weight during baking. Only a few percent of moisture could be removed from the samples in drying oven during the dry matter measurements.

In case of dry matter content, factors had no measurable effect. According to the results of ANOVA, effect of protein source and protein source : sugar ratio on dry matter content [$F(2, 30) = 3.562, P = 0.041$; $F(4, 30) = 5.967, P = 0.001$, respectively] were both very small. The effect of the interaction of protein source : sugar ratio was also low and insignificant [$F(8, 30) = 1.060, P = 0.416$].

According to the Tukey HSD post hoc test, dry matter content results of sample groups made with LEW and RDE differed significantly, but results of sample groups made with RDP were not significantly different from the other two sample types. In case of protein source : sugar ratio, three homogeneous group were separated by the Tukey test with the following sample groups (for ease of reading, only the sugar ratio is shown): 1.) 2, 1, 1.5; 2.) 1, 1.5, 2.5; 3.) 1.5, 2.5; 3. There were more overlaps among the groups.

3.3. Texture

Average fracture force result of the samples made with LEW, RDE and RDP were 22.01 N, 25.03 N, and 28.04 N, respectively. Similar fracture force (calculated from breaking stress) and breaking mechanism were obtained in previous studies in case of meringues with different, five sugar contents similar to the recipe presented here (O'Charoen et al., 2014). Fracture force results are shown in Fig. 2.

It is necessary to mention that the penetration of the probe in the sample up to the fracture was examined, the work performed by the probe up to the fracture, and adhesion of the sample did not provide any extra information because they showed a similar trend to the fracture force values, but their variance was too large for statistical evaluation. However, for the completeness of the analysis, these dependent variables were also used in performing the MANOVA.

