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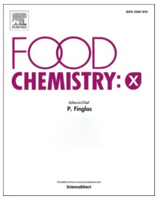

Is aquafaba suitable as a coffee creamer and foam enhancer in instant coffee?

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ABSTRACT

Coffee is commonly consumed with a creamer to reduce the acidic taste, and rich foam is an important feature, particularly in instant coffee. We examined two aquafaba (AF) powders, chickpea and navy bean, as coffee creamers and foam enhancers using physical, chemical, and LC-Q-Orbitrap High-Resolution Mass Spectrometry methods. Chickpea AF powder contained more protein and phenolic content than navy bean AF, while the latter exhibited greater pH, total sugars, saponin, and ash levels. Navy bean AF also showed better flowability and solubility than that of chickpea, hence worse hygroscopicity. Interestingly, adding either AF powder to instant coffee (1 % dw/v) increased protein by 15 % and phenolic content by 4.23 %, but not whiteness. The LC-Q-Orbitrap analysis elucidated their foam properties. Coffee-added chickpea AF foams are better than free coffee and navy bean AF, although the latter's foam is more stable. Thus, AF can enhance coffee froth not act as a whitening agent.

1. Introduction

Aquafaba (AF) is a thick, semitransparent fluid formed when legume seeds are cooked in water. The pulse seeds are usually consumed as they are or prepared in different traditional cuisines, while AF is discarded as a by-product (Lima et al., 2024; Sahin et al., 2024). Pulses, which include cowpeas, lentils, chickpeas, navy beans, and peas, are the most important crops farmed globally (Lin et al., 2008). AF is mostly composed of proteins, which vary depending on the pulse seed variety, polysaccharides, and some minor compounds such as saponins (He, Meda, et al., 2021).

This solution possesses a variety of functional qualities, including emulsification, gelation, thickening, and, notably, foamability. Therefore, recent studies have focused on its potential as a vegan ingredient in a variety of food formulas, such as mayonnaise, meringue, mousse, muffins, and whipped cream substitutes (Kim & Shin, 2022; Stasiak et al., 2023). Exploiting this ingredient also contributes to worldwide efforts to combat global warming and environmental pollution, reduce anthropogenic greenhouse gas emissions, and recycle natural resources (Gerber et al., 2013).

Coffee, along with water and tea, is one of the most popular drinks consumed worldwide. The preparation of coffee varies according to social, geographical, and cultural contexts, as well as personal preferences (Lim et al., 2019; Olechno et al., 2020). One type of coffee product that is simple and most convenient to prepare quickly is instant coffee. Pouring hot water or cold water over it makes it simple for customers to create a cup of coffee (Mostafa, 2024). It is high in antioxidants, carbohydrates (galactomannans and arabinogalactans), and caffeine. In addition to espresso coffee, coffee foam is a crucial quality attribute of this type of coffee (Shankaran & Chinnaswamy, 2019).

Foaming has been highlighted as a rapidly growing processing operation in the food manufacturing sector (Deotale et al., 2023). In instant coffee, a professional barista uses recent innovations to form tiny gas bubbles that create a smooth, creamy, and richer mouthfeel (Shankaran & Chinnaswamy, 2019). Aside from being appealing, coffee foam traps fragrance volatiles and prevents heat loss (Illy & Viani, 2005). Research on foamability and foam stability in various coffee varieties indicates that foamability is linked to protein content in espresso coffee, while foam stability depends on the polysaccharide content (Nunes & Coimbra, 1998). Limited research has been conducted on improving foam qualities in instant coffee. Gmoser et al. (2017) described the stabilizing mechanism for dispersed particles in instant coffee. Large particles are primarily responsible for stabilizing tiny gas bubbles by diffusing to lamella borders and increasing the viscosity of

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the liquid-air contact. Furthermore, Shankaran and Chinnaswamy (2019) indicated that the optimal conditions for achieving maximum foamability of instant coffee are 10 % coffee solids and a flow rate of 0.4 L gas/min. Nonetheless, no investigation into improving the foaming properties of instant coffee has been attempted yet.

This study was designed to assess the potential of aquafaba from two distinct pulses (chickpea and navy bean) to be utilized as a substitute for coffee creamer and foam enhancer in instant coffee.

