THE EFFECT OF THE ADDITION OF DIFFERENT ACIDS ON THE FUNCTIONAL PROPERTIES OF LIQUID EGG WHITE WITH STORAGE

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This study evaluated the impact of phosphoric, citric, and ascorbic acids on the functional properties of liquid egg white over a two-week storage period at 4 °C. The acids, commonly used for preservation, were added to homogenized and pasteurized liquid egg white, reducing its pH from 7.4 ± 0.2 to approximately 5.9 ± 0.1. Specifically, 40 ml of phosphoric acid, 20 ml of citric acid, and 32 ml of ascorbic acid solutions were added. Measurements were taken in week 1 and week 2 to assess changes in viscosity, and foaming properties. Results showed that acid treatment influenced rheological characteristics: phosphoric acid slightly increased structural integrity, citric acid weakened the gel network, and ascorbic acid significantly increased viscosity. Over time, protein degradation altered flow behavior, with viscosity increasing in ascorbic acid-treated samples but generally decreasing in the others. These findings offer insights into how acidification can modify the processing and storage stability of liquid egg white.

Keywords: Liquid egg white, Phosphoric acid, Citric acid, Ascorbic Acid

Introduction

Eggs are among the most versatile and nutritionally valuable ingredients in the food industry, widely used for their unique functional properties such as emulsification, foaming, coagulation, and gelation. Liquid whole egg, which combines both yolk and albumen in a standardized, pasteurized form, is especially valued in commercial food manufacturing for its consistent quality and ease of use (McNamara, 2013). It plays a critical role in bakery products, emulsified sauces, dairy analogs, ready meals, and confectionery, offering emulsifying, foaming, gelling, thickening, and binding properties that are difficult to replicate with synthetic or single-function additives.

Despite these advantages, the functional performance of liquid egg products can be variable and is often affected by multiple factors such as pasteurization temperature, storage time, and protein denaturation (Puglisi & Fernandez, 2022). Additionally, there is an increasing demand from the food industry for egg-based ingredients that not only retain their traditional roles but also perform optimally under modern processing conditions, including high-shear mixing, heat treatment, and prolonged storage. These challenges create a need for the enhancement of liquid egg systems in a way that preserves their natural composition while improving functional reliability and product quality (Hintono et al., 2023).

In recent decades, the egg product industry has continued to innovate, responding to consumer demands for convenience, safety, and specific functional properties. For instance, fractionation processes now allow for the isolation of egg whites and yolks or even specific proteins like ovalbumin and lysozyme, which have applications in food, pharmaceuticals, and cosmetics (Zhang et al., 2023). Today, egg products are a global industry, with trade regulations and technological advancements enabling widespread access to safe, convenient, and functional egg-based ingredients across multiple sectors(Michele Suman et al., 2013). Nowadays approximately 30% of total consumption of eggs is in the form of processed products (Lechevalier et al., 2011).

Liquid egg products require effective preservation methods to maintain their safety, quality, and functionality for use in the food industry. Each preservation method targets specific challenges associated with microbial growth, chemical changes, and storage stability. Pasteurization is widely employed to eliminate pathogens such as Salmonella while retaining the functional properties of the egg proteins, making it an essential step for safety compliance.

Non-thermal preservation techniques, such as high-pressure processing (HPP) and ultraviolet-C (UV-C) irradiation, are increasingly being used to avoid the heat-induced degradation of proteins while ensuring microbial safety. HPP applies high pressure to inactivate microorganisms and extend shelf life without altering the nutritional and functional properties of the liquid egg. UV-C irradiation uses ultraviolet light to achieve microbial reduction and is particularly suited for maintaining the raw characteristics of liquid egg products.

Other innovative methods, such as the addition of natural preservatives like plant, leverage antioxidant and antimicrobial properties to prevent spoilage and improve product stability. Packaging technologies also play a vital role, with oxygen-barrier materials being used to minimize oxidation and quality loss during storage.

Each preservation method addresses specific aspects of liquid egg product stability, ensuring their safe consumption, enhanced usability in food applications, and longer marketability in the food supply chain.

Acidification for example, lowers the pH to inhibit microbial growth, thereby enhancing shelf life while maintaining the natural texture and flavor of the product. The application of food-grade acids is a common approach in food processing to extend shelf life, inhibit microbial growth, and modify functional characteristics. Acids such as citric acid, phosphoric acid, and ascorbic acid are widely accepted in the food industry due to their safety profiles, ease of incorporation, and additional benefits, including antioxidant activity, in the case of ascorbic acid, and pH regulation. The addition of acids to egg white not only reduces the pH but may also induce conformational changes in the protein structure, affecting their gelling capacity, viscosity, and foaming characteristics. These changes, depending on the type and concentration of acid used, can be beneficial or detrimental to the final food product.

This study presents a novel investigation into the impact of food-grade acidification on the functional properties of liquid egg white by systematically evaluating the effects of phosphoric, citric, and ascorbic acids at a fixed concentration during refrigerated storage. Unlike previous research that addressed pH adjustments in egg-based systems, this work examines how specific acid types influence pH modulation, color stability, rheological behavior, and foaming capacity over time. The evaluation was conducted at two storage intervals—week 1 and week 2—providing insight into these properties under cold storage. The primary goal is to determine which acid treatments most effectively preserve or enhance the quality and techno-functional attributes of liquid egg white, with potential implications for extending shelf life and improving performance in food processing applications.