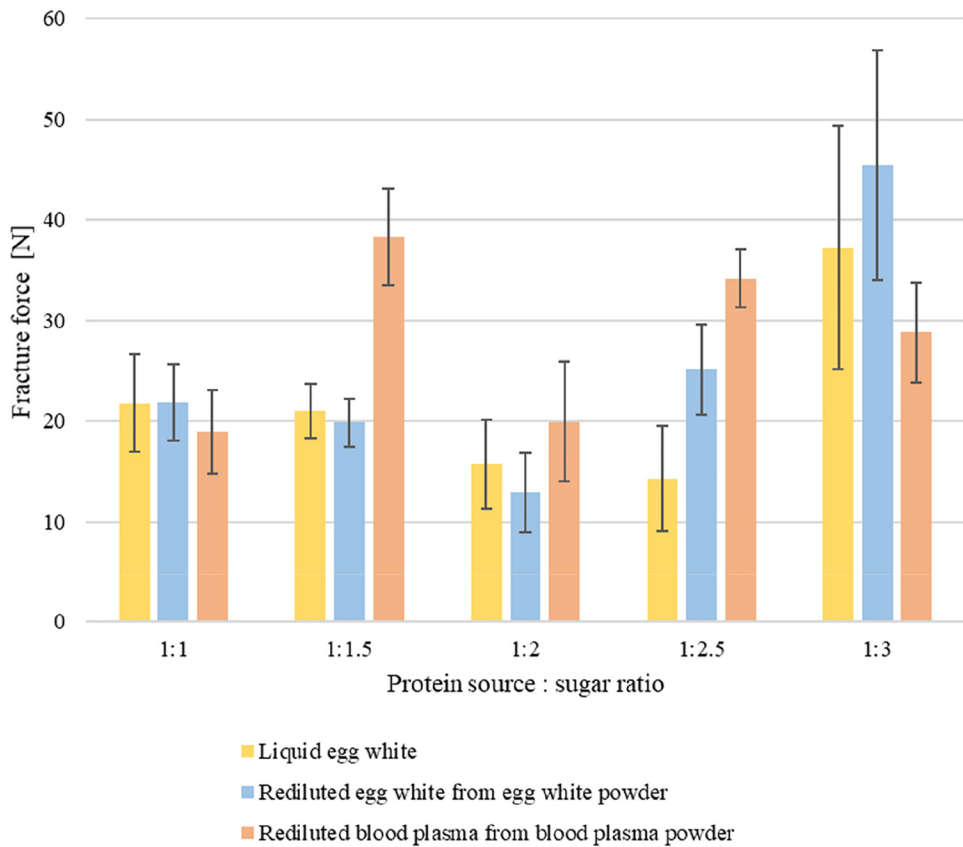


Fig. 2. Fracture force [N] results of meringue sample groups made with different protein sources (liquid egg white, rediluted egg white from egg white powder, rediluted blood plasma from blood plasma powder) and different protein source : sugar ratios (1:1, 1:1.5, 1:2, 1:2.5, 1:3)

Meringue is a solid foam with a large number of air bubbles of different sizes and various distribution. For this reason, there was a large standard deviation in the results of texture measurement. However, the value of the unexplained variance rate suggested that the protein source : sugar ratio was a major determinant of the measured texture properties [Wilks' lambda = 0.120, $F(20.000, 87.182) = 3.908$, $P < 0.01$]. An important observation was that the used protein source had no significant effect on the texture properties [Wilks' lambda = 0.528, $F(10.000, 52.000) = 1.953$, $P = 0.058$]. However, the interaction of protein source and protein source : sugar ratio factors was the best way to determine the dependent variables [Wilks' lambda = 0.068, $F(40.000, 116.126) = 2.476$, $P < 0.01$]. The effect of the interaction of the two factors was stronger than the effect of the protein source : sugar ratio alone. The closer the Wilks' lambda value is to zero, the better the texture attributes can be explained by the factors. This revealed that the texturising effect of blood plasma was similar to that of egg white.

This is partially confirmed by the Tukey post hoc test. In case of the work performed by the probe up to the fracture, and adhesion of the sample, there were no significant differences between the results of the sample groups ($P = 0.05$). In case of fracture force, two homogeneous groups were separated by the Tukey test ($P = 0.05$). The first group included samples made with LEW and samples made with RDE, while the second group included samples made with RDE and samples made with RDP. Thus, for the most assessable, most important attribute, the effect of blood plasma was not significantly different from the effect of similarly prepared egg white, but was significantly different from the effect of non-powdered LEW ($P = 0.05$).

In terms of protein source : sugar ratio, significant differences in the effect on fracture force were only observed between the 1:3 ratio and all other ratios ($P = 0.05$). No significant differences were observed for the other measured texture attributes based on protein source : sugar ratio according to the Tukey's post hoc test ($P = 0.05$). Average fracture force result of the samples made with different protein source : sugar ratio were: 1:2 – 16.18 N, 1:1 – 20.8521 N, 1:2.5 – 24.55 N, 1:1.5 – 26.40 N, 1:3 – 37.15 N. The findings that proteins in blood plasma and

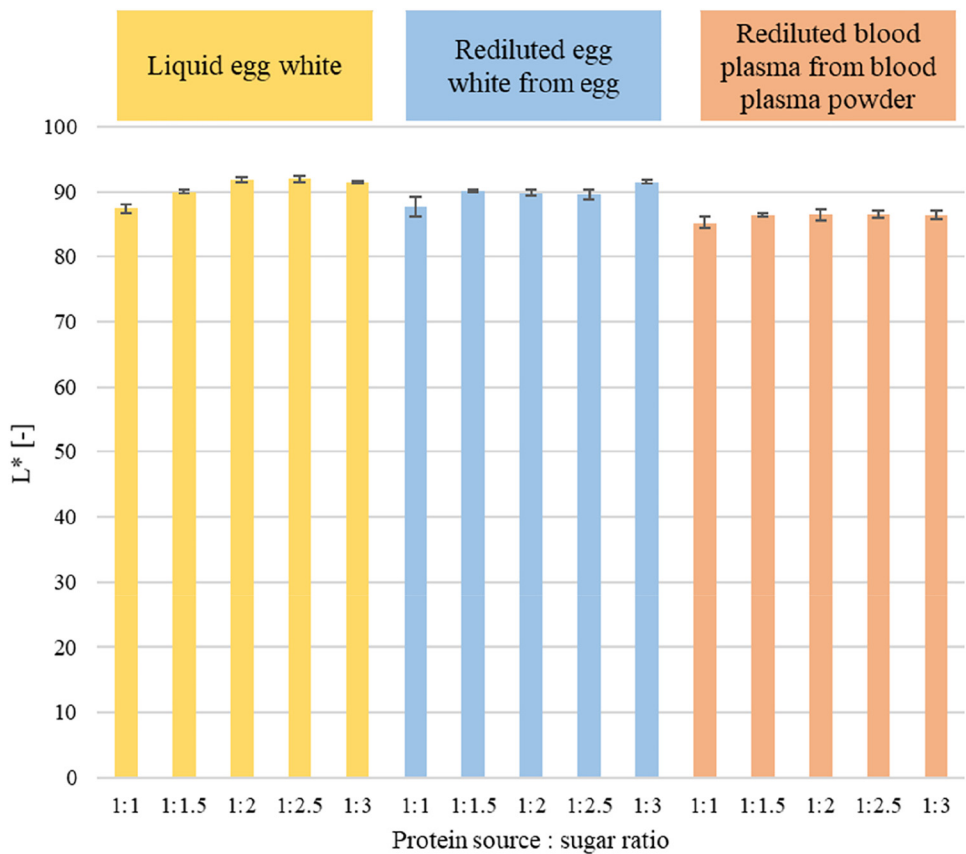


Fig. 3. Lightness (L^*) [-] results of meringue sample groups made with different protein sources (liquid egg white, rediluted egg white from egg white powder, rediluted blood plasma from blood plasma powder) and different protein source : sugar ratios (1:1, 1:1.5, 1:2, 1:2.5, 1:3)

egg white have similar texturising effects in similar states are consistent with other previous researches, and therefore blood plasma may be a suitable substitute for egg white in foam foods (Johnson et al., 1979; Lee et al., 1991; Csurka et al., 2021b, 2022).

3.4. Colour

Figure 3 clearly shows that meringues made from plasma powder are darker than meringues made from egg white signal. The average lightness of the sample groups with blood plasma was 86.21, the average lightness of the sample groups with RDE was 89.73 and the average lightness of the sample groups with LEW was 90.52. However, only the samples made with LEW were significantly different from the other samples based on the red-green colour factor and the yellow-blue colour factor, and the samples made with RDE and RDP were not significantly different from each other ($P = 0.05$).

As shown in Figs 4 and 5, there was no clear trend in the colour factors of the different sample groups and the nominal differences were very small. Although the red-green colour

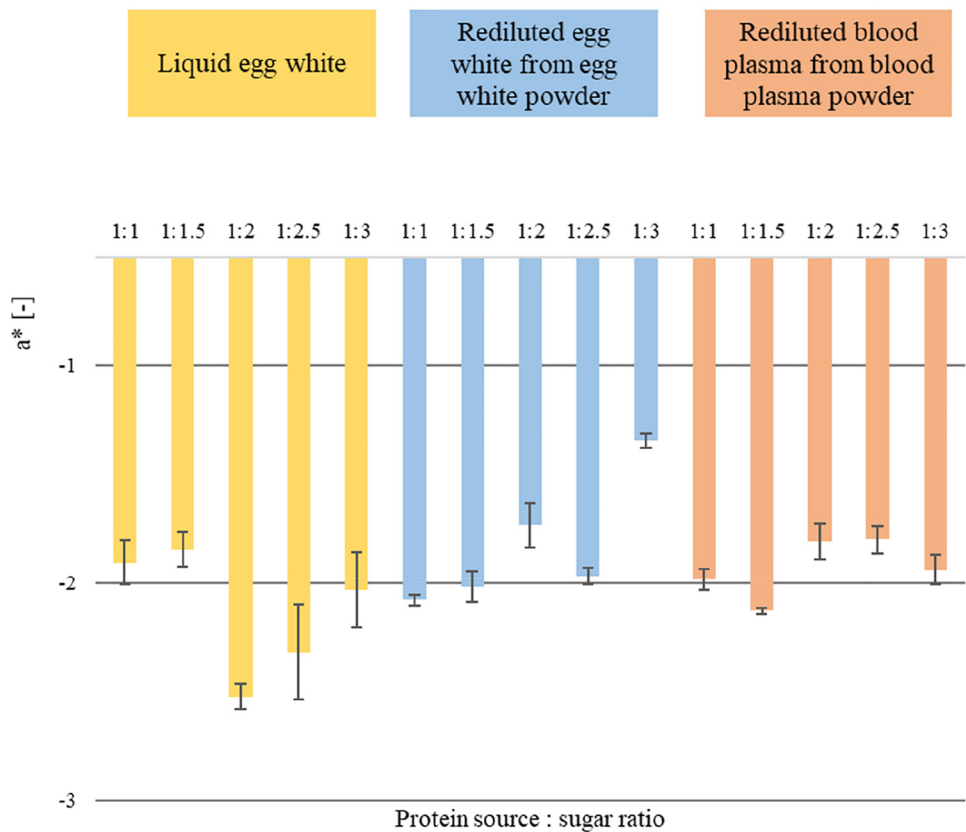


Fig. 4. Redness-greenness (a*) [-] results of meringue sample groups made with different protein sources (liquid egg white, rediluted egg white from egg white powder, rediluted blood plasma from blood plasma powder) and different protein source : sugar ratios (1:1, 1:1.5, 1:2, 1:2.5, 1:3)

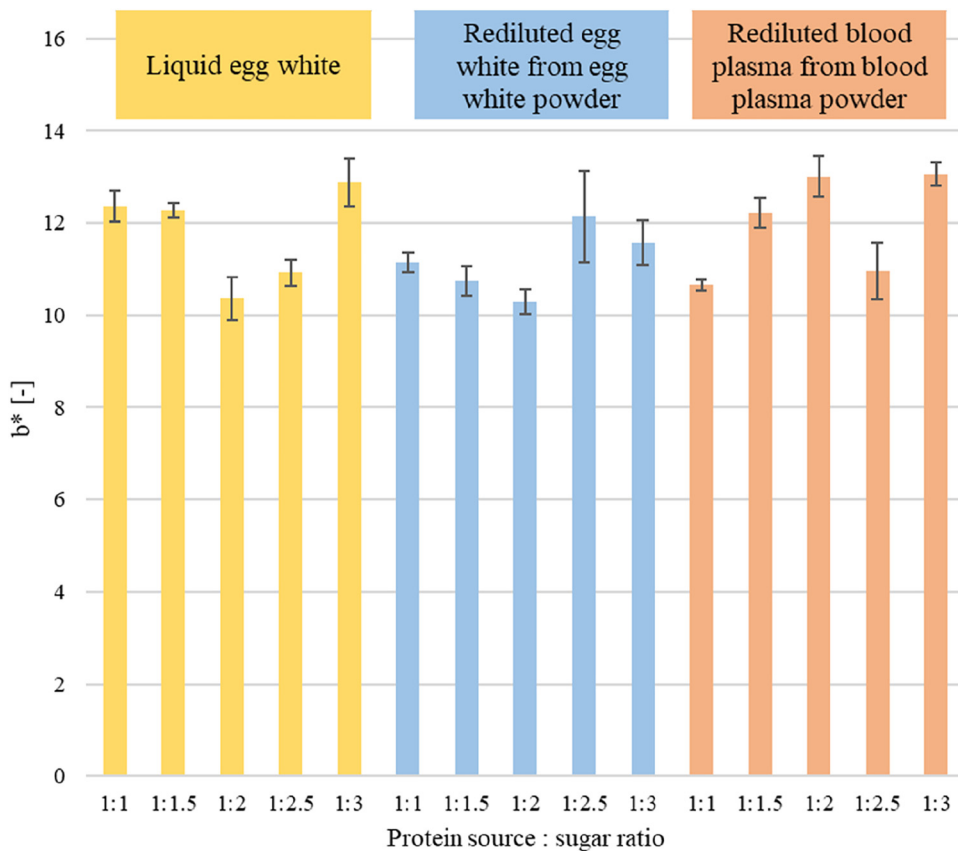


Fig. 5. Yellowness-blueness (b^*) [-] results of meringue sample groups made with different protein sources (liquid egg white, rediluted egg white from egg white powder, rediluted blood plasma from blood plasma powder) and different protein source : sugar ratios (1:1, 1:1.5, 1:2, 1:2.5, 1:3)

factor values were very slightly different from zero, all sample group values were closer to the green colour. The yellow-blue colour factor values showed that all sample groups were closer to the yellow colour. Previous studies also observed similar values for all three colour parameters for a control meringue sample prepared according to a similar recipe (Yüceer and Caner, 2021; Yüceer and Asik, 2020).

In terms of protein source : sugar ratio, the samples with a 1:1 ratio were the darkest based on the lightness factor. These were significantly different from the other sample groups, but the other sample groups did not differ significantly from each other ($P = 0.05$). Similar observations were noted for the red-green colour factor and the yellow-blue colour factor, but the samples with a 1:3 ratio were significantly different from the other samples ($P = 0.05$). The other sample groups were not significantly different from each other ($P = 0.05$).

It is important to highlight that the statistically significant differences were nominally not significant. This can be clearly seen in Fig. 6, which shows photos of the different samples.

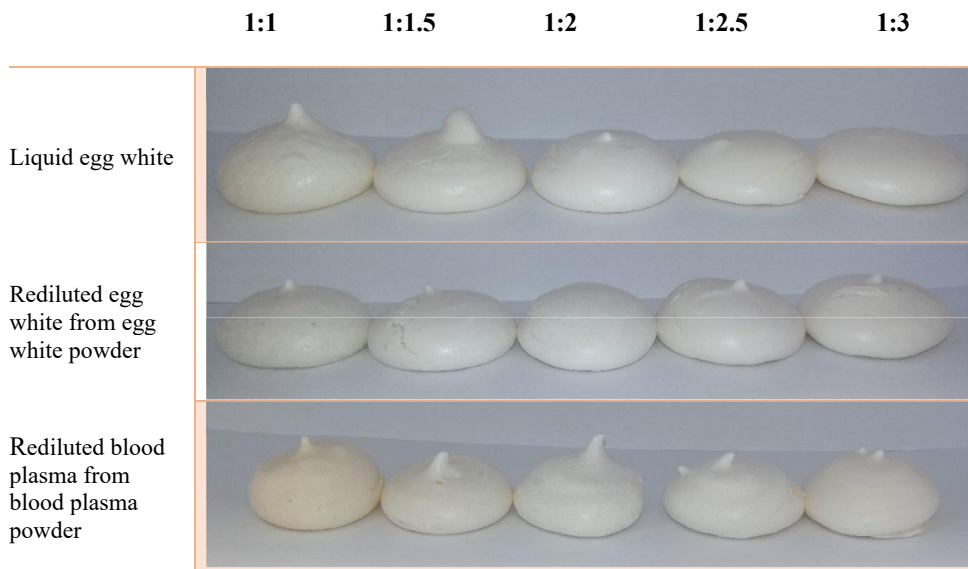


Fig. 6. Picture of meringue samples made with different protein sources (liquid egg white, rediluted egg white from egg white powder, rediluted blood plasma from blood plasma powder) and different protein source : sugar ratios (1:1, 1:1.5, 1:2, 1:2.5, 1:3)

Only the colour of the sample made with blood plasma, with a 1:1 protein source : sugar ratio, can be properly separated from the colour of other samples by the human eye. For this sample group the effects are cumulated: the lightness factor of the sample groups with a 1:1 protein source : sugar ratio was significantly different from the other sample groups, and the lightness factor of the sample groups with blood plasma was also different from the other sample groups.

According to the result of MANOVA, the effects of protein source [Wilks' lambda = 0.037, $F(6.000, 56.000) = 39.132, P < 0.01$] and protein source : sugar ratio [Wilks' lambda = 0.081, $F(12.000, 74.373) = 9.805, P < 0.01$] on colour parameters were significant and very strong. The interaction of protein source and protein source : sugar ratio had also a significant effect on colour parameters [Wilks' lambda = 0.030, $F(24.000, 81.810) = 7.960, P < 0.01$], which was stronger than the two effects separately alone. Although the effects were significant, they made nominally very little difference to the colour parameters.

According to the Tukey post hoc test, all three sample groups prepared with different protein sources were significantly different from each other based on their lightness factor ($P = 0.05$).

In Fig. 6, in addition to colour, the retention of the meringues can be observed. In the case of the LEW, the more sugar added, the less it held its shape at the end of drying in the oven. This may be due to the fact that the sugar crystals melt and liquefy under the influence of heat, softening the whole stock. The yellowing is probably also the result of caramelisation. In the case of the meringues made with RBP, all the meringues had the same good consistency, retention, whereas the parameters of the foam whipping were the same for all samples.

3.5. Sensory evaluation

Meringues made with blood plasma got average 1.88 (in case of 1:1 protein source : sugar ratio) and 2.44 (in case of 1:3 protein source : sugar ratio) ranks, while meringues made with egg white got 3.71–4 ranks to flavour preference. The taste of the meringues with blood plasma was different from the usual meringues, it tasted foreign. For this reason, it received lower scores. However, this flavour was less noticeable or disturbing at higher sugar content, because sample with the higher sugar was scored 23% better on average. Meringues with higher sugar content were much sweeter, and also, the characteristic smell and taste of the protein source was suppressed, making them free from foreign odours. Furthermore, meringues with a higher sugar ratio were harder for the panellists than meringues with a 1:1 ratio.

Ranks of smell preference were between 3.63 and 3.75 with high standard deviation in case of all sample groups. Trend could not be observed in case of smell preference.

In case of texture preference, sample group made with blood plasma with 1:3 protein source : sugar ratio got the highest rank, but ranks were close to each other with high standard deviation. In case of hardness, panellists felt that the samples with higher sugar content were harder. On average, samples with a 1:3 ratio ranked 0.98 points higher than samples with a 1:1 ratio. It is

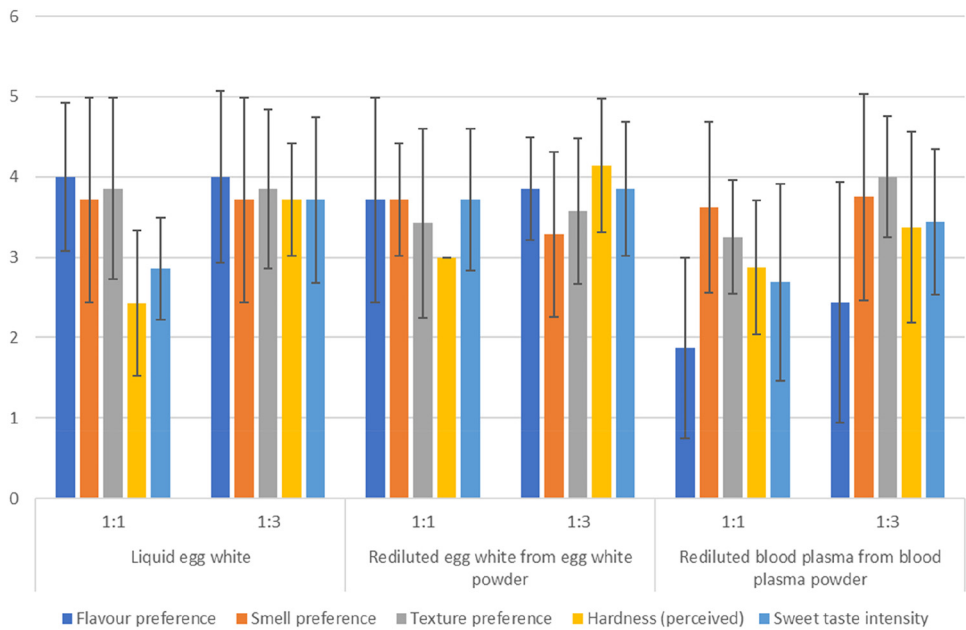


Fig. 7. Evaluated sensory properties (flavour preference, smell preference, texture preference, hardness, sweet taste intensity) of meringue sample groups made with different protein sources (liquid egg white, rediluted egg white from egg white powder, rediluted blood plasma from blood plasma powder) and different protein source : sugar ratios (1:1, 1:1.5, 1:2, 1:2.5, 1:3)

interesting to note that the difference observed for objectively quantified hardness is not reflected in the texture preference. This can be explained by the fact that everyone has different tastes, with some preferring softer and others harder meringues. In a study with increased number of panellists, it may be worthwhile to use cluster analysis to segment the panellists according to their preferences.

When objectively ranked on sweet taste intensity, all panellists perceived the difference between samples with a 1:1 and 1:3 protein source : sugar ratio: samples with a 1:3 ratio scored 0.58 points higher on average.

Interestingly, one of the panellists was allergic to egg, so she could only taste the product with plasma powder. (Due to the small number of panellists and the value of the information that the panellist could provide, we did not exclude her from the analysis. The panellist indicated the allergy after being informed. Only RDP meringues were prepared for her on a thoroughly cleaned tray. Separate storage of samples excluded cross-contamination of samples.) In her opinion, it is a very good alternative and she enjoyed the product. As she cannot eat eggs, there was no comparison for her and she was happy to be able to consume some meringues. An interesting research topic for the future could be to investigate the market potential of products made with animal blood plasma using specifically egg-white allergic panellists.

Sensory results could not be statistically evaluated because of the high standard deviations and non-compliances with conditions of statistical tests. However, trend-like differences can be observed in the results shown in Fig. 7.

4. CONCLUSION

This comprehensive study has delved into the meringue texture, colour, dry matter content, baking loss, and sensory evaluation, with a focus on the influence of protein sources and the protein : sugar ratios. The findings offer insightful contributions to the field of food science, especially in the search for egg white substitutes in foam-based food products. The results of the measured techno-functional properties showed that blood plasma is a perfect substitute for egg white. The effect of the proteins in the two protein sources was very similar in terms of texture, colour and baking loss (and thus dry matter content). In case of sensory properties, with particular regard to the taste preference, for the average consumer, meringues with blood plasma were slightly inferior to meringues with eggs. However, for people with egg allergies who do not consume normal meringue, the difference is not noticeable, and blood plasma products may be beneficial for them. Observable trends suggest that differences in protein source and sugar ratios subtly influence consumer perceptions, an area ripe for further exploration.

The research findings have significant implications for the food industry, particularly in the development of foam-based food products. The equivalence of blood plasma to egg white in texture properties, coupled with minimal differences in colour and sensory perception, positions blood plasma as a viable alternative protein source. This is particularly relevant in the context of dietary restrictions, allergen concerns, or sustainability objectives, where diversification of protein sources is beneficial.

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