2. Materials and methods

2.1. Raw materials and reagents

The canned white chickpea (*Cicer arietinum*) and white navy bean (*Phaseolus vulgaris)* were purchased from California Garden Products Inc., 31,642 Avenida Los Cerritos, San Juan Capistrano, USA. A jar of instant coffee was purchased from Misr Café Company (10th of Ramadan City, Egypt). The commercial creamer of Dream Company was acquired from Dreem Mashreq Foods, Alexandria, Egypt. It contains glucose syrup, saturated palm oil, sodium caseinate, stabilizers (potassium phosphate and sodium tripolyphosphate), emulsifiers (mono- and di-glycerides of fatty acids and sodium stearoyl lactylate), and an anti-caking agent (silicon dioxide).

Chemicals such as vanillin, gallic acid, bovine serum albumin, formic acid (99 %), and reagents such as Bradford, Folin-Ciocalteu, dinitrosalysilic acid (DNSA), and rhodanine were purchased from Sigma Aldrich (Darmstadt, Germany). Methanol and acetonitrile, ACN, of LC-MS grade were acquired from Merck (Darmstadt, Germany) and CARLO ERBA (Milan, Italy), respectively. The ultra-pure water was produced by the MilliQ UF-Plus system, manufactured by Millipore in Germany.

2.2. Aquafaba foam preparation and drying

The liquid from the can was collected and beaten at maximum speed for 15 min using a Moulinex (QA503DB1, France) mixer to create firm foam. The AF foam was spread on a silicone mat with a thickness of 3 mm and dried at 50 °C for one hour. A household grinder (Genuine LM241, Moulinex, France) was used to grind the dry foam, which was then kept at 4 °C until analysis (Aslan & Ertaş, 2021).

2.3. Coffee beverage preparation

Instant coffee powder (20 g/1.5 L) was diluted with distilled water at 50 °C. The coffee beverage was divided into 50-ml glass bottles for four experimental batches. The first batch contained coffee without any added aquafaba (AF) powder. The second and third batches included coffee with 1 % (*w/v*) dry weight of any AF powder that completely dissolved. The fourth batch consisted of a mixture containing 0.5 % (w/v) dry weight of each AF powder. The percentage of AF powder is the lowest, with no aroma changes. All bottles were pasteurized at 85 °C for 5 min. The same coffee beverage samples were also prepared with tap water (Olechno et al., 2020).

2.4. Chemical analysis

The AF powder was dried in an oven at 130 °C for an hour, or until the weight remained constant, to ascertain the moisture content. Ash content was determined according to the AOAC method (2016). Bradford reagent was used to estimate the protein content of AF powder and coffee samples, with bovine serum albumin serving as a standard (Sapan et al., 1999). A quantity of 500 mg of AF powder was dissolved in distilled water, then 5 mL of Coomassie brilliant blue reagent and 100 μL of diluted AF, or coffee sample, were combined for five minutes. The absorbance of the mixture was recorded at 595 nm with a T60-UV visible spectrophotometer (PG, Leicestershire, LE17 5BH, UK). The acidity was determined by titration with 0.1 N NaOH after dissolving AF powder in distilled water. The technique by Mostafa (2024) was used to determine the total phenolic content in AF powder or coffee beverage samples. Briefly, AF powder (1 g) was dissolved in 50 mL of distilled water, then 1 mL of the diluted sample or coffee beverage sample was combined with 2.5 mL of 10 % Folin-Ciocalteu reagent, and 2 mL of sodium carbonate was added after 5 min. The same spectrophotometer was used to record the absorbance at 760 nm after the tubes were placed in the dark for 30 min. TPC was calculated as gallic acid equivalents. The DNSA method (Miller, 1959) at A_{540} was used to quantify the reducing sugar content of the diluted coffee samples, which was expressed as mg glucose/mL. The anthrone reagent was used to determine total sugars at 620 nm with the same spectrophotometer after diluting the sample, 50 mg in 1000 mL of distilled water (Ludwig & Goldberg, 1956). Saponin content was estimated according to Sahin et al. (2024) with some modifications. AF powder (0.5 g) was mixed with 10 mL of 80 % methanol and agitated for 4 h. The mixture was then centrifuged at 2795*g* (Hermle, Z300, Germany) for 10 min to collect the supernatant. Five milliliters of 80 % (*v/v*) methanol were added to tubes, centrifuged again, and repeated before pooling all supernatants. Two hundred μL of this extract was mixed with 50 μL of the same solvent. Then, 0.25 mL of vanillin reagent (80 mg/mL in methanol) and 2.5 mL of 72 % H_2SO_4 were added. Tubes were vortexed and kept for 10 min in a water bath at 60 °C. The absorbance was read at 520 nm against the distilled water as a blank, and the results were calculated as mg/g dry weight.

The coffee beverage sample was diluted (1:4 DW) and combined with pre-heated KIO_3, 2.5 %, for two minutes at 30 °C in order to assess the amount of hydrolyzable tannins. Conversely, the condensed tannins were measured using the aforementioned spectrophotometer employing the vanillin-HCl technique (Mostafa, 2023). Briefly, the coffee beverage sample was diluted (1:1 DW), and then 1 mL was combined with 2.5 mL vanillin (4 %, in methanol) and 2.5 mL HCl (8 %, in methanol). The absorbance at 500 nm was measured after 30 min of dark incubation. The blank was a diluted coffee sample with 5 mL of distilled water.

2.5. Physical analysis

A digital pH meter from Adwa (AD1030, Romania) was used to monitor the pH value of AF powder (after dilution in distilled water) or coffee beverage samples. CR-410 (Konica Minolta, Tokyo, Japan) was used to test the color characteristics of coffee beverage samples or AF foam. The model AR 200 hand refractometer (New York, USA) was utilized to ascertain the soluble solid content (TSS) in coffee beverage samples.

Bulk and tapped density were determined by the method of Aslan and Ertaş (2021) and calculated by Eqs. (1) and (2).

$$\text{Bulk density (Db)} = \frac{Powder\ mass\ (g)}{Powder\ volume\ (mL)} \tag{1}$$

$$\text{Tapped density (Dt)} = \frac{Powder\ mass\ (g)}{Tapped\ powder\ volume\ (mL)} \tag{2}$$

Eqs. (3) and (4) were applied to calculate the Carr index (CI) and Hausner ratio (HR), which serve as indicators of flowability and cohesiveness, respectively, using the estimated Db and Dt (Caliskan & Dirim, 2016). The amount of moisture absorbed by one gram of the sample after a week at 25 °C in a closed container containing a saturated NaCl solution is known as hygroscopicity. It was calculated as g/100 g dry solids. Wettability is the time needed to wet all of the powder sample particles completely. A sample (0.5 g) was dropped onto a 50 mL surface of distilled water, and the time it took for all of the particles to become wet was recorded in seconds (Aslan & Ertaş, 2021).

$$CI = \frac{Dt - Db}{Dt} \times 100 \tag{3}$$

$$\mathrm{HR} = \frac{Dt}{Db} \tag{4}$$

The water solubility index (WSI) was estimated by mixing 2.5 g of AF powder with 30 mL of distilled water for 5 min. After that, the mixture was centrifuged at 2795*g* for 10 min. The wet solid was weighed, while the supernatant was dried in a petri dish for 24 h at 50 °C. The weight of dry matter is an indication of solubility (Jafari et al., 2017). The WSI and water absorption index (WAI) were calculated by Eqs. (5) and (6).

$$\mathrm{WSI} = \frac{Weight\ of\ the\ dry\ matter}{Initial\ sample\ weight} \times 100 \tag{5}$$

$$\mathrm{WAI} = \frac{Weight\ of\ wet\ solid\ after\ centrifugation}{Initial\ sample\ weight} \times 100 \tag{6}$$

2.6. Foam attributes analysis

Foam attributes such as foamability and foam stability were first evaluated in freshly collected AF liquid. A defined volume of AF liquid (50 mL) was whipped by a Moulinex mixer (QA503DB1, France) for 15 min, and then the formed foam was completely transferred to a graduated cylinder. The volume of foam is an indication of foamability. By measuring the volume of foam every 30 min for three hours at 30 °C, foam stability was evaluated (Tabtabaei et al., 2019).

Secondly, the foam properties of free instant coffee beverage and coffee beverage samples containing AF powder were assessed. The foamability was estimated by mixing 15 mL of the sample with a coffee frother mixer (SKU, ge810ha0uoyq9nafamz, China) into a graduated tube for one minute. The foamability was expressed in milliliters. The volume of the foam of a 50-mL sample was measured every hour for 7 h to assess its stability, and the findings were plotted versus the time (Shankaran & Chinnaswamy, 2019).

2.7. LC-Q-Orbitrap high-resolution mass spectrometry (HRMS) analysis

The sample was prepared as follows: A homogenized AF powder weighing 1.00 ± 0.01 g was transferred into 50 mL polypropylene centrifuge tubes. Each tube was then filled with 10 mL of a 50:50 MeOH/water solution (*v*/v), agitated for 10 min at 700 rpm, then centrifuged (Hermle, Gosheim, Germany) for 10 min at 4 °C. The supernatant was filtered through a 0.45 μm polytetrafluoroethylene filter into an amber glass vial and then injected into the HPLC-Orbitrap HRMS for analysis.

The proposed chromatographic separation was conducted using a Thermo Scientific Vanquish High-Performance Liquid Chromatography (Thermo Scientific, Bremen, Germany). The stationary phase consisted of a ZORBAX Eclipse Plus C18 reversed-phase column (150 mm × 4.6 mm, 5 μm particle size). The mobile phase was a binary gradient system composed of eluent A (0.1 % formic acid in water) and eluent B (ACN containing 0.1 % formic acid). The gradient elution profile was identical for both positive and negative ionization modes: 0 % B for the initial 0.5 min, linearly increasing to 100 % B over 8.5 min, then returning to 0 % B within 4 min, followed by a 2.5 min re-equilibration period, resulting in a total run time of 15 min. The mobile phase flow rate was maintained at 0.5 mL/min. The column temperature was set at 40 °C, while the sample tray was kept at 25 °C. For each analysis, 30 μL of the sample was injected into the HPLC system. The Q-Exactive Orbitrap mass spectrometer (Thermo Scientific, Bremen, Germany) was employed for the analysis conducted in this research. The mass spectrometer was equipped with a heated electrospray ionization (HESI) source, capable of operating in both positive and negative ionization modes. The HESI temperature was kept at 350 °C, while the capillary temperature was maintained at 325 °C. The S-lens RF level was optimized to 50 V, and the sheath and auxiliary gas flows were adjusted to 50 and 12 units, respectively. The automatic gain control goal was fixed at 3×10^6, with a maximum injection time of 100 ms. With a scan range of 70–1050 *m/z*, the mass spectrometer was run in Full MS/vDIA scan mode, employing a resolution of 70,000 for Full MS. For vDIA, a resolution of 17,500 was used, with the mass range split into five segments: 100–200 m/z, 195–300 m/z, 295–400 m/z, 395–500 m/z, and 495–1050 m/z. Data processing and acquisition were performed using TraceFinder software (version 4.1) from Thermo Fisher Scientific (Bremen, Germany).

2.8. Statistical analysis

To compare the samples, CoStat software (Berkeley, CA, USA) was used using Tukey's test (Gauderman, 1988). The means of three replicates were statistically compared at a significant level of $p \leq 0.05$.

3. Results and discussion

3.1. Compositional analysis of AF powder

The AF powder from chickpeas and navy beans was compared to the powder from a commercial creamer (Table 1). The data demonstrate that the moisture levels of the samples ranged from 2.24 to 5.63 %, and navy bean AF was lower than dried chickpea AF ($p \leq 0.05$). According to previous studies, the moisture content of dried foodstuffs must be ≤5 % to ensure powder preservation during storage (Abdullah et al., 2020), as evidenced by the samples. The ash content varied considerably ($p \leq 0.05$) between samples. The commercial creamer had the lowest value at 0.38 %, whereas navy bean AF outperformed chickpea AF. Ray et al. (2014) revealed that navy bean contains roughly double the amount of several minerals found in chickpeas, including K, Mg, and Cu, which could explain the results.

Legumes are well known to be a great source of protein (He, Meda, et al., 2021). The protein concentration in AF samples showed that both AF powders had higher protein content than the commercial creamer, with chickpea AF having the highest ($p \leq 0.05$). The protein proportion found in both AF powders is the result of protein loss from legumes when cooked. Protein concentration and composition are known to influence the foaming properties and capacity of various proteins (Zhang et al., 2022). Stantiall et al. (2018) also found that garbanzo chickpea cooking water contained a higher protein content than navy beans. Tas et al. (2022) determined the protein and soluble protein contents of chickpea and navy bean seed powders. They reported non-significant differences in protein content; however, the soluble protein was significantly greater in chickpea powder (12.80 vs. 11.6 %), which might be solubilized in its aquafaba. Comparable to the current study, the protein content of Kabuli chickpea AF was 16.29 % (Sahin et al., 2024) and 13.61–15.28 % in navy bean AF powder (Golzi et al., 2023). On the other hand, it ranged between 22.65 % and 26.8 % in AF of canned chickpeas (Kim & Shin, 2022; Shim et al., 2018), which could be greater than this study due to the precision of the determination. It may also be attributed to the concentration of liquid via the spray-drying process or the legume cultivar.

The acidity of the AF powder from both tested legumes was substantially higher than that of the commercial creamer. This is primarily due to the addition of citric acid to can-containing beans during preparation to improve the color (Lima et al., 2024). The opposite was observed in pH values. This means that both powders tend to be more acidic, whereas commercial creamers are neutral, possibly due to the inclusion of sodium phosphate. In 2005, Golde and Schmidt assessed a coffee creamer prepared with two distinct protein sources: soy protein isolate and sodium caseinate. They observed that the pH and total solids of the creamer manufactured with soy protein isolate were lower than those made with sodium caseinate. This was also noted in the current investigation, although using chickpeas rather than navy beans.

Phenolic compounds are highly valued for their potential health benefits, including the prevention of obesity, diabetes, Parkinson's, and Alzheimer's diseases (de Araújo et al., 2021). Chickpea and navy bean AF had significantly lower total phenolic content (TPC) compared to commercial creamer ($p \leq 0.05$), and chickpea AF powder was

Table 1

Chemical composition of aquafaba powder of chickpea and navy bean in comparison with the commercial coffee creamer.

Sample	Moisture	Ash	Protein	Total sugar	pH	Acidity	Saponin	Phenolic compounds
	%	%	g/100 g dw	g/100 g dw		mg/g	mg/g dw	mg GAE/g dw
Chickpea	*$3.63^{a} \pm 0.26$	$0.90^{b} \pm 0.003$	$16.52^{a} \pm 1.14$	$10.66^{b} \pm 0.97$	$5.81^{c} \pm 0.000$	$4.13^{a} \pm 0.13$	$7.31^{b} \pm 0.34$	$0.96^{b} \pm 0.00$
Navy bean	$2.54^{b} \pm 0.26$	$1.25^{a} \pm 0.000$	$10.55^{b} \pm 0.16$	$16.39^{a} \pm 0.95$	$6.02^{b} \pm 0.001$	$4.41^{a} \pm 0.20$	$11.52^{a} \pm 0.01$	$0.43^{c} \pm 0.14$
Commercial coffee creamer	$2.92^{ab} \pm 0.09$	$0.28^{c} \pm 0.007$	$8.19^{b} \pm 0.21$	$12.21^{b} \pm 0.11$	$7.12^{a} \pm 0.004$	$0.96^{b} \pm 0.00$	$0.00^{c} \pm 0.00$	$1.44^{a} \pm 0.04$

[*] Different letters within the rows indicate significant difference at ($p \leq 0.05$) as calculated by Tukey's test.

significantly higher than navy bean AF. In navy bean seeds, numerous phenolic compounds, including sinapic, ferulic, and p-coumaric acids, were found (Lin et al., 2008), while its water extract had 1.76 mg GAE/g dw (Sutivisedsak et al., 2010). The phenolic content of navy bean AF powder has not been the subject of any prior research. The TPC content of chickpea and white kidney bean seeds was only compared by Gan et al. (2017), and in that study, chickpea seeds showed a greater amount (186 vs. 182 mg GAE/100 g).

Total sugars significantly differed between the AF powder of navy bean and both chickpea powder and commercial creamer ($p \leq 0.05$). Navy bean AF contained the highest percentage of sugars, followed by commercial creamer, which may be attributable to the added glucose syrup. Tas et al. (2022) discovered that navy bean seed powder has more carbohydrates than chickpea powder (72.23 vs. 67.69 g/100 g). The same pattern was observed in saponin content. Navy bean AF powder had the highest significant content, followed by chickpea powder ($p \leq 0.05$). Saponins are known to cause hemolysis by interacting with cholesterol in the erythrocyte membrane. Clinical studies have evidenced that saponins affect the human immune system in ways that help to protect against cancer and lower cholesterol levels (Shi et al., 2004). Contrarily, AF of garbanzo chickpea contains less saponin than haricot beans (4.5 vs. 5.9 mg/g), which could be because the seeds were pre-soaked and cooked for 90 min (Stantiall et al., 2018) rather than canned, as tested in this study.

3.2. *The physical and functional attributes of AF powder*

Table 2 demonstrates substantial variations in bulk and tapped density between commercial creamer and chickpea powder ($p \leq 0.05$), with the latter having the lowest density among the examined samples. Bulk and tap density are critical indicators for evaluating any food powder. They are important properties for industrial packaging because they express the volume occupied by the powder and influence rehydration, packing, and shipping costs (Dehghannya et al., 2018). Thus, AF chickpea powder can be purchased at a lower cost because it can fit in a smaller package than navy bean AF powder. A similar result was found by Aslan and Ertaş (2021) for the bulk and tapped densities of chickpea AF powder, which were 0.762 and 0.815 g/cm^3, respectively.

The Carr index was used to assess flowability, whereas the Hausner ratio measures cohesion. Both rely on the densities of bulk and tap. The flowability ranged from 4.16 % to 8.11 %, with navy bean AF powder having the highest value ($p \leq 0.05$). According to Asokapandian et al. (2016), the flowability value according to standards must be less than 15 %, with lower values indicating better flow quality of powder materials. This means that, while all samples meet the required value, the commercial creamer outperforms both powders, followed by chickpea AF powder. The results also show that all samples had a cohesiveness value below the standard value of 1.18, with no significant differences ($p > 0.05$). According to Aslan and Ertaş (2021), the cohesiveness values of AF chickpea powder varied from 1.04 to 1.07 based on the drying temperature. Our results are still superior to those of the Golzi et al. (2023) study, which found that navy bean AF powder had a Hausner ratio of 1.30 and a Carr index of 22 %.

Water in any powder serves as a plasticizer and influences the sticking point temperature and glass transition. Hygroscopicity is described as the powder's tendency to collect moisture from a high-relative humidity environment in order to reach equilibrium with the atmosphere. It is critical since it is dependent on drying and storage conditions, as well as suitable packaging. It primarily impacts chemical, physical, and microbiological stability (Juarez-Enriquez et al., 2017). Hygroscopicity varied significantly among samples ($p \leq 0.05$). Navy bean AF powder had the greatest value (14.07 %), followed by chickpea. This means that both powders, particularly navy beans, require special storage conditions away from humid environments, as well as the inclusion of anti-caking chemicals such as calcium carbonate. The commercial creamer has minimal hygroscopicity due to the inclusion of an anti-caking agent, silicon dioxide, as stated on the label. Aslan and Ertaş (2021) found higher values (18.56–22.83 %) in chickpea AF powder, possibly due to the different chickpea cultivars.

Wettability is defined as the time necessary for liquid to pass via capillary forces in the powder bulk (Tontul et al., 2016). As seen in Table 2, both AF powders take significantly longer time to get completely wet than the commercial creamer ($p \leq 0.05$). Aslan and Ertaş (2021) found that adding foam stabilizers such as carboxymethyl cellulose and Na-alginate to chickpea AF powder resulted in longer durations (19.95–18.40 min). Acceptable and desirable wettability is defined as less time and faster solubility (Dehghannya et al., 2018), which is achieved by the currently tested AF powder. Higher wettability in AF of legumes is also associated with a higher amount of soluble carbohydrates (Golzi et al., 2023).

The water solubility index (WSI) of a powder is an indicator of the amount of soluble particles in a sample (Aslan & Ertaş, 2021). The WSI of the various AF powders was not statistically different ($p > 0.05$), but they were significantly lower than the commercial creamer. That could be owing to the presence of emulsifiers such as mono- and di-glycerides of fatty acids and sodium stearoyl lactylate in the latter. According to Rosida et al. (2016), the solubility of a powder material is correlated with its water content; high water content causes low solubility because it forms clumps that take a long time to break the bonds between the particles and affect the product's ability to dissolve. This may help to explain the differences between AF powders based on their moisture content (Table 1). The WSI of canned chickpea AF powder was 80.28 %,

Table 2

Physical properties of aquafaba powder of chickpea and navy bean in comparison with the commercial coffee creamer.

Sample	Bulk density	Tapped density	Carr index	Hausner ratio	Hygroscopicity	Wettability	WSI	WAI
	g/cm^3	g/cm^3	%		mg/100 g dw	minute	%	%
Chickpea	*$0.57^{b} \pm 0.015$	$0.60^{b} \pm 0.00$	$7.41^{b} \pm 0.001$	$1.06^{a} \pm 0.028$	$13.71^{b} \pm 0.07$	$4.20^{a} \pm 0.07$	$69.90^{b} \pm 5.25$	$0.63^{a} \pm 0.012$
Navy bean	$0.60^{ab} \pm 0.000$	$0.65^{a} \pm 0.01$	$8.11^{a} \pm 0.162$	$1.10^{a} \pm 0.017$	$14.07^{a} \pm 0.09$	$4.25^{a} \pm 0.00$	$77.80^{b} \pm 0.69$	$0.48^{b} \pm 0.034$
Commercial coffee creamer	$0.63^{a} \pm 0.009$	$0.66^{a} \pm 0.01$	$4.16^{c} \pm 0.006$	$1.04^{a} \pm 0.000$	$13.20^{c} \pm 0.10$	$2.44^{b} \pm 0.08$	$98.93^{a} \pm 0.00$	$0.04^{c} \pm 0.000$

[*] Different letters within the rows indicate significant difference at ($p \leq 0.05$) as calculated by Tukey's test.

whereas that made from soybean was higher at 81.06 %, according to Kim and Shin (2022), which is close to the results of the current study.

The water absorption index (WAI) measures the powder's ability to absorb water. It is the amount of water absorbed per gram of dry sample and is related to the reconstitution of the powder in liquids. In addition to wettability, WSI and WAI are crucial in coffee creamers since they must be easily soluble in coffee (Rosida et al., 2016). Both AF powders had higher WAI than commercial creamer ($p \leq 0.05$), with chickpea having the greatest value. The WAI of cooked chickpea AF examined by Aslan and Ertaş (2021) was greater than the value found in our investigation (2.82%). That could be related to the legume preparation method. Additionally, samples with higher protein content not only had more small protein particles but also contained smaller starch fragments that contributed to high WAI values (Pelgrom et al., 2013). Golzi et al. (2023) reported that WAI of the freeze-dried navy bean AF ranged from 0.37 to 0.46%, which is comparable to the most recent record.

Color values can affect the consumer's acceptability of coffee. The color analysis was performed to evaluate the foam of fresh AF before dehydration and after adding AF powder to the coffee (Table 3). The L* value varied dramatically across AF samples and the commercial creamer, with chickpea AF foam being the lightest, followed by navy bean. Similarly, a* values varied between samples ($p \leq 0.05$) and were all negative. Navy bean AF foam recorded the highest a* value score (−1.47), meaning it tends to be light green. Chickpea AF foam had the greatest b* value, indicating a bright green-yellow tint, while commercial creamer had the lowest ($p \leq 0.05$). Nguyen et al. (2021) conducted the only study to investigate the color properties of AF foam. Near values were recorded in chickpea AF foam (L* = 87.61, a* = −1.07, b* = 4.66), but no reports on AF navy bean foam.

The term chroma refers to color saturation degree, often known as chromatic intensity. Hue, on the other side, is the range of colors and their pigments on the color wheel. Hue ranged from red (0°) to yellow (90°), green (180°), blue (270°), and black to red (360°). Both are important in color characteristics because they represent the tone and brightness of the sample (Pandiselvam et al., 2023). The chroma value of chickpea foam was much higher, indicating a higher intensity than navy bean foam and commercial creamer. This is explained by the fact that it has the greatest b* value. In contrast, the commercial creamer outperformed the tested AF foam in terms of color hue angle ($p \leq 0.05$). This is explained by its low a* value.

Regarding the color attributes of instant coffee beverage after the addition of AF powder (1 %), Table 3 indicates that this addition has a significant ($p \leq 0.05$) effect on color characteristics, including L* and b*. It decreased the L* value, which means the coffee became darker. The addition of both AF powders to the coffee did not substantially affect a* readings ($p > 0.05$). On the other hand, the b* value of coffee was (+ yellow), which was greatly reduced by adding AF powder. Coffee with chickpea AF powder has a lower b* value compared to navy bean ($p \leq 0.05$), resulting in a deeper yellow color. The inclusion of AF powder also influences the chroma of the instant coffee beverage. It decreased more with the addition of AF chickpeas than with AF navy bean powder. The hue angle of the instant coffee beverage remained consistent in the case of AF navy bean; however, it decreased significantly with the addition of AF powder of chickpea. All coffee samples had hue values ranging between 0 and 90°, indicating a red-yellow hue. Golde and Schmidt (2005) found that coffee with soy protein isolate added as a creamer had higher a* and b* values than coffee with sodium caseinate creamer. Hue was higher and chroma was lower in coffee made with soy protein isolate than in coffee made with sodium caseinate, as demonstrated in this study, particularly with chickpea AF. Kim and Shin (2022) also discovered a decrease in the a* and b* values of muffin crust and crumb when AF powder from canned chickpeas or soybeans was added (2.5 %) compared to muffins made with egg white powder. That suggests a lower whitening ability of AF powder, which is also demonstrated by plant protein isolates such as soy and wheat (Golde & Schmidt, 2005).

3.3. *The impact of AF powder addition to instant coffee*

The physicochemical parameters of free instant coffee beverage were compared to those of AF powder-added coffee. Table 4 depicts the changes in coffee after the addition of 1 % AF powder. It should be noted that the addition of AF powder greatly raised the soluble solids, pH (from 4.84 to 5.16), and protein content (by 11.74 %–15 %), while decreasing the acidity (by 3.85 %–14 %) of free instant coffee beverage. The AF powder has a higher protein content and pH (5.58–6.02) (Table 1) compared to free coffee (4.8), which explains these changes. Furthermore, the reducing sugar content of free instant coffee was dramatically increased by AF addition ($p \leq 0.05$), with the sweetest coffee being that including chickpea AF powder. This indicates that coffee will often have a reduced acidity, a higher protein content, and a sweeter taste when AF powder is added.

Coffee is known as a rich source of phenolic compounds such as caffeic, ferulic, and chlorogenic acids, with variations among brands ranging from 94.2 to 129.5 mg GAE/g dw (Lee et al., 2019). The current investigation found that instant coffee contains 116.59 μg gallic acid/mL. Interestingly, the addition of 1 % AF chickpea powder considerably raised the total phenolic content of coffee ($p \leq 0.05$), but not navy bean ($p > 0.05$). That could be connected to the phenolic compound concentration of AF chickpea powder, which is roughly double that of navy bean powder (Table 1). These compounds play a key role in the prevention and management of diabetes, obesity, and related illnesses (de Araújo et al., 2021), and AF chickpea-added instant coffee is the best option. Although there are no reports of AF addition to coffee, several studies have revealed the phenolic component content of chickpea and navy bean seeds (Gan et al., 2017; Ganesan & Xu, 2017).

In terms of anti-nutritional chemicals, instant coffee contains detectable levels of hydrolyzed and condensed tannins. Besides caffeine, they are responsible for coffee's bitter taste. Its anti-nutritional effect stems mostly from its propensity to form strong complexes with proteins and impede the absorption of micronutrients like iron, resulting in poorer protein bioavailability and nutritional value (de Araújo et al., 2021; Mostafa, 2023). The addition of AF chickpea powder significantly reduced hydrolyzable tannins by 25 %, whereas the addition of AF navy bean did not affect them appreciably ($p > 0.05$). That could be because navy beans contain more tannin in their outer skin (Ross et al., 2010). On the other hand, condensed tannins were dramatically reduced by AF addition, particularly with navy bean. It may be due to destroying

Table 3
Color attributes of aquafaba foam of chickpea and navy bean in comparison to the commercial coffee creamer, and the coffee-added chickpea and navy bean powder (1 % dw/v) in comparison to the free instant coffee beverage.

	Sample	L*	a*	b*	Chroma*	Hue°
Aquafaba foam	Commercial coffee creamer	*$84.84^{c} \pm 0.34$	$-2.22^{c} \pm 0.07$	$5.30^{c} \pm 0.17$	$5.74^{c} \pm 0.15$	$-67.30^{a} \pm 0.77$
	Chickpea	$89.45^{a} \pm 0.93$	$-1.67^{b} \pm 0.01$	$8.06^{a} \pm 0.15$	$8.32^{a} \pm 0.01$	$-78.29^{b} \pm 0.20$
	Navy bean	$86.50^{b} \pm 0.23$	$-1.47^{a} \pm 0.02$	$7.43^{b} \pm 0.01$	$7.57^{b} \pm 0.17$	$-78.80^{b} \pm 0.16$
Coffee + aquafaba powder	Free instant coffee	$42.73^{a} \pm 1.41$	$17.66^{a} \pm 0.56$	$33.58^{a} \pm 1.60$	$37.85^{a} \pm 1.16$	$62.61^{a} \pm 1.78$
	Chickpea	$36.23^{c} \pm 0.92$	$17.37^{a} \pm 0.19$	$24.08^{c} \pm 1.23$	$29.70^{c} \pm 0.88$	$54.22^{b} \pm 1.69$
	Navy bean	$39.46^{b} \pm 0.53$	$17.02^{a} \pm 0.54$	$28.34^{b} \pm 0.50$	$33.06^{b} \pm 0.35$	$59.03^{a} \pm 1.13$

* Different letters within the rows indicate significant difference at ($p \leq 0.05$) as calculated by Tukey's test.

Table 4
Physicochemical properties of coffee-added aquafaba of chickpea and navy bean (1 %, dw/v) in comparison to the free coffee beverage.

Sample	TSS	pH	Acidity	Protein	Reducing sugars	Phenolic compounds	Anti-nutritional factor	
							Hydorlