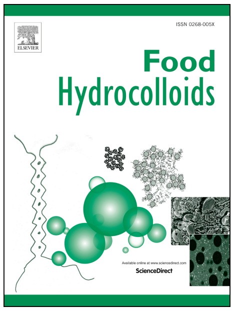

Chickpea cooking water (Aquafaba): Technological properties and application in a model confectionery product

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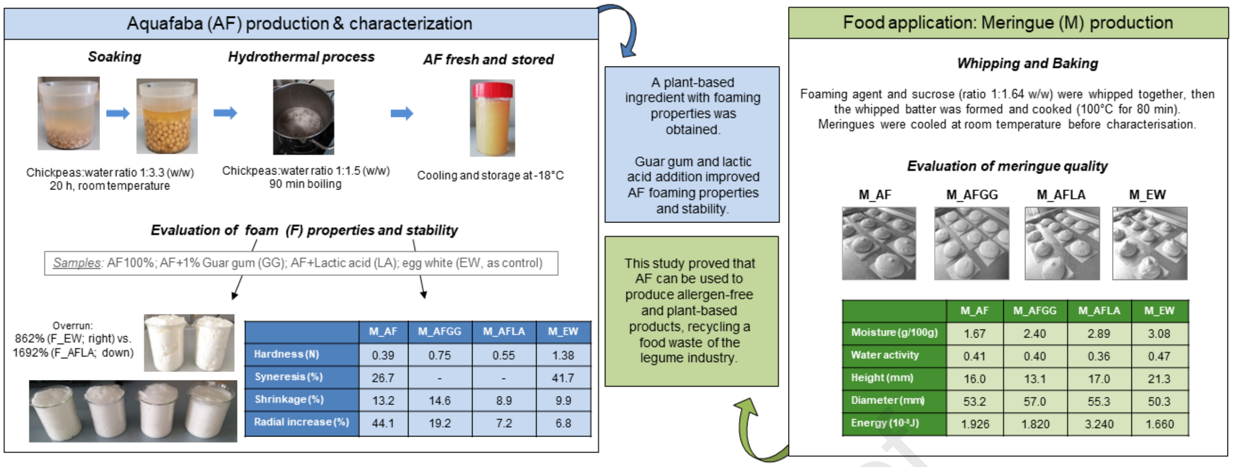

Aquafaba (AF) production & characterization

Soaking

Chickpeas:water ratio 1:3.3 (w/w)
20 h, room temperature

Hydrothermal process

Chickpeas:water ratio 1:1.5 (w/w)
90 min boiling

AF fresh and stored

Cooling and storage at -18°C

Evaluation of foam (F) properties and stability

Samples: AF100%; AF+1% Guar gum (GG); AF+Lactic acid (LA); egg white (EW, as control)

Overrun:
862% (F_EW; right) vs.
1692% (F_AFLA; down)

	M_AF	M_AFGG	M_AFLA	M_EW
Hardness (N)	0.39	0.75	0.55	1.38
Syneresis (%)	26.7	-	-	41.7
Shrinkage (%)	13.2	14.6	8.9	9.9
Radial increase (%)	44.1	19.2	7.2	6.8

A plant-based ingredient with foaming properties was obtained.

Guar gum and lactic acid addition improved AF foaming properties and stability.

This study proved that AF can be used to produce allergen-free and plant-based products, recycling a food waste of the legume industry.

Food application: Meringue (M) production

Whipping and Baking

Foaming agent and sucrose (ratio 1:1.64 w/w) were whipped together, then the whipped batter was formed and cooked (100°C for 80 min). Meringues were cooled at room temperature before characterisation.

Evaluation of meringue quality

M_AF **M_AFGG** **M_AFLA** **M_EW**

	M_AF	M_AFGG	M_AFLA	M_EW
Moisture (g/100g)	1.67	2.40	2.89	3.08
Water activity	0.41	0.40	0.36	0.47
Height (mm)	16.0	13.1	17.0	21.3
Diameter (mm)	53.2	57.0	55.3	50.3
Energy (10^{-3}J)	1.926	1.820	3.240	1.660

Chickpea cooking water (Aquafaba): Technological properties and application in a model confectionery product

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Abstract

This study aimed at evaluating the techno-functionalities of chickpea cooking water (aquafaba, AF) produced from dry chickpeas, and investigating its application in a model confectionary product. Pasteurized egg white (EW) was used as the reference sample. The addition of guar gum (GG; 1% of AF) and acidification with lactic acid (LA; down to pH 4) were explored to enhance AF foaming capacity and stability. The presence of GG hydrocolloid helped increase foam (F) stability (i.e., F_AFGG showed no syneresis in comparison to the 27% of F_AF) and hardness (+92% than F_AF), while acidification doubled overrun. Significantly ($p<0.05$) different foaming stabilities (i.e., syneresis, geometrical indices and air bubble coalescence) up to 120 min at 6±2°C were evidenced according to the foaming agent used. The technological properties of meringues made by using the different foaming agents and sucrose (ratio 1:1.64 w/w) were also investigated. The presence of hydrocolloid resulted in the highest whipped batter density (0.59g/mL) and the lowest baking loss (30.6%) associated with intermediate water activity (0.398) and moisture content (2.40g/100g) but the lowest height (13.1mm). Conversely, acidification improved AF performance in terms of meringue height (17mm) and texture ($3.24*10^{-3}$J). This study proved that AF, a recycled ‘waste’ product, possesses interesting technological properties - further enhanced by adding GG and LA - usable for plant-based food applications.

Key words: *Aquafaba, guar gum, acidification, foaming properties, texture, egg/gluten-free (vegan) meringues*

1. Introduction

Plant-based foods are finished products consisting of ingredients derived from plants that include vegetables, fruits, grains, nuts, seeds and legumes. The number of these types of products has been spreading exponentially thanks to increasing consumer demand for vegetarian, vegan and other alternatives to animal products (Lee & Okos, 2011; Alcorta, Porta, Tárrega, Alvarez, & Vaquero, 2021); however, they often test poorly for texture and sensory acceptability when compared with conventional products (Geera et al. 2011; Ghazaei, Mizani, Piravi-Vanak, & Alimi, 2015; Herald, Aramouni, & Abu-ghoush, 2008). Legumes (e.g., chickpeas, peas, lentils) are sources of proteins, starch, vitamins, minerals and essential aminoacids (e.g., lysine is commonly used to replace animal proteins in our diet), and have foaming, emulsifying, gelling and thickening properties used primarily for mayonnaise, cheese, ice cream, chocolate, and baked goods (Alcorta et al., 2021; Boye, Zare, & Pletch, 2010; Geera et al. 201; He, Meda, Reaney, & Mustafa, 2021; Herald et al., 2008; Stantiall, Dale, Calizo, & Serventi, 2018).

Aquafaba is the raw material obtained by soaking and cooking chickpeas in boiling water or by applying high pressures, or the liquid contained in commercially canned chickpeas (Serventi, 2020). The traditional process to produce aquafaba (AF) consists of three steps: 1. soaking dry chickpeas to allow water permeation into the legume to reduce subsequent cooking time and to facilitates the leaking out of anti-nutritional compounds; 2. draining the chickpeas to reduce anti-nutritional compounds in the soaking water (e.g., saponins, phytic acid, α-galactosidase, oxalates, proteolytic enzymes, trypsin inhibitors; Frias, Vidal-Valverde, & Sotomayor, 2000) and 3. boiling or high pressure cooking (Serventi, 2020). In the last few years, many studies have focused on the optimization of the boiling process, mainly in terms of chickpeas:cooking water ratio, boiling time and pH (Bird, Pilkington, Saputra, & Serventi, 2017; Serventi, Wang, Zhu, Liu, & Fei, 2018; Stantiall et al., 2018; Lafarga, Villaró, Bobo, & Aguiló-Aguayo , 2019). During cooking, approximately 5 to 8 g/100g of the total solids are transferred to the water (Serventi et al., 2018) and their chemical composition can be broken down as follows (Bird et al., 2017; Stantiall et al., 2018): 1.2 g/100g of low water-soluble carbohydrates, 0.04 g/100g of high water-soluble carbohydrates, 2.4 g/100g of insoluble fiber, 1.0 g/100g of protein, 0.6 g/100g of ash and 4.5 mg/g of saponins. Similar results were reported by Alsalman, Tulbek, Nickerson, & Ramaswamy (2020), Damian et al. (2018) and He et al. (2021) for AF obtained from dry or canned chickpeas. Buhl, Christensen, & Hammershøj (2019) showed that the protein content of AF at pH 4.5 is 13.65 g/L and most of the water-soluble proteins have low molecular weight (≤24 kDa). The presence of proteins, carbohydrates and saponins confers emulsion, gelling and foaming properties (Serventi et al., 2020) to AF that can be used in the production of plant-based products. It is known that proteins can aggregate at the air-water or water-oil interface lowering the surface tension and allowing the incorporation of air bubbles or oil drops that form a cohesive film with sufficient elasticity to stabilize foams and emulsions (Klamczynska, Czuchajowska & Baik, 2001; Mariotti, Pagani, & Lucisano, 2013; Wu, Clifford, & Howell, 2007). Instead, polysaccharides have thickening properties that enable them to retain water and improve foam and emulsion stability by gelling or modifying the viscosity of the aqueous phase (Bouyer, Mekhloufi, Rosilio, Grossiord, & Agnely, 2012). Furthermore, the absorption of water by low molecular weight soluble carbohydrates and proteins contributes to the gelling properties of AF (Serventi et al., 2018; Stantiall et al., 2018). According to Chung, Sher, Rousset, Decker, & McClements, saponins are still used in the food industry as emulsifying and foaming agents. For instance, Mustafa, He, Shim, & Reaney (2018) demonstrated that AF from canned chickpeas has a foaming capacity (i.e., overrun) similar or even higher compared to commercial and fresh egg white (180-475% vs. 281% and 311%, respectively). Contrary results were found by Stantiall et al. (2018) who reported overrun values of 400% for egg white and 58% for aquafaba. This discrepancy can be partially explained by the different whipping times applied: 7 min by Stantiall et al. (2018) and 15 min by Mustafa et al. (2018) who noticed aquafaba needed more time in comparison to egg white, for an increase in AF foaming capacity (+19%). Instead, Buhl et al. (2019) showed that changing the pH (from 3 to 8.5) of canned chickpea AF diminished the foaming capacity; however, foam stability increased near the pH isoelectric point (4.6). Aquafaba can also be used as a vegetal gelling agent for mousse or baked goods by using it as a fat replacer (Beeber et al., 2019). Since AF is a vegan product, gluten-free and cholesterol-free, its application as a structuring and foaming agent (to replace egg white) in plant-based products (e.g., mayonnaise, butter, meringue, chocolate mousse, ice cream, cakes and bread) has been increasing. According to Bird et al. (2017), Mustafa et al. (2018), Serventi et al. (2018) and Lafarga et al. (2019), color, texture and sensory qualities of gluten-free baked goods (bread, crackers) and mayonnaise differed significantly from traditional products. Finally, an application of AF for meringue production, traditionally obtained using egg white and sucrose, was investigated by Stantiall et al. (2018) who showed that AF meringues have palatability, color and a sensory quality like traditional ones, but with a lower consistency. Lafarga et al. (2019) and Meurer, de Souza, & Ferreira Marczak (2020) showed that the texture and color of meringues can be improved by subjecting aquafaba to ultrasound treatment.

The present study aimed at exploring other strategies, such as the addition of hydrocolloid (i.e., guar gum) and lactic acid, to improve the techno-functionalities of aquafaba and to investigate the effect of these ingredients on the quality of a plant-based confectionery product, such as meringue, whose structure consist of solid foam.

2. Materials and methods

2.1 Materials

Dry chickpeas (Garbanzo bean; Melandri Gaudenzio S.r.l., Italy; DC) and sucrose (white caster sugar) were purchased from a local supermarket in Milan (Conad S.C., Italy), as well as pasteurized egg white (Carrefour

S.p.A., Italy; EW). Guar gum (GG) and food grade lactic acid 80% (LA) were purchased from La dolciaria S.r.l. (Italy) and A.C.E.F. S.p.A (Italy), respectively. All chemicals were obtained from Merck KGaA, (Darmstadt, Germany) and used as received.

2.2 Aquafaba production

Aquafaba (AF) production is summarized in Figure 1. Dry chickpeas (400 g) were soaked in distilled water (chickpeas:water ratio of 1:3.3) at 25°C for 20 h and then were washed three times with distilled water in order to remove bitter compounds (e.g., phytic acid and tannins; Alsalman et al., 2020). Afterwards, the soaked chickpeas (SC) were boiled in distilled water (SC:water ratio of 1:1.5) through an induction hob (KP1071, Severin, Germany) for 90 min. Then the sample was cooled to room temperature (approximately 1 h) and then strained from the cooking water (i.e., AF). Plastic jars were used to store aliquots (150 g) of AF at -18°C until characterization (< 30 days).

2.3 Aquafaba and egg white characterization

AF and EW were characterized in terms of dry matter (g/100g), density (g/mL), apparent viscosity (Pa*s), pH and color. In particular, the apparent viscosity of AF and EW was evaluated at 20°C according to Kumbár, Nedomová, Strnková, & Buchar (2015) using a rheometer MCR 102 (Anton Paar, Germany) equipped with coaxial cylinders CC27. The results were expressed as apparent viscosity (η; Pa*s) (which is the ratio of shear stress, σ, and shear strain rate, γ; Steffe, 1996) as a function of shear rate (from 0.279 to 186 s^{-1}). In accordance with Kumbar et al. (2015), viscosities at a shear rate of 100 s^{-1} were computed. The shear stress and shear rate were also fitted to some of the common rheological models, such as the Herschel-Bulkley model (Eq. 1) and Power Law (or Ostwald-de-Waele; Eq. 2) model (Steffe, 1996) that can be described mathematically as follows:

Eq. 1 $\sigma = \sigma_0 + K * \gamma^n$

Eq. 2 $\sigma = K * \gamma^n$

where σ is the shear stress (Pa), σ_0 is the yield stress (Pa), K is the consistency index (Pa*s^n), γ is the shear rate (s^{-1}), and n is the flow behavior index (dimensionless).

The colorimetric indices were measured on approximately 75 g of sample placed in a black plastic cylindrical container (50 mm in height x 50 mm in diameter) in order to minimize the effect of external light, using a Minolta Chroma Meter II (Minolta, Japan) equipped with standard Illuminant C and tarred by a standard plate (Y:87.7, X:0.308, y:0.315). Results were expressed in the CIELAB space: L* (lightness; from black (0) to white (100)), a* (from green (-) to red (+)) and b* (from blue (-) to yellow (+)). At least three replicates ($n \geq 3$) were performed for each analysis.

2.4 Chickpea characterization

Dry, soaked and cooked chickpeas were characterized in terms of: moisture (g/100g; Official Standard Method AACC 44-15A, 2000); total nitrogen content (Kjeldahl method according to the AOAC, 2000) adopting a conversion factor of 6.25; energy (J) necessary to compress sample up to 70% of strain (test speed of 0.20 mm/s; trigger force equal to 20 g) using a TA-HDplus Texture Analyser (Stable Micro Systems, UK) equipped with a 250 kg load cell and a plate probe (100 mm diameter). The Texture Exponent TEE32 V 3.0.4.0 Software (Stable Micro System, UK) was used to control the instrument and to process data. At least three replicates ($n \geq 3$) were performed.

2.5 Foam production

The following foams (F) were produced and characterized: F_AF (100% aquafaba), F_AFGG (1% guar gum added to 99% of AF), F_AFLA (lactic acid acidification of AF down to pH 4.0), F_EW (100% egg white). Previous studies (Chang at al., 2020; Sadahira et al., 2015) indicated that polysaccharides with thickening properties can be used to enhance the foam stability of protein, verified by the decrease in drainage rate. GG was preferred to other gelling polysaccharides because its viscosity is higher to owing to its large molecular weight and it has high hydration ability (Dickinson, 2003). Furthermore, a previously study reported that foam stability improved by adding GG to egg white powder (Chang at al., 2020). The amount of GG used in the present study was in conformity to the producer’s indication. Acidification threshold was defined according to Buhl et al. (2019) and Lafarga et al. (2019) who demonstrated that foam stability increased near the pH isoelectric point (pH 4.6) of AF.

In accordance with preliminary trials, the liquid mixture (150 g) was whipped using a planetary mixer (N-50G, Hobart Corporation, USA), equipped with a wire whisk, for 10 min at speed level 3 (580 rpm) for samples containing AF and for 10 min at speed level 2 (281 rpm) for EW.

2.6 Foam characterization

Overrun

Immediately after whipping (t0), foams were characterized in terms of overrun (%; difference between foam height and initial solution height with respect to initial solution height) using a caliper.

Foam stability and bubble distribution

During storage at 6±2°C up to 160 min, foam stability and bubble distribution were measured as follows: Foam (3 g) was put in petri dishes (n=3) and scans were taken every 20 min in 256 grey scale levels at 600 dpi resolution using Epson Perfection V850pro scanner (Seiko Epson Corporation, Japan). Images were processed using specific software (Image Pro-Plus 7.0; Media Cybernetics Inc., USA), the total foam area (mm^2) for each storage time and foam radial area increment (FRAI, %) were measured; then a central portion (crop size = 465 mm^2) was selected from each image and the objects (bubbles) were identified, counted and classified into four classes according to bubble size: 1) $0.005 \leq x < 0.025$ mm^2; 2) $0.025 \leq x < 0.5$ mm^2; 3) $0.05 \leq x < 1$ mm^2 and 4) $1 \leq x < 25$ mm^2. The following parameters were measured for each class for each storage time: bubble number with respect to the total bubbles counted (%), bubble area with respect to the total aerated area of the crop, and mean bubble area (mm^2). Furthermore, for each storage time, the total aerated area with respect to the crop area was measured to calculate the ability of each foaming agent to entrap air (%). Finally, foam shrinkage (FS, %) was evaluated by putting 4 g of foam on a flat strainer (openings 1.28 mm^2) stored at 6±2°C for 120 min, and photographing (every 20 min) the foam using a camera (Canon PowerShot G7 X MARK II, Japan). After size calibration, the photos were processed using specific software (Image Pro-Plus 7.0; Media Cybernetics Inc., USA) and the foam area was measured in order to evaluate FS over time. With respect to FRAI, which is an indicator of general foam stability, FS is an indication of bubble stability as the reduction in foam area is mainly due to bubble coalescence and/or gas release. In order to quantify the foam syneresis (%) for each storage time, the liquid collected below the strainer used for FS evaluation was weighed.

Foam hardness

Foam hardness (N) was determined using a TA-HDplus Texture Analyser (Stable Micro Systems, UK) equipped with a 10 N load cell and a plate probe (diameter 45 mm). Foams were put in petri dishes (60 x 9 mm) and filled to maximum volume then allowed to rest for 10 min at refrigeration temperature (4±2°C) before being compressed up to 30% strain at 1 mm/s speed (hold time 60 s; trigger force 4 g). At least eight replicates (n=8) were performed for each recipe.

2.7 Meringue production

Figure 1 shows the flowsheet of meringue (M) production. AF-foaming agent (150 g; AF, AFGG, AFLA or EW) was first defrosted at 4°C overnight, then put into a planetary mixer (N-50G, Hobart Corporation, USA) and whipped while slowly adding the white sucrose (246 g) applying the same whipping conditions (i.e., time and speed) reported above (§ 2.5). Then the whipped batter was transferred to a pastry bag equipped with a nozzle (10 mm diameter) and squeezed onto a baking tray covered with baking paper in order to form twelve meringues (40 mm diameter, corresponding to an average weight of 6 g). Baking conditions were determined during preliminary trials: Meringues were cooked in a static oven (AKPM 759/IXL, Ignis, Whirlpool S.r.l., Italy) at 100°C for 80 min and then left to rest for 20 min with the oven off and slightly opened and for 30 min at room temperature for cooling them.

2.8 Meringue characterization

Meringue whipped batter was characterized in terms of density (g/mL). Meringues were characterized immediately after cooling at room temperature (t0) in terms of baking loss, geometrical features, color, texture, water activity and moisture.

Baking loss, geometrical features, color

Baking loss (%) was calculated as the difference between the weight of the whipped batter and the meringue, with respect to the weight of the whipped batter. Maximum height and diameter (mm) were measured using a caliper. Colorimetric indices were determined using a Minolta Chroma Meter II (Minolta, Japan) equipped with standard Illuminant C (§2.3).

Texture

Meringue texture was assessed with a TA-HDplus Texture Analyzer (Stable Micro Systems, Surrey, UK) equipped with a 10-blade Kramer shear cell and a 250 kg load cell. The Texture Exponent TEE32 V 3.0.4.0 software (Stable Micro System, Surrey, UK) was used to control the instrument and for data acquisition. One meringue (approximate 6 g) was compressed, sheared, and extruded through the bottom openings of the Kramer cell with the blades moving at 1.5 mm/s speed, to simulate chewing. The total energy (10^{-3} J) necessary to compress/extrude sample was extrapolated from the force–deformation curve as an index of product hardness. At least eight replicates were performed for each meringue recipe.

Water activity and moisture

For water activity (AquaLab Series CX-3, Decagon Devices Inc. WA, USA) and moisture (g/100g; AACC Official Standard Method 44-15A, 2000) evaluations, two meringues were ground with a Blender (Heavy Duty Blender, Waring Commercial, USA) for 10 seconds, to produce a homogeneous and representative sample (i.e., mixture of dry crust and moist internal part).

2.8 Statistical analysis

Results were expressed as mean±standard deviation values. If not otherwise specified, three replicates were performed for each sample. All data were subjected to one-way analysis of variance (ANOVA), followed by the Least Significant Difference (LSD) test to identify significant differences among the samples ($p<0.05$). Data were processed by STATGRAPHIC® Centurion 18 (Statpoint Technologies Inc., VA, USA).

3. Results and discussion

3.1 Chickpea and foaming agent properties

In order to monitor the effects of soaking and cooking, the chemical and physical characteristics of dry, soaked and cooked chickpeas were evaluated (Table 1). Moisture content was found to be significantly ($p<0.05$) different for all samples, starting from 9.9 (DC) and reaching 63.2 g/100g (CC) at the end of cooking; this was expected as during the production of AF, chickpeas absorb a considerable amount of water. As regards protein content, Singh, Singh Sandhu, & Kaur (2004) reported values between 16 and 21 g/100g of proteins; similarly, DC protein content was equal to 22.9 g/100g (d.b., dry basis) while SC showed a significantly ($p<0.05$) lower value (21.6 g/100g d.b.) which could be due to the release of water-soluble material (e.g., proteins) into the soaking water as was also reported by Alsalman et al. (2020). As for the geometric characteristics, a significant increase (78% and 21%, respectively) in area and diameter was noticed during soaking at room temperature due to the absorption of water; then a further area and diameter increase occurred during cooking (up to 83% and 33%, respectively) even if it was not significantly ($p>0.05$) higher than SC, suggesting that most of the water permeated into the chickpea during the soaking phase as already evidenced by the increase in moisture. As expected, the energy necessary to compress dry chickpeas was the highest (1.885 J) followed by soaked and cooked chickpeas (0.961 and 0.146 J, respectively), confirming that even if less water was absorbed during the hydrothermal treatment (i.e., cooking) a further de-structuration of the product occurred. Table 2 shows the physical properties of the foaming agents. Rheological analysis indicated that both AF and EW exhibited a shear-thinning flow behavior; in particular, Herschel-Bulkley model indices resulted as follows: $\sigma_0=0.0076$ and 0.0029 Pa, K=0.0046 and 0.0062 Pa*s^n, n=0.9282 and 0.9455, $R^2=0.99992$ and 0.99998 for AF and EW, respectively; while Power Law (or Ostwald-de-Waele) model was described as follows: K=0.0078 and 0.0080 Pa*s^n, n=-0.1982 and -0.1151, $R^2=0.9127$ and 0.8747, for AF and EW, respectively. In order to compare samples, viscosities at 100 s^{-1} were computed. As expected, AF had a lower viscosity than EW ($3*10^{-3}$ vs. $5*10^{-3}$ Pa*s, respectively) due to the different composition (e.g., protein content, etc.) of the foaming agents. EW viscosity agreed with literature data (Kumbar et al., 2015), which reported values of approximately $5.5*10^{-3}$ Pa*s after 1 week of storage. AF viscosities were not comparable with literature data since different AF samples (e.g., homemade or canned aquafaba, obtained at different cooking conditions, in the presence of salt and/or ethylenediamine tetracetic acid) were investigated and different rheological tests were applied (Alsalman et al., 2020; Shim et al., 2018; Stantiall et al., 2018). Density and dry matter were also found to differ significantly ($p<0.05$) among the foaming agents and were consistent with literature data, in fact Stantiall et al. (2018) reported a density of 1.020 g/mL and a dry matter content of 5.13 g/100g for cooking water derived from Garbanzo chickpeas, and a value of 1.040 g/mL for egg white; these slight differences could be explained by the composition and heterogeneity of the raw materials and the conditions used for AF-production. As regards the pH, AF had a value of 6.15 while the value of EW was equal to 8.41; these values were in line with Stantiall et al. (2018) who reported values of 6.26 and 9.20 for aquafaba and pasteurized egg white, respectively. Lightness (L*) did not appear to differ significantly, while redness and yellowness differed slightly: AF had a* value closer to zero and lower b* value than EW.

3.2 Foaming properties and stability

Foams are formed when proteins unfold, forming an interfacial skin that keeps air bubbles in suspension and prevents their collapse (Boye et al., 2010). The protein unfolding is generally obtained by mechanical stress (i.e., whipping); in fact, during whipping protein molecule adsorbs to air-water interface gradually and unfolds partially at interface, with hydrophobic and hydrophilic groups exposing to gas and liquid phase, respectively (Sadahira et al., 2015). As previously mentioned, AF contains low and high water-soluble carbohydrates, insoluble fiber, protein, and saponins (Bird et al., 2017; Stantiall et al., 2018) that exhibit different technological properties. AF proteins are amphiphilic molecules containing hydrophilic groups that interact with water, as well as hydrophobic groups that stabilize interactions with the gaseous phase allowing to form a foam structure. Recently, He et al. (2021) investigated the mechanism of AF foam structure and reported that proteins aggregate at the air-water interface, lowering the interfacial tension of the solution and inducing a partial unfolding of proteins. This lower interfacial tension allows air bubbles to be encapsulated and the association of protein molecules which stabilize foams. The same authors reported that AF polysaccharides, thanks to their hydrophilic character and high molecular weight have water-holding and thickening properties that can enhance foaming stability by gelling or modifying the viscosity of the aqueous continuous phase, thereby improving overrun, as well as slow down air bubble movement and coalescence. Furthermore, polysaccharide–protein complexes obtained during AF production also influence the rheological and technological properties of AF depending of their charge (He et al., 2021). Lastly, even if part of saponins is removed during chickpea soaking, saponins are present in AF and exhibit foaming properties by massing together at the water/air interface, thus mitigating unfavorable molecular interactions between phases, lowering interfacial tension and helping to generate foam (Bird et al., 2017; Chung et al., 2017; Stantiall et al., 2018). Depending on the food application (e.g., beverages, mousses, meringue cakes and whipped toppings) different technological properties of the foaming agent can be exploited and explored. The following sections presents the main techno-functionalities of foaming agents intended for a solid foam application (i.e., meringue).

Evaluation of overrun and foam texture

Foam properties and stability are reported in Table 3. Values for AF did not differ significantly from the reference in terms of overrun (781 vs. 862% for AF and EW, respectively) but generally were higher than literature data: Mustafa et al. (2018) showed that canned aquafaba reached overrun values similar or even higher compared to commercial and fresh egg white (180-475% vs. 281% and 311%, respectively), while Stantiall et al. (2018) reported values of 58% for aquafaba and 400% for egg white; these differences can be attributed to the different whipping conditions used and the composition of the foaming agents that led to a different level of entrapped air in the sample. Furthermore, EW was subjected to a pasteurization process (§ 2.21) that can affect its foaming properties. As reported by Alamprese, Cigarini & Brutti (2019), the most common treatment applied in the egg industry is thermal pasteurization (commonly 2.5–6 min at 64.4–68 °C) which is very efficacious in suppressing pathogens; however, since egg proteins are very sensitive to high temperatures, attention must be paid to avoid coagulation which leads to deleterious effects (e.g., loss of foaming, emulsifying, and gelling capacities), thus limiting the functionality of liquid egg products as food ingredients. The same authors mentioned that ohmic heating is a promising alternative to conventional heat pasteurization (e.g., promotes better foaming properties). As the EW used in the current study was a commercial product, the exact technique and conditions involved in the pasteurization process are unknown to us, however according to the overrun value obtained we can deduce that the pasteurization conditions were not severe. The two methods guaranteed to enhance AF properties (i.e., GG addition and acidification) allowed more air to be trapped inside the protein-polysaccharides matrix. In particular, the presence of GG slightly increased the overrun (+8%), while acidification significantly increased overrun (+54%). In addition, Lafarga et al. (2019) and Buhl et al. (2019) noticed that foam stability increased near the isoelectric point (pH=4.6). In terms of foam strength, all samples differed significantly: F_EW had the highest hardness (1.38 N), followed by F_AFGG (0.75 N) and F_AFLA (0.55 N), while F_AF showed the lowest consistency (0.39 N); this confirms that the addition of both guar gum and lactic acid contribute to structure the foam (e.g, create a stronger polysaccharide-protein and/or protein-protein network with entrapped air). In fact, GG, as well as the other polysaccharides naturally present in AF, can interact with proteins forming covalent conjugates between proteins and polysaccharides (He at al., 2021) or complex stabilize by electrostatic interaction. Furthermore, GG addition promoted the exposure of hydrophobic amino acids and the interaction between protein molecules at air-water interface (Chang et al., 2010). While lowering the pH down to the pI the net charge of protein changes towards zero value and electrostatic forces are minimal (Buhl et al., 2019), this can stabilize and eventually make more structured the foam.

Evaluation of entrapped air

Figure 2 and Table 4, show the central crops of the foam image that were processed by image analysis technique in order to identify bubbles and to classify them according to their dimension: from 1 (the smallest) to 4 (the largest). The foaming agents were able to entrap air in different ways. Among the fresh foams, F_AF was characterized by intermediate size bubbles (62% of the bubbles belong to class 3), while the reference foam had a high number of small (mean area, 0.01 mm^2) and large (mean area, 1.91 mm^2) bubbles with the highest percentage of aerated area occupied by the larger bubbles (47 and 24% of the bubble belong to class 3 and 4, respectively). Compared to F_AF, the two strategies investigated had opposite effects on air bubble distribution. In fact, the presence of GG resulted in a finer structure (24 and 18% of the bubble belong to class 1 and 2, respectively), presumably due to the increase of the system viscosity thanks to the thickening properties of GG (Bouyer et al., 2012; He et al., 2021). Furthermore, Chang et al. (2010) evidenced that after adding GG to egg white powder, the binding of protein with GG molecule (reflected by the increased in size) hindered the charged chain, promoting the exposure of hydrophobic amino acids and inducing interaction between protein molecules at the air-water interface; this - together with the denser viscosity of the system - can explain the higher number of small air bubbles. While the addition of lactic acid resulted in a high percentage of medium-to-large bubbles (68% of the bubbles belong to class 3) and a more aerated foam (total entrapped air of 23% vs. 17-19% for all the other foams; data not shown); the last result is consistent with the highest overrun value of F_AFAL mentioned above. The positive effects of lactic acid addition can be explained by the change in the protein surface charge due to the acidification of AF down to pH levels near the isoelectric region, where the net charge of the proteins is zero and the electrostatic forces are minimal. In fact, as reported by Buhl et al. (2019), the surface charge pattern of centrifugated aquafaba as a function of pH changed from a net negative charge (at pH 8.5) towards a positive charge due to decreased pH levels (down to pH 3). The pI value was determined to be pH 4.6.

Literature data generally focused on egg white foam and on a narrow range of bubble dimensions; in particular, Kampf et al. (2003) obtained fresh egg white foams having a bubble dimensional class of 0.04-0.18 mm^2, while the addition of xanthan gum determined an increase especially in big bubbles (from 0.03 to 0.33 mm^2). Ptasezk et al. (2014) studied bubble distribution of foams based on egg white proteins, xanthan gum and arabic gum: the bubble dimension was found to be in the range of 0.002-0.24 mm^2 with higher distribution between 0.002 and 0.05 mm^2. They concluded that the presence of 0.9% xanthan gum resulted in foams with visibly smaller air bubbles while adding arabic gum preserved air bubble populations similar to those obtained from pure egg white protein. In general, any differences were the result of different formulations (e.g., foam agent, sugar and hydrocolloid addition, etc.), whipping conditions and method applied for bubble quantification.

In this current study, bubble size distribution was also investigated during foam storage (60 and 120 min) at 6±2°C in order to evaluate foam stability. As expected, over time, for all samples, there was a decrease in the number of small bubbles (class 1 and 2) in favor of the medium and large (class 3 and 4) bubbles due to the coalescence phenomena; this can be appreciated in Figure 2, and it was quantified in terms of the mean area of bubbles (Table 3) for each time. For F_AF, bubbles belonging to class 3 and 4 increased their mean area by 19 and 29%, respectively, during 120 min of storage. The addition of GG resulted in a more stable foam as the mean area of bubbles increased by 3.2% for classes 2, 3 and 7% for class 4, respectively; this is consistent with literature data; for instance, Bouyer et al. (2012) mentioned that polysaccharides (e.g., GG) improve foam stability by modifying the viscosity of the aqueous phase; Chang et al. (2010) reported that adding GG to egg white protein resulted in overall increases in viscosity that could slow down gravity drainage and improve foam stability by blocking the flow of the liquid continuous phase. Acidification turned out to be useful in constraining the coalescence of the small bubbles (the increase in the mean area of bubbles was <2% for classes 1-3), however the largest bubbles significantly increased. In fact, even if for F_AFLA only 0.87% of the counted bubbles belonged to class 4, they accounted for 31% of the bubble area, showing a mean area of 2.154 mm^2 after 120 min of storage compared to 1.269 mm^2 for fresh foam. For F_EW, only bubbles belonging to class 3 showed an increase in the mean area of bubbles (by 20%) over time, accompanied by an increase in the number of large bubbles over time; this behavior is consistent with the highest syneresis value of F_EW (Table 3).

Evaluation of foam stability

In order to assess foam stability, the leaking of liquid from foam (i.e., syneresis) during 120 min of storage at refrigeration temperature (6±2°C) was measured (Table 3). F_AF showed better stability in comparison to F_EW, showing a syneresis of 27% vs. 42%. Both applied strategies (i.e., GG addition and acidification) improved AF-foam stability, leading to zero losses (i.e., syneresis); this confirmed that GG have thickening properties that enable sample to retain water better stabilizing the aerated structure, while lactic acid addition affected protein surface charge minimizing electrostatic forces. In accordance, Buhl et al. (2019) found that aquafaba foam at pH near pI remained highly stable, in terms of liquid drainage, for up to 1 h. Foam shrinkage -which is due to bubble coalescence and gas release- revealed that F_AFLA exhibited limited shrinkage (8.9%) compared to the reference foam (9.9%; Table 3), while the FS value for F AFGG (14.6%) did not significantly differ from that for F_AF; furthermore the addition of GG increased the intermediate radial area, probably due to the heavier structure obtained with the addition of guar gum as confirmed by the total entrapped air (17% vs. 19-23%, respectively for F_AFGG and the other samples; Figure 2). For the entire storage period (data not shown) of 120 min, F_AF was the most unstable foam characterized by higher (up to 45%) and faster FRAI kinetic (data not shown), suggesting that F_AF needs to be prepared just before its final use (e.g., for meringue or mousse production); conversely, the FRAI value for F_AFLA was 16.3% lower than F_AF, confirming once again that acidification is an easy method to obtain a more stable foam similar to the reference sample in terms of shrinkage and FRAI.

3.3 Meringue properties

The physical characteristics of meringues are reported in Table 5, while meringues before and after cooking are shown in Figure 4. As regards the whipped batter density, the addition of GG resulted in the highest value (0.59 g/mL) which means that the gelling capacity played an important role in creating a less aerated structure, followed by the sample containing EW (0.43 g/mL) and then the remaining samples (M_AF and M_AFLA which have values ≤0.37 g/mL). This behavior indicates that the addition of sucrose to make whipped batter for the meringue, did not modify the differences between AF and EW found previously; while the presence of sucrose seems to equalize the differences between AF and AFLA since the densities of M_AF and M_AFLA were not significantly ($p>0.05$) different. As regards the cooking weight loss, M_AFGG had the lowest value (30.6%) confirming that GG is an excellent thickener that binds water while M_AF was characterized by the highest value (35.2%) followed by M_AFLA (33.6%) and M_EW (31.3%); these results are like those of Stantiall et al. (2018) regarding Garbanzo aquafaba (approximately 37-38%) and egg white (approximately 25%) meringues. In terms of moisture, Stantiall et al. (2018) reported values of 6.1 and 10 g/100g for aquafaba meringues and pasteurized egg white meringues, respectively, while our samples showed lower values: 1.7 and 3.08 g/100g respectively for M_AF and M_EW; these differences can be explained by the different cooking conditions applied and the lower surface area of the meringues produced by Stantiall et al., (2018) which lost less water during the cooking phase (100°C for 75 min for meringues of 25 g each). Regarding the water activities, M_EW showed the highest value (0.470) while the addition of GG and LA resulted in intermediate values. As product color, appearance (e.g., geometrical indices) and texture play a key roles in food appreciation and, thus, in its consumption (Cappa et al., 2021) they were also measured. Meringue color was significantly affected by the foaming agent (i.e., AF or EW) used and the ingredients added to AF: values for lightness were higher for M_AFLA and M_AF (95.7 and 95.1, respectively), followed by M_AFGG (94.4) and M_EW (93.3), while M_EW and M_AFGG scored higher for green (-1.7 and -1.2, respectively) and yellow (7.7 and 2.0, respectively) values, compared to M_AF and M_AFLA which had values close to zero (0.7 and 0.2, respectively). Different chromatic coordinates were reported in literature: Stantiall et al. (2018) found values of $a^* = -7$ and of $b^* = 16.5$ for meringues with aquafaba, while values of $a^* = -0.1$ and $b^* = 1.8$ for samples with egg white; Lafarga et al. (2019) reported values of $a^* = 0.6$ and $b^* = 3.5$ for meringues with aquafaba, and values of $a^* = -0.8$ and $b^* = 3.5$ for samples with egg white. These differences could be attributed to the difference in raw materials (e.g., canned aquafaba) as well as the cooking conditions (e.g., browning phenomenon). As regards the geometrical characteristics, GG addition had a negative impact both on diameter and height resulting in the largest and thinnest meringues (57 and 13.1 mm, respectively). LA addition negatively affected the diameter while improving meringue height and texture. In fact, M_AFLA resulted in the highest consistency (compression energy of $3.24*10^{-3}$ J) compared to other samples that showed values lower than $1.93*10^{-3}$ J, indicating that the addition of lactic acid created a better structured product. This is an important result as Stantiall et al. (2018) showed that AF meringues have palatability, color and a sensory quality similar to traditional ones, but with a lower consistency, and Lafarga et al. (2019) and Meurer et al. (2020) indicated that the texture of meringues can be improved by subjecting aquafaba to ultrasound treatment which is a treatment more expensive than the acidification investigate in this study.

4. Conclusions

The hydrothermal process used to produce chickpea cooking water resulted in a plant-based ingredient with good foaming properties, somehow similar to those of egg white, especially when some ingredients were added. Indeed, the addition of guar gum and lactic acid improved the overrun and stability of aquafaba foam; in particular, acidification produced higher overruns compared to other samples (1692% and 862%, respectively for F_AFLA and F_EW) without exhibiting syneresis phenomena when refrigerated (6±2°C). As regards the application of aquafaba in a confectionary product (i.e., meringues), the presence of GG resulted in products with the poorest geometrical characteristics while LA increased product height and consistency. Furthermore, M_AFAL meringues came closest to the reference sample in terms of weight and moisture content. In conclusion, this study proved that aquafaba, a recycled ‘waste’ product, has techno-functionalities usable for allergen-free and plant-based food applications, such as solid foams (i.e., meringue).

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Fig. 1 Flow sheet of aquafaba (left) and meringue (right) production.

Fig. 2 Foam (F_AF, F_AFGG, F_AFLA, F_EW, from top to bottom) crop images at 0, 60, 120 min of storage (from left to right).

Fig. 2, online version only. Foam (F_AF, F_AFGG, F_AFLA, F_EW, from top to bottom) crop images with the indication of bubbles belonging to different dimensional classes (red, $0.005 \leq x < 0.025$ mm^2; light blue, $0.025 \leq x < 0.05$ mm^2; green, $0.05 \leq x < 1$ mm^2; blue, $1 \leq x < 25$ mm^2) at 0, 60, 120 min of storage (from left to right).

Fig. 3 Meringues (M) before (left) and after (right) cooking (M_AF, M_AFGG, M_AFLA, M_EW, respectively from top to bottom).

Fig. 3, online version only. Meringues (M) before (left) and after (right) cooking (M_AF, M_AFGG, M_AFLA, M_EW, respectively from top to bottom).

Table 1 Dry, soaked and cooked chickpea properties (DC, SC and CC, respectively).

Sample code	**Moisture (g/100g)**	**Protein (g/100g d.b.)**	**Area (mm^2)**	**Diameter (mm)**	**Energy (10^{-3} J)**
DC	9.9±0.4^{a}	22.9±0.8^{b}	89±10^{a}	12.2±1.2^{a}	1885±398^{c}
SC	56.6±0.9^{b}	21.6±0.5^{a}	158±13^{b}	16.2±1.1^{c}	961±212^{b}
CC	63.2±1.5^{c}	22.1±0.2^{ab}	163±19^{b}	15.4±1.2^{b}	146±37^{a}

Note: In the same column, values followed by different letters are significantly different ($p<0.05$);

d.b., dry basis.

Table 2 Physical properties of foaming agents.

Sample code	**Density (g/mL)**	**Dry matter (g/100g)**	**Apparent viscosity (10^{-3} Pa*s)**	**pH**	**L***	**a***	**b***
AF	1.013±0.004^{a}	3.39±0.01^{a}	3.23±0.16^{a}	6.145±0.104^{a}	29.4±0.2^{a}	-0.1±0.2^{b}	2.3±0.2^{a}
EW	1.024±0.012^{b}	11.28±0.03^{b}	4.93±0.07^{b}	8.413±0.014^{b}	29.4±0.2^{a}	-0.9±0.1^{a}	3.6±0.3^{b}

Note: AF, aquafaba; EW, egg white; L, lightness; a*, green–red index; b* blue-yellow index. In the same column, values followed by different letters are significantly different (p<0.05).*

Table 3 Foam (F) properties and stability.

Sample code	**Overrun* (%)**	**Hardness* (N)**	**Syneresis** (%)**	**Shrinkage** (%)**	**Radial increase** (%)**
F_AF	781±9^{a}	0.389±0.035^{a}	26.7±3.2^{a}	13.2±2.0^{bc}	44.1±7.2^{c}
F_AFGG	851±78^{a}	0.748±0.044^{c}	-	14.6±0.3^{c}	19.2±4.5^{b}
F_AFLA	1692±97^{b}	0.551±0.062^{b}	-	8.9±1.5^{a}	7.2±2.1^{a}
F_EW	862±93^{a}	1.377±0.132^{d}	41.7±4.0^{b}	9.9±0.8^{ab}	6.8±1.8^{a}

Note: AF, aquafaba; EW, egg white; GG, guar gum; LA, lactic acid; “-“, not detectable; “”, performed on fresh foam; “**”, performed on stored (at 6°C for 120 min) foam. In the same column, values followed by different letters are significantly different ($p<0.05$).*

Table 4 Foam (F) bubble properties.

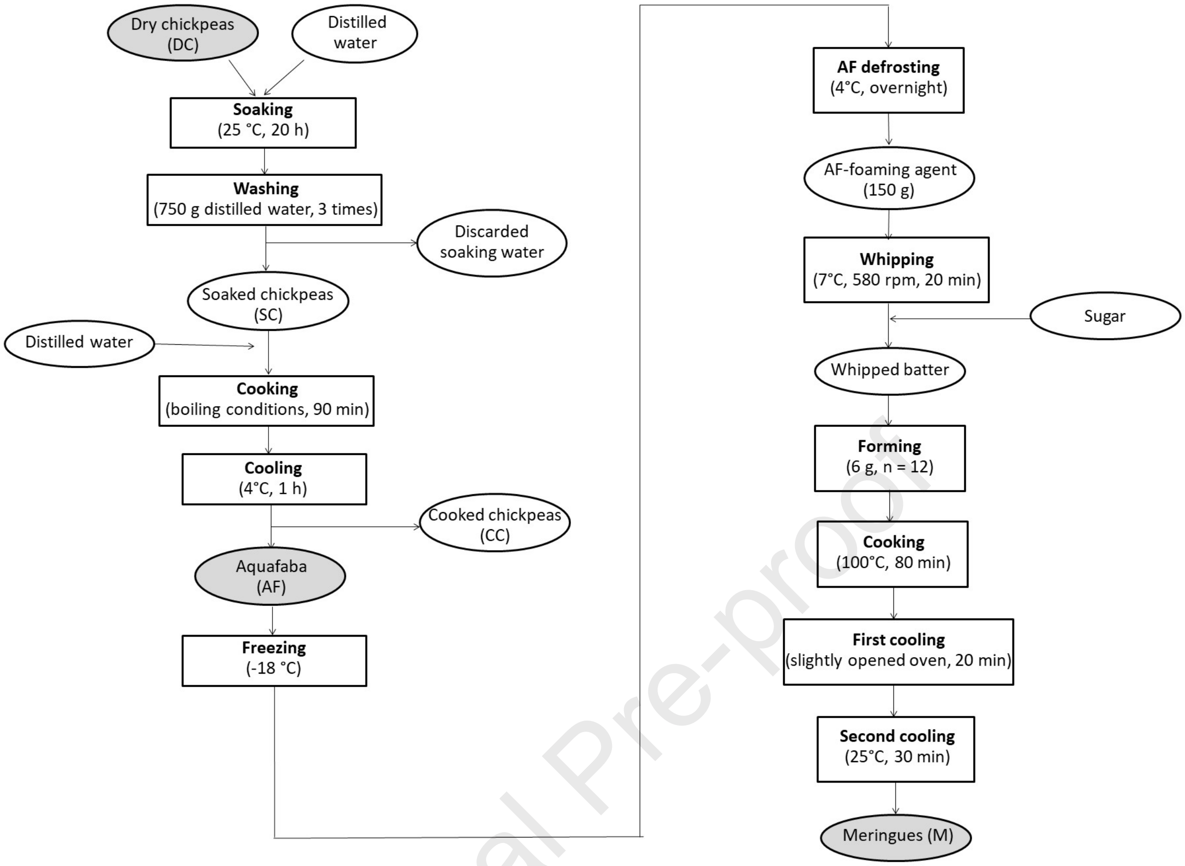
Sample code	Time (min)	Class code	Bubble number (%)	Bubble area (%)	Mean Area (mm^2)
F_AF	0	1	67.2±2.5^{c}	18.2±1.6^{b}	0.0104±0.0001^{a}
	0	2	15±0.5^{b}	13.3±0.4^{ab}	0.0344±0.0007^{a}
	0	3	17.7±2.1^{b}	61.8±5.9^{c}	0.1353±0.0048^{a}
	0	4	0.11±0.03^{a}	8.8±2.8^{a}	1.3464±0.2149^{b}
	60	1	62.1±5.7^{d}	11.9±3.2^{a}	0.0103±0.0001^{a}
	60	2	13.7±0.7^{b}	8.5±1.8^{a}	0.0347±0.0004^{a}
	60	3	24.3±5.7^{c}	68.5±5.4^{b}	0.1587±0.0096^{a}
	60	4	0.28±0.05^{a}	11.2±2.7^{a}	1.7562±0.2796^{b}
	120	1	69.1±1.1^{d}	15.5±1.9^{a}	0.0102±0.0001^{a}
	120	2	13.0±0.9^{b}	9.7±1.7^{a}	0.0339±0.0003^{a}
	120	3	17.6±1.9^{c}	61.7±6.4^{b}	0.1608±0.0158^{a}
	120	4	0.34±0.05^{a}	11.2±2.2^{a}	1.7337±0.2127^{b}
F_AFGG	0	1	71.1±1.1^{d}	24.0±2.6^{b}	0.0107±0.0001^{a}
	0	2	16.4±1.4^{c}	17.7±3.3^{b}	0.0338±0.0001^{a}
	0	3	12.3±1.3^{b}	50.5±4.8^{c}	0.1308±0.0171^{b}
	0	4	0.2±0.07^{a}	9.8±0.9^{a}	1.4456±0.0894^{c}
	60	1	64.1±2.0^{d}	13.5±1.3^{a}	0.0106±0.0001^{a}
	60	2	15.3±1.7^{b}	10.5±2.2^{a}	0.0345±0.0001^{a}
	60	3	20.1±2.2^{c}	63.2±1.2^{b}	0.1603±0.0173^{a}
	60	4	0.54±0.09^{a}	12.8±2.6^{a}	1.5876±0.2771^{b}
	120	1	62.8±2.5^{d}	12.6±2.3^{a}	0.0107±0.0001^{a}
	120	2	14.4±1.8^{b}	9.4±2.1^{a}	0.0348±0.0001^{b}
	120	3	22.3±2.6^{c}	64.4±1.8^{b}	0.1573±0.0104^{c}
	120	4	0.39±0.07^{a}	13.7±2.9^{a}	1.5529±0.0227^{d}
F_AFLA	0	1	63.6±1.6^{d}	13.7±0.7^{c}	0.0105±0.0001^{a}
	0	2	15.4±0.7^{b}	10.9±0.3^{b}	0.0349±0.0003^{a}
	0	3	20.8±1.0^{c}	67.6±2.0^{d}	0.1885±0.0155^{a}
	0	4	0.27±0.01^{a}	7.8±1.8^{a}	1.2693±0.0224^{b}
	60	1	60.6±2.0^{d}	9.2±2.3^{a}	0.0104±0.0002^{a}
	60	2	14.3±0.3^{b}	7.2±1.5^{a}	0.0346±0.0006^{a}
	60	3	24.5±1.9^{c}	66.1±8.3^{b}	0.1885±0.0155^{a}
	60	4	0.32±0.03^{a}	17.6±11.2^{a}	2.1537±0.6324^{b}
	120	1	61.4±3.6^{d}	8.5±1.7^{a}	0.0103±0.0002^{a}
	120	2	14.4±0.8^{b}	6.7±1.3^{a}	0.0344±0.0001^{a}
	120	3	23.4±3.1^{c}	59.7±9.7^{c}	0.1932±0.0261^{a}
	120	4	0.87±0.22^{a}	30.8±0.9^{b}	2.1349±0.6015^{b}
F_EW	0	1	77.0±2.1^{c}	19.4±2.3^{a}	0.0101±0.0002^{a}
	0	2	11.9±0.8^{b}	9.9±0.8^{a}	0.0342±0.0003^{a}
	0	3	10.7±2.4^{b}	46.6±9.5^{b}	0.1521±0.0225^{a}
	0	4	0.44±0.01^{a}	24.4±10.4^{a}	1.9077±0.3754^{b}
	60	1	72.0±3.0^{c}	13.2±1.4^{a}	0.0100±0.0002^{a}
	60	2	12.2±1.6^{b}	6.6±0.4^{a}	0.0339±0.0004^{ab}
	60	3	15.2±2.3^{b}	54.0±10.7^{c}	0.1939±0.0111^{b}
	60	4	0.74±0.16^{a}	32.2±7.6^{b}	1.6923±0.2201^{c}
	120	1	72.4±0.6^{d}	13.3±3.2^{a}	0.0100±0.0002^{a}
	120	2	11.5±0.8^{b}	7.2±2.1^{a}	0.0343±0.0006^{a}
	120	3	15.3±1.0^{c}	50. ±5.8^{c}	0.1840±0.0166^{a}
	120	4	1.13±0.22^{a}	35.1±2.7^{b}	1.8167±0.2386^{b}

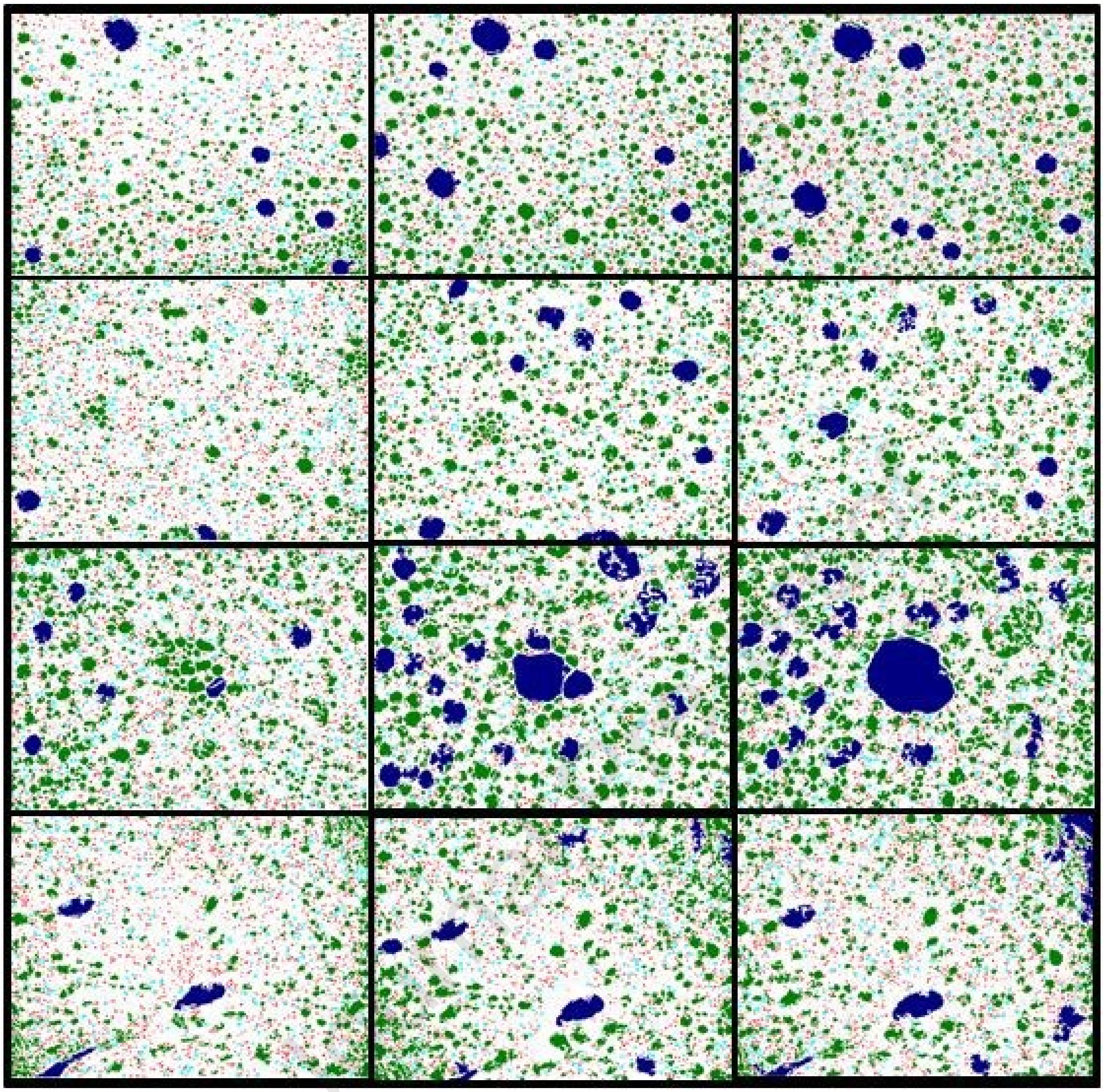
Note: AF, aquafaba; EW, egg white; GG, guar gum; LA, lactic acid. In the same column, values followed by different letters are significantly different ($p<0.05$).

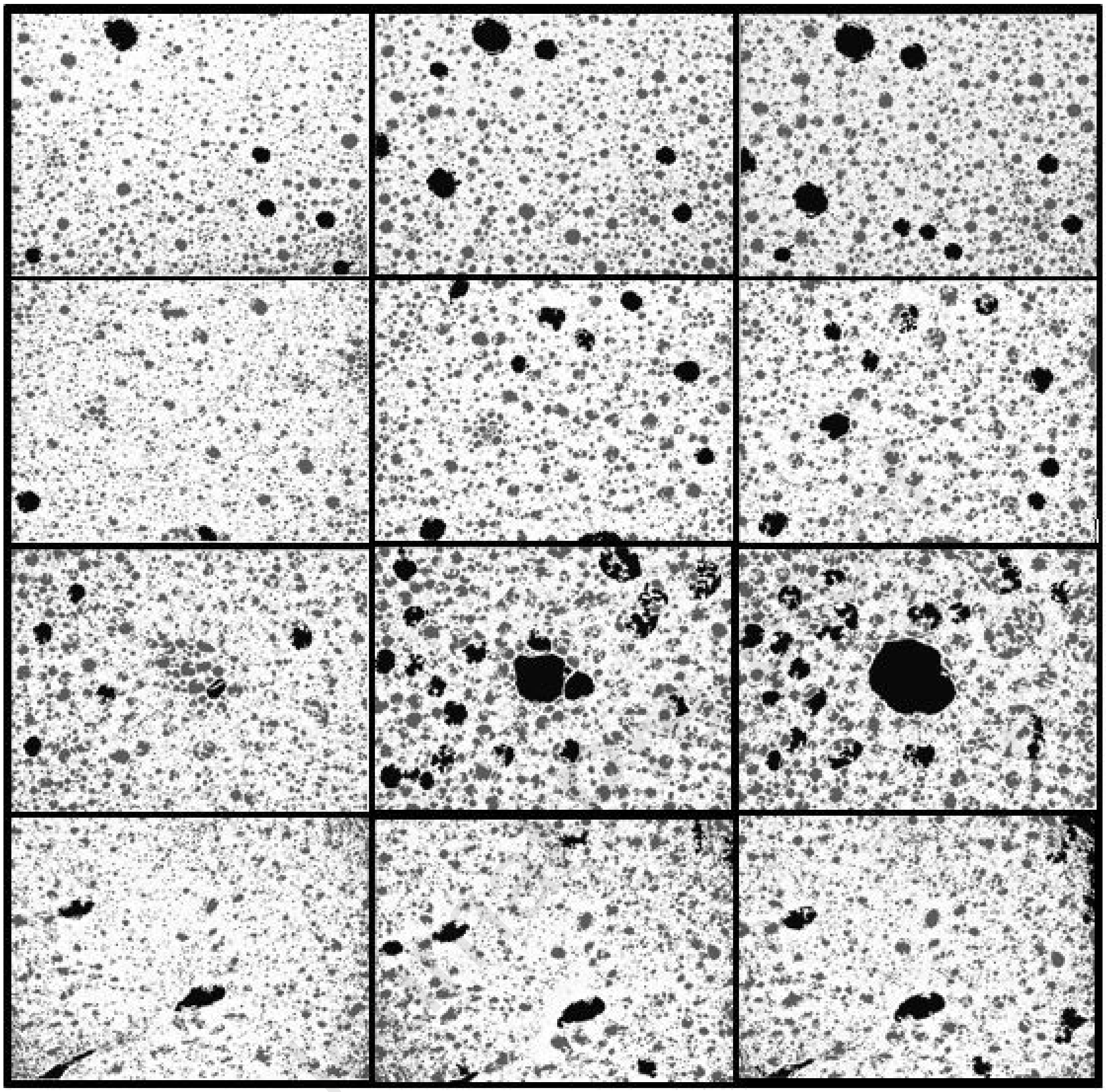
Table 5 Whipped batter density and qualitative characteristics of meringues (M).

Sample code	**Whipped batter density (g/mL)**	**Cooking weight loss (%)**	**Moisture (g/100g)**	**Water activity**	**L***	**a***	**b***	**Diameter (mm)**	**Height (mm)**	**Energy (10^{-3}J)**
M_AF_1	0.34 ± 0.01^{b}	35.4 ± 1.0^{a}	1.65 ± 0.11^{a}	0.427 ± 0.004^{b}	95.3 ± 0.4^{ab}	-1.0 ± 0.1^{b}	1.0 ± 0.1^{b}	52.0 ± 0.8^{a}	15.0 ± 0.6^{a}	1.885 ± 0.225^{a}
M_AF_2	0.33 ± 0.01^{a}	35.0 ± 0.7^{a}	1.68 ± 0.10^{a}	0.394 ± 0.008^{a}	94.9 ± 0.6^{a}	-0.4 ± 0.1^{a}	0.4 ± 0.2^{a}	54.4 ± 1.7^{b}	17.0 ± 1.3^{b}	1.967 ± 0.403^{a}
M_AF mean	*0.33±0.01*	*35.2±0.9*	*1.67±0.10*	*0.405±0.025*	*95.1±0.5*	*-0.68±0.3*	*0.70±0.4*	*53.2±1.8*	*16.0±1.4*	*1.926±0.319*
M_AFGG_1	0.59 ± 0.01^{a}	30.7 ± 0.3^{a}	2.50 ± 0.14^{a}	0.413 ± 0.011^{b}	94.5 ± 0.5^{a}	-1.3 ± 0.1^{b}	1.9 ± 0.4^{a}	56.6 ± 1.7^{a}	13.4 ± 0.3^{b}	1.690 ± 0.157^{a}
M_AFGG_2	0.58 ± 0.01^{a}	30.6 ± 0.9^{a}	2.30 ± 0.33^{a}	0.383 ± 0.010^{a}	94.3 ± 0.5^{a}	-1.1 ± 0.1^{a}	2.0 ± 0.3^{a}	57.4 ± 2.5^{a}	12.9 ± 0.4^{a}	1.951 ± 0.173^{b}
M_AFGG	*0.59±0.01*	*30.6±0.6*	*2.40±0.27*	*0.398±0.019*	*94.4±0.5*	*-1.2±0.2*	*2.0±0.3*	*57.0±2.1*	*13.1±0.5*	*1.820±0.210*^{a}
M_AFLA_1	0.32 ± 0.01^{a}	33.2 ± 1.2^{a}	3.06 ± 0.20^{b}	0.353 ± 0.001^{a}	96.9 ± 0.9^{b}	-0.1 ± 0.1^{a}	-0.1 ± 0.2^{a}	55.0 ± 1.9^{a}	16.2 ± 1.2^{a}	3.117 ± 0.182^{a}
M_AFLA_2	0.32 ± 0.01^{a}	33.9 ± 1.2^{a}	2.77 ± 0.06^{a}	0.361 ± 0.001^{a}	94.2 ± 1.2^{a}	-0.8 ± 0.1^{b}	0.7 ± 0.2^{b}	55.6 ± 1.5^{a}	17.9 ± 1.3^{b}	3.347 ± 0.256^{a}
M_AFLA	*0.32±0.01*	*33.6±1.3*	*2.89±0.19*	*0.357±0.006*	*95.7±1.7*	*-0.37±0.4*	*0.23±0.4*	*55.3±1.7*	*17.0±1.5*	*3.240±0.247*
M_EW_1	0.41 ± 0.01^{b}	31.9 ± 0.6^{b}	2.88 ± 0.04^{a}	0.494 ± 0.048^{b}	91.7 ± 1.6^{a}	-1.9 ± 0.2^{a}	8.5 ± 1.1^{b}	50.0 ± 2.6^{a}	21.4 ± 1.3^{a}	1.470 ± 0.226^{a}
M_EW_2	0.36 ± 0.01^{a}	30.6 ± 0.8^{a}	3.21 ± 0.08^{b}	0.432 ± 0.004^{a}	95.0 ± 1.3^{b}	-1.5 ± 0.3^{b}	6.7 ± 0.6^{a}	51.0 ± 2.2^{ab}	21.2 ± 1.6^{a}	1.850 ± 0.205^{b}
M_EW mean	*0.38±0.03*	*31.3±0.9*	*3.08±0.19*	*0.470±0.048*	*93.3±2.2*	*-1.73±0.3*	*7.68±1.3*	*50.3±2.4*	*21.3±1.4*	*1.660±0.287*

Note: AF, aquafaba; EW, egg white; GG, guar gum; LA, lactic acid; Number 1 or 2 indicates the technological replicate; in the same column, different letters correspond to significantly differences (p<0.05).


Dry chickpeas (DC)
Distilled water
Soaking (25 °C, 20 h)
Washing (750 g distilled water, 3 times)
Discarded soaking water
Soaked chickpeas (SC)
Distilled water
Cooking (boiling conditions, 90 min)
Cooling (4°C, 1 h)
Cooked chickpeas (CC)
Aquafaba (AF)
Freezing (-18 °C)
AF defrosting (4°C, overnight)
AF-foaming agent (150 g)
Whipping (7°C, 580 rpm, 20 min)
Sugar
Whipped batter
Forming (6 g, n = 12)
Cooking (100°C, 80 min)
First cooling (slightly opened oven, 20 min)
Second cooling (25°C, 30 min)
Meringues (M)





Highlights

Aquafaba exhibited overrun not significantly different from egg white

Addition of guar gum and lactic acid increased foaming capacity and stability over time

Lactic acid resulted in more developed and structured meringues

Aquafaba is an egg/gluten-free (vegan) ingredient usable in confectionary

Declaration of interests

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

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Authors' Contributions: Deborah Tufaro: investigation, methodology, formal analysis, writing (original draft), writing (review & editing). Carola Cappa: conceptualization, methodology, data curation, resources, project administration, writing (original draft), writing (review & editing), supervision.