Materials and Methods

Materials

homogenized and pasteurized liquid egg white were obtained from a liquid egg plant (Capriovus Ltd., Szigetcsép, Hungary). Ascorbic acid was obtained from Chem-lab NV (Belgium), both citric acid 99% and phosphoric acid 99% were obtained from Sigma-Aldrich (Germany).

Sample Preparation

A homogenized and pasteurized liquid egg white samples were mixed with different acids. Liquid egg white pH was reduced from 7.4 ± 0.2 to 5.9 ± 0.1, 5.9 ± 0.1 and 5.9 ± 0.1 with phosphoric acid (PA), citric acid (CA) and ascorbic acid (AA) samples respectively, by adding 40 ml of phosphoric acid, 20 ml of citric acid and 32 ml of ascorbic acid solutions to the liquid egg white, then homogenized using robot coupe MiniMP160 mixer (France), color, pH, viscosity, and foaming ability and stability were measured on week 1 and week 2 after storing at 4 °C. Samples that didn't receive any treatment acted as reference sample.
The solution of each acid, which was added, are made by dissolving acids in tap water to reach a solution with pH =1.

pH Measurment

The pH value of liquid egg white samples was measured in triplicate, using a portable pH meter (Testo 206; Testo-AG, Germany) by immersing a pH electrode about 1 cm into the liquid samples.

Color Measurment

The color values of liquid whole eggs were measured using CIELAB (CIE, 1986) scoring system. The following parameters were obtained: L* (lightness), a* redness (+a, red; –a, green), and b* yellowness (+b, yellow; –b, blue) by using Konica Minolta CR-400 colourimeter (Konica Minolta Sensing Inc., Japan) making sure calibration was carried out before taking a reading. Results from L*, a*, and b* were recorded as the mean of five random readings.

Examination of Rheological Properties

At the day of production samples were used to examine the rheological behavior of liquid whole egg, it was done using MCR 92 rheometer (Anton Paar, Les Ulis, France) in rotational mode equipped with a concentric cylinder with a concentric cylinder (cup diameter 28.920 mm, bob diameter 26.651 mm, bob length 40.003 mm, active length 120.2 mm, positioning length 72.5 mm). To control the equipment, Anton Paar RheoCompass software was used. A constant temperature of 15 °C was kept throughout the rheological measurements, shear stress was measured by logarithmically increasing and decreasing shear rate between 1 and 1000 1/s for 32 measurement points and in triplicates for each sample.

Following the literature this study chose Herschel Bulkley model to describe the rheological behavior of liquid whole egg. Herschel Bulkley model is often chosen for liquid egg products because it exhibits a yield stress and shear thinning behavior and this model takes into consideration these factors. (Atılgan & Unluturk, 2008)

Equation (1) was used to analyze the flow curves (shear rate-shear stress diagrams).

$$\tau = \tau_0 + K\dot{\gamma}^n \quad (1)$$

Where:

τ = shear stress (Pa)

τ_0 = the yield stress (Pa)

$\dot{\gamma}$ = the shear rate (1/s)

K = the consistency coefficient (Pas^n)

n = is the flow behavior index.

2.5. The foaming ability and stability measurments

The foaming ability and stability of egg white were evaluated by whipping 100 g of liquid egg white at room temperature (25°C) using a hand mixer (Philips double blend hand mixer, Germany) set at 1,500 rpm for 60 seconds. Immediately after whipping, the foam was transferred into a 100 mL graduated cylinder, and the foam volume was recorded to determine the foaming ability.

The foaming ability was calculated as the percentage increase in volume relative to the initial liquid egg white volume. Seen in the following equation:

$$FA\ \% = ((Vf - Vi)/Vi) * 100\% \quad (2)$$

Where:

FA % = Foaming ability %

Vf =Final Foam Volume (mL)

Vi =Initial liquid egg white Volume (mL)

To assess foam stability, the foam volume was measured at 5, 10, 30, and 60-minute intervals to observe structural retention over time. The percentage of retained foam was then calculated to determine stability using the following equation:

$$FS\% = (Vt / Vf) * 100\% \quad (3)$$

Where:

Fs % = Foaming Stability %

Vt =Foam Volume at Specific Time (mL)

Vf =Initial Foam Volume After Whipping (mL)

Results

Liquid egg white pH was reduced from 7.4 ±0.1 to 5.9±0.1, 5.9±0.2 and 5.9±0.1 for phosphoric acid, citric acid and ascorbic acid samples respectively by adding 40 ml of phosphoric acid, 20 ml of citric acid and 32 ml of ascorbic acid solutions to the liquid egg white, then color, and viscosity were measured. Samples were stored for 7 days at 4°C then again pH, color, and viscosity were measured.

pH results

Liquid egg white pH was reduced from 7.4 ±0.1 to 5.9±0.1, 5.9±0.2 and 5.9±0.1 for phosphoric acid, citric acid and ascorbic acid samples respectively by adding 40 ml of phosphoric acid, 20 ml of citric acid and 32 ml of ascorbic acid solutions to the liquid egg white. As mentioned in the methods part the acids were prepared by being dissolved in tap water to lower its pH to 1. The pH behavior of liquid egg white during storage was influenced by the type of acid added and potential biochemical changes occurring over two weeks. Initially, the pH of fresh liquid egg white was 7.4± 0.1, which was lowered to 5.9 ± 0.1 using phosphoric acid, citric acid, and ascorbic acid. However, after two weeks of storage at 4°C, pH changes were observed across different treatments, with a more notable pH decline in the phosphoric acid-treated sample. Figure 1 shows the effect of these acids on the pH values of liquid egg white for the first and second week. The control sample, which did not receive any acid treatment, maintained its natural alkalinity during the first week, with a measured pH of 7.4 ± 0.1. By the second week, however, the pH slightly increased to 7.59± 0.3., reflecting a trend toward greater alkalinity over time.

The phosphoric acid-treated sample displayed the most substantial pH changes. In the first week, the pH was measured at 5.8 ± 0.1, indicating an initial drop from the natural baseline. By the second week, this value declined even further, reaching 4.86 ± 0.1, the lowest pH observed across all treatments and time points. This suggests a continued acidification trend over the storage period. In the citric acid-treated sample, the pH remained relatively stable. The value was recorded at 5.9 ± 0.1 during the first week and slightly increased to 6.02 ± 0.2 in the second week. Despite this minor increase, the overall variation was minimal, and the sample showed consistent stability in pH over time. The ascorbic acid-treated sample also began with a pH of 5.9 ± 0.1 in the first week, but pH slightly inceased to 6.1± 0.1 for the second week, the initial pH value placed it in the same range as the citric acid sample.

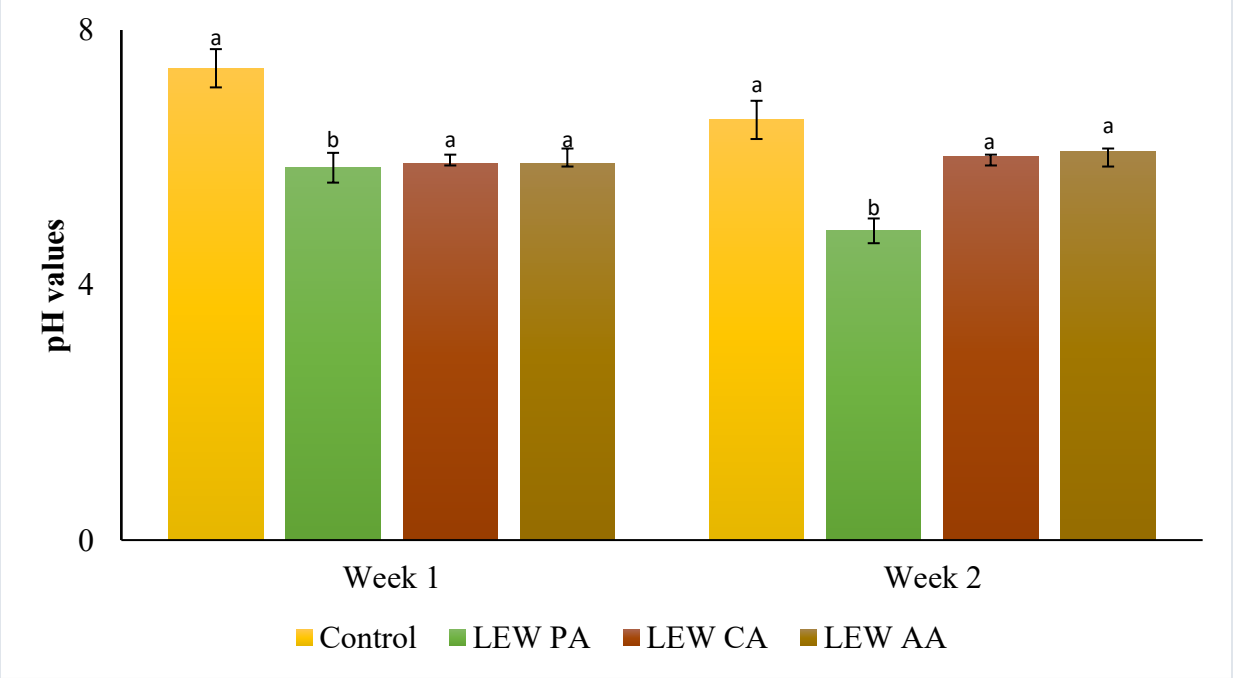


Figure1: The effect of adding different acids to liquid egg white pH values during 2 weeks of storage.

Color Results

In the initial week of storage, the control sample exhibited relatively high L* values, indicating a brighter appearance, accompanied a* negative which indicates an increase in green hue and b* positive yellowish hue, typical of fresh liquid egg white. The a* values remained slightly negative,

reflecting the presence of green tones, while the b* values were moderately high due to the presence of natural yellow pigments such as riboflavin.

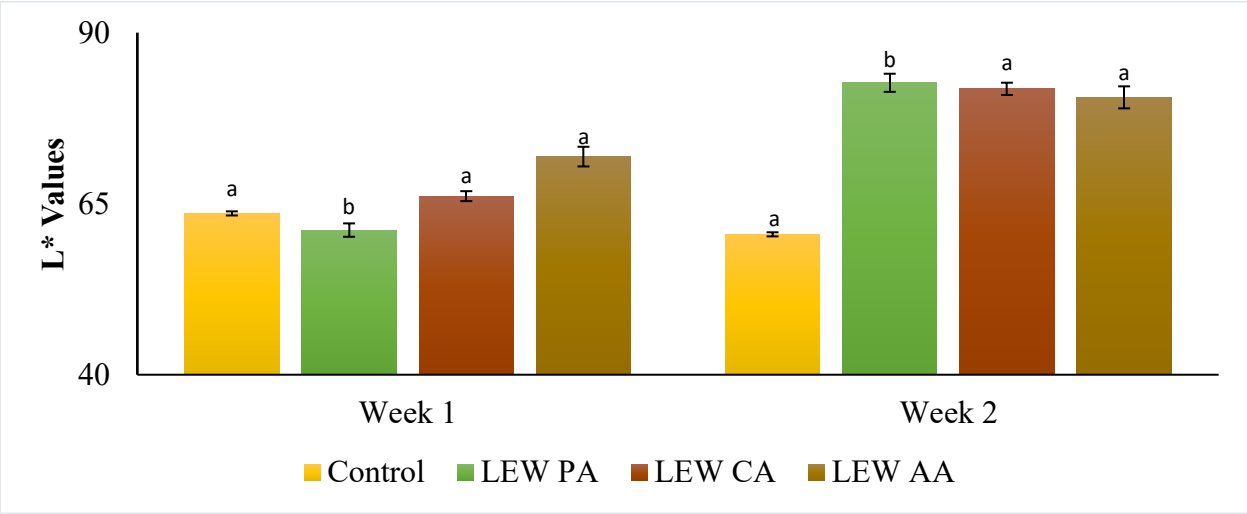
Upon treatment with different acids, variations in color parameters became apparent. In Week 1, the sample treated with phosphoric acid showed a marked reduction in L* values compared to the control, indicating a darker appearance. The L* value of the phosphoric acid-treated sample was the lowest among all treatments. In contrast, citric acid and ascorbic acid treatments led to noticeable increases in L* values, signifying an enhancement in brightness. Among these, the ascorbic acid -treated sample recorded the highest L* value, indicating the most prominent lightening effect at this stage.

In terms of the a* parameter, all acid-treated samples showed more negative values compared to the control, suggesting a shift towards greener tones. The citric acid-treated sample exhibited the most negative a* value, indicating the strongest green shift, followed by phosphoric acid and then ascorbic acid. The a* value for the control remained close to zero, indicating minimal deviation from neutral tones.

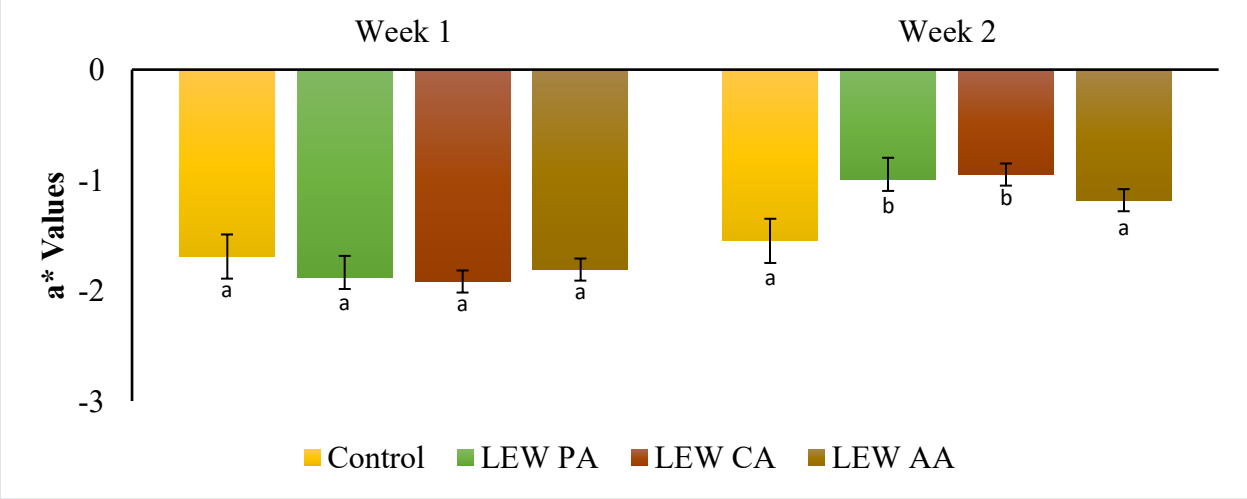
Regarding the b* values, all acid treatments resulted in a decrease compared to the control. The phosphoric acid and citric acid treatments produced the lowest b* values, indicating a reduction in yellow intensity. The ascorbic acid-treated sample showed a less pronounced reduction in b*, maintaining some of the yellow characteristics of the control. Overall, acid addition in Week 1 led to significant modifications in the chromatic properties of the samples.

By Week 2, the L* values increased across all acid-treated samples compared to Week 1, with phosphoric acid and citric acid treatments yielding the highest L* values, followed by ascorbic acid. The control sample maintained a consistent L* value with insignificant change. The a* values of all acid-treated samples became less negative, with the most substantial increases observed in phosphoric acid and citric acid samples, indicating a movement toward zero. The ascorbic acid-treated sample also showed an increase in a* values, though the change was comparatively insignificant. The b* values decreased further in all acid-treated samples compared to Week 1, with the lowest values recorded in phosphoric acid and citric acid treatments, followed by ascorbic acid. The control sample's b* values remained relatively unchanged. Across all color parameters the changes were greater in Week 2 than Week 1, with phosphoric acid and citric acid treatments producing the most significant deviations from the control values. All acid-treated samples showed a change in color attributes over time, with

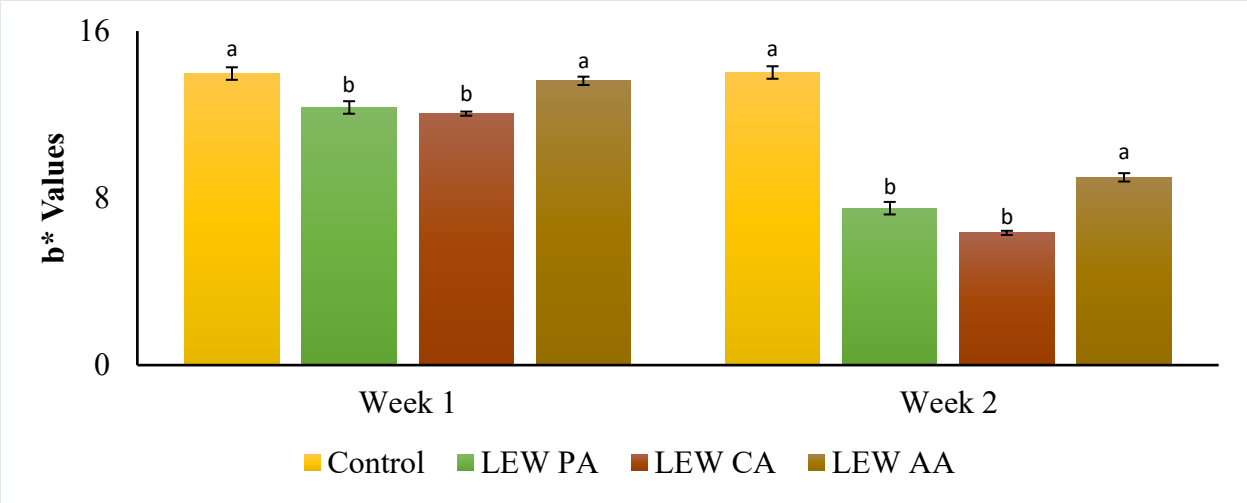
progressive increases in brightness, reductions in yellow intensity, and shifts toward less green coloration. The differences between treatments became more distinct over the two-week period.



(a)



(b)



(c)

Figure 2: The effect of adding different acids to liquid egg white on color parameter: (a) L* values, (b) a* values, (c) b* values, during 2 weeks of storage in comparison to the control group.

Change in rheological properties

In the initial week of storage, the rheological parameters of liquid egg white demonstrated distinct variations among the control and acid-treated samples. The yield stress (τ_0), which indicates the minimum stress required to initiate flow (Lang & Rha, 1982), was recorded at 0.087 ± 0.001 Pa in the control sample. Treatment with phosphoric acid resulted in a slight increase in τ_0 to 0.089 ± 0.001 Pa. In contrast, citric acid treatment led to a reduction in τ_0, decreasing it to 0.080 ± 0.001 Pa. The ascorbic acid-treated sample showed a marginally lower τ_0 value of 0.086 ± 0.001 Pa compared to the control, indicating a minor variation.

The consistency coefficient (K), which reflects the viscosity characteristics of the samples under shear (Lang & Rha, 1982), also differed notably across treatments. The control sample exhibited a K value of 0.189 ± 0.001 $Pa \cdot s^n$. Phosphoric acid treatment led to a decrease in K to 0.173 ± 0.001 $Pa \cdot s^n$, while the citric acid-treated sample showed a slightly higher value at 0.181 ± 0.001 $Pa \cdot s^n$, though still lower than the control. Interestingly, the sample treated with ascorbic acid demonstrated the highest K value among all treatments, reaching 0.316 ± 0.001 $Pa \cdot s^n$, which suggests a substantial change in the sample's flow consistency.

The flow behavior index (n), which describes the extent of non-Newtonian behavior (Lang & Rha, 1982), also varied among treatments. The control sample recorded an n value of 1.563 ± 0.071. A slight reduction was observed in the phosphoric acid-treated sample with an n value of

1.525 ± 0.021, and the citric acid treatment yielded an n value of 1.544 ± 0.051. The lowest n value was observed in the ascorbic acid-treated sample at 1.480 ± 0.061, indicating the greatest deviation from Newtonian flow behavior in the first week.

After two weeks of refrigerated storage, the rheological properties of the samples underwent further alterations. The control sample exhibited a decline in τ_0, dropping from its initial value of 0.087 ± 0.001 Pa to 0.080 ± 0.001 Pa. The phosphoric acid-treated sample followed a similar trend, decreasing from 0.089 ± 0.001 Pa to 0.080± 0.004 Pa. The most pronounced reduction was seen in the citric acid-treated sample, where τ_0 decreased from 0.080 ± 0.001 Pa to 0.075 ± 0.001 Pa. In contrast, the ascorbic acid-treated sample showed an increase in τ_0, rising from 0.086 ± 0.001 Pa to 0.090± 0.002 Pa, indicating a different behavior over time compared to the other treatments.

The K values showed noticeable changes during the second week. The control sample's K value dropped from 0.189 ± 0.001 $Pa \cdot s^n$ to 0.170 ± 0.001 $Pa \cdot s^n$. The phosphoric acid-treated sample also experienced a decrease in K, falling from 0.173 ± 0.001 $Pa \cdot s^n$ to 0.170 ± 0.001 $Pa \cdot s^n$. The citric acid treatment showed the greatest reduction in consistency, with K declining from 0.181 ± 0.001 $Pa \cdot s^n$ to 0.150 ± 0.001 $Pa \cdot s^n$. On the other hand, the ascorbic acid-treated sample exhibited an increase in K, from 0.316 ± 0.001 $Pa \cdot s^n$ to 0.350 ± 0.001 $Pa \cdot s^n$, further differentiating its behavior from the other samples and indicating a unique evolution in viscosity over time.

As for the flow behavior index (n), the control sample showed a slight increase from 1.563 ± 0.071 to 1.570 ± 0.871. The citric acid-treated sample also exhibited a small increase in n, from 1.544 ± 0.181 to 1.550 ± 0.632, reflecting similar changes. The phosphoric acid-treated sample remained relatively stable, with a minor increase in n from 1.525 ± 0.342 to 1.530 ± 0.602. In contrast, the ascorbic acid-treated sample showed a further decrease in n from 1.480 ± 0.061 to 1.450 ± 0.670, marking a continued shift toward more pronounced non-Newtonian flow characteristics.

Table1: Measured results of Herschel-Bulkley model at different acids addition to liquid egg white in comparison to control group. * are for significantly different groups (Tukey's $p<0.05$).

Sample	τ_0 (Pa)	K ($Pa.s^n$)	n
Conrtol week1	0.087 ± 0.001	0.189 ± 0.001*	1.563 ± 0.071

Control week 2	0.080 ± 0.001*	0.170 ± 0.001*	1.570 ± 0.871
PA week 1	0.089 ± 0.001	0.173 ± 0.001*	1.525 ± 0.342*
PA week 2	0.080± 0.004*	0.170 ± 0.001*	1.530 ± 0.602*
CA week 1	0.080 ± 0.001*	0.181 ± 0.001*	1.544 ± 0.051*
CA week 2	0.075 ± 0.001*	0.150 ± 0.001*	1.550 ± 0.632*
AA week 1	0.086± 0.001	0.316 ± 0.001*	1.480 ± 0.061*
AA week 2	0.090± 0.002*	0.350 ± 0.001*	1.450 ± 0.670*

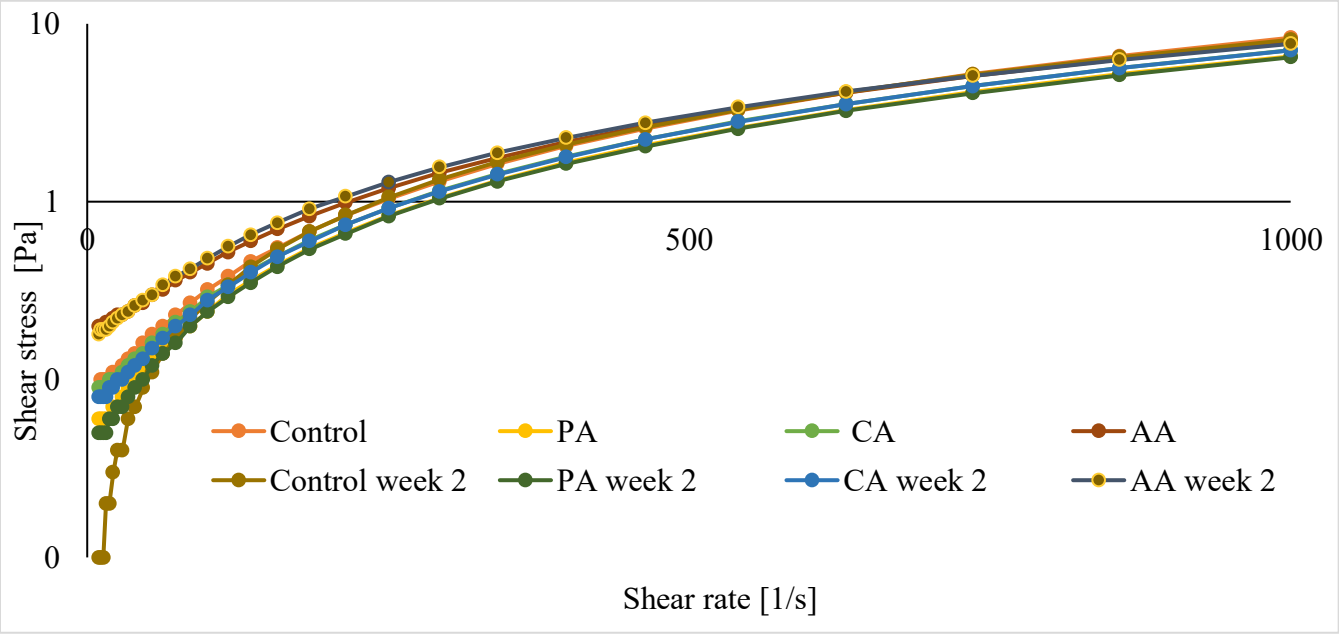


Figure 3: The flow curve (shear rate vs. shear stress) of added different acids to liquid egg white sample for 2 weeks of storage.

Foaming ability and stability

Table 2 shows the fomaing ability of liquid egg white samples treated with different acids, after a week and 2 weeks of storage. In comparison to the control group which had a foaming ability of 50% ± 1.2%, the foaming ability of liquid egg white remained unchanged in samples treated with phosphoric acid with 50% ± 0.9% and citric acid with 50% ± 1.1 indicating no significant difference. However, the sample treated with ascorbic acid showed a significantly lower foaming ability 37.5% ± 1.1%, $p < 0.05$ relative to the control.

As for the second week of storage, all samples showed a decline in foaming ability compared to week 1 within treatment but phosphoric acid and citric acid treatments should an increase when compared to the results of control samples on the second week of storage. The control sample decreased to 35% ± 1.3%, while the phosphoric acid and citric acid treatments showed higher values at 40% ± 0.7% and 42.5% ± 0.3%, respectively, though statistical significance was not indicated. The ascorbic acid-treated sample further declined to 30% ± 0.8%, which was lower than the control but also not marked as significantly different.

Table 2: foaming ability of liquid egg white samples treated with different acids, after a week and 2 weeks of storage. * are for significantly different groups (Tukey's $p<0.05$).

Sample	Control	PA	CA	AA
Week 1	50%±1.2%	50±0.9%	50±1.1%	37.5±1.1%*
Week 2	35±1.3%	40±0.7%	42.5±0.3%	30±0.8%

The foaming stability of liquid egg white samples showed variation across treatments and storage duration. In week 1, the control sample had a foaming stability of 28.3% ± 1.0%, while the phosphoric acid and citric acid treated samples both showed slightly higher values at 30.0% ± 0.8% and 30.0% ± 1.2%, respectively. The ascorbic acid treated sample exhibited the lowest foaming stability at 27.3% ± 1.3%.

By week 2, all samples experienced a reduction in foaming stability. The control sample decreased to 24.1% ± 1.2%, phosphoric acid -treated to 26.8% ± 1.2%, and citric acid -treated to 28.1% ± 1.1%. The ascorbic acid -treated sample showed the lowest value, decreasing further to 23.1% ± 1.7%.

Table 3: foaming ability of liquid egg white samples treated with different acids, after a week and 2 weeks of storage.

Sample	Control	PA	CA	AA
Week 1	28.3%±1.0%	30.0%±0.8%	30.0%±1.2%	27.3%±1.3%
Week 2	24.1%±1.2%	26.8%±1.2%	28.1%±1.1%	23.1%±1.7%

Discussion

The pH of liquid egg white plays a critical role in determining its functional and microbiological stability. Fresh liquid egg white is naturally alkaline, with an initial pH of approximately 7.4±0.1, largely due to the presence of carbonates and basic amino acids. Upon acidification using phosphoric acid, citric acid, and ascorbic acid, the pH was reduced to a target value of 5.9±0.1. This adjustment aimed to assess the comparative influence of different acids on the physicochemical behavior of the liquid egg white during refrigerated storage.

The control sample, which remained untreated, exhibited a modest but notable increase in pH from 7.4 ± 0.1 to 7.59 ± 0.3 over the two-week storage period. This upward trend may be attributed to microbial metabolism or protein degradation, both of which can release basic compounds such as ammonia or other amine derivatives, leading to a shift toward alkalinity. Similar increases in pH during storage have been previously reported in unacidified egg products, supporting the observation that the absence of acidification allows endogenous and microbial biochemical reactions to progress with minimal buffering.

Among the acidified samples, the phosphoric acid-treated group showed the most pronounced acidification during storage. While the initial pH was 5.9 ± 0.1, it declined significantly to 4.86 ± 0.1 by the second week. This continued pH reduction suggests that phosphoric acid not only effectively lowered the initial pH but also possibly enhanced biochemical transformations during storage that favored the release of additional acidic byproducts. These could include phosphate-mediated protein modifications or enzymatic reactions promoting the generation of organic acids. The enhanced acidity in the phosphoric acid-treated group offer additional microbial protection, which is beneficial from a preservation standpoint, though its impact on functional and sensory properties warrants further investigation (H.K. Yavuz & M.M. Özcan, 2018).

In contrast, the citric acid-treated sample maintained a relatively stable pH profile over time. Starting at 5.9 ± 0.1, it slightly increased to 6.02 ± 0.2 after two weeks, suggesting a strong buffering capacity and relative biochemical inertness compared to phosphoric acid. Citric acid is a tricarboxylic acid with chelating properties, which may limit protein-metal interactions that contribute to pH shifts during storage. This buffering effect likely helped to preserve the structural and functional integrity of egg white proteins, making citric acid a promising acidulant for maintaining stability (Książek, 2023).

Similarly, the ascorbic acid-treated sample began with a pH of 5.9 ± 0.1 and increased marginally to 6.1 ± 0.1. Though ascorbic acid has known antioxidant and reductive properties, which can lead to oxidative reactions under certain storage conditions, its behavior in this study more closely resembled that of citric acid. The mild increase in pH could be due to oxidative degradation of ascorbic acid itself or interactions with reactive species in the protein matrix, resulting in a partial loss of acidity over time. However, the overall change was limited, indicating that ascorbic acid also imparted a relatively stable pH environment (Yin et al., 2022).

Color is a key quality parameter for liquid egg white, often reflecting both freshness and physicochemical changes induced by treatment or storage. The L*, a*, and b* values observed in this study demonstrated that acid treatments significantly altered the chromatic attributes of liquid egg white over time.

In the first week, phosphoric acid treatment resulted in a notable decrease in L* values, indicating a darker appearance, due to protein-acid interactions or minor pigment transformations (Chang et al., 2016). Conversely, citric and ascorbic acids increased L* values, with ascorbic acid producing the brightest samples, suggesting a whitening effect that may be related to pigment bleaching or light scattering from protein modification.

The a* values across all acid-treated samples were more negative than the control, reflecting a shift toward green tones. Citric acid induced the most negative a* values, possibly linked to changes in pigment state or protein conformation (Tan et al., 2022). These shifts diminished by Week 2, as a* values approached neutrality, indicating stabilization or partial reversion of initial color changes (Katekhong & Charoenrein, 2017).

Reductions in b* values following acid addition indicate a loss of yellow coloration, potentially due to the destabilization of riboflavin or other yellow chromophores. Phosphoric and citric acids led to the most pronounced decline, while ascorbic acid showed a milder effect. This trend continued in Week 2, reinforcing the progressive reduction in yellow intensity across all treatments (Katekhong & Charoenrein, 2017).

The rheological properties of liquid egg white were significantly influenced by acid type and storage duration. Yield stress (τ_0) showed minimal variation in Week 1, with phosphoric acid slightly increasing τ_0 and citric acid reducing it, suggesting minor effects on initial structural

rigidity. Ascorbic acid had little influence in the short term but uniquely increased τ_0 after two weeks, indicating potential protein structuring over time (Ahmed et al., 2007).
Changes in the consistency coefficient (K) were more pronounced. Ascorbic acid significantly increased K in both weeks, indicating enhanced viscosity, due to protein interactions or stabilization effects. In contrast, all other treatments, including the control, showed a decline in K over time, with citric acid causing the most notable drop, reflecting reduced consistency.
The flow behavior index (n) values suggested that all samples exhibited pseudoplastic behavior, with slight treatment-related differences. The lowest n values in ascorbic acid-treated samples indicate a more shear-thinning nature, which became more pronounced over time. This contrasts with the relatively stable or slightly increasing n values in the other samples, suggesting limited structural evolution (Weijers et al., 2006).
Overall, ascorbic acid demonstrated a unique rheological profile characterized by increasing yield stress and consistency, coupled with greater shear-thinning behavior over storage.

The foaming ability and stability of liquid egg white were influenced by acid type and storage duration, with notable differences observed between treatments and across the two-week refrigerated period. In the first week, both phosphoric acid and citric acid treatments preserved foaming ability at levels comparable to the control, suggesting minimal interference with protein unfolding and air incorporation mechanisms (Bovšková & Míková, 2011). In contrast, ascorbic acid treatment significantly reduced foaming ability, possibly due to protein structural modifications or aggregation that impaired interfacial film formation, critical for foam development (Ding et al., 2022). After two weeks, a general decline in foaming ability was evident in all samples, consistent with protein deterioration or aggregation over time. However, phosphoric acid and citric acid treatments maintained higher foaming ability than the control, suggesting a potential protective effect against functional degradation during storage. Although these differences were not statistically significant, they imply that phosphoric acid and citric acid may help retain the interfacial activity of egg white proteins better than the control or ascorbic acid treatments. The ascorbic acid-treated sample showed the most pronounced decline, further supporting its detrimental effect on foaming capacity, likely due to pH-induced protein conformational changes or oxidative instability (Mohammadi Nafchi et al., 2013).

Foaming stability followed similar trends, where phosphoric acid and citric acid treatments consistently showed slightly improved stability compared to the control across both time points. At week 1, phosphoric acid and citric acid samples exhibited a higher stability, compared to the control, while the ascorbic acid-treated sample had the lowest value. By week 2, all samples declined, yet citric acid maintained the highest foaming stability, followed by phosphoric acid, with ascorbic acid showing the lowest stability .These results suggest that citric and phosphoric acids may enhance protein network integrity at the air–liquid interface over time, thereby moderating foam collapse (Bovšková & Míková, 2011). Conversely, the continual decline in foaming performance observed with AA may be attributed to its reductive properties affecting protein cross-linking or destabilizing protein networks essential for foam retention (Mohammadi Nafchi et al., 2013).

Conclusions

This study demonstrated that the type of acid added to liquid egg white, significantly influences its functional properties during refrigerated storage. Although ascorbic acid was initially considered a promising additive for its nutritional benefits, the results of this study reveal that its application in liquid egg white compromises key functional properties during refrigerated storage. Ascorbic acid significantly reduced foaming ability and flow consistency while intensifying non-Newtonian behavior, making it less suitable for maintaining the techno-functional quality of the product. Phosphoric and citric acids maintained or slightly enhanced rheological stability and foaming properties over the two-week period, meanwhile, ascorbic acid adversely affected both rheological parameters and foaming performance, particularly reducing foaming ability and flow consistency. Overall, the findings highlight that acid selection plays a critical role in determining the techno-functional stability of liquid egg white, with implications for its processing and shelf-life in food applications.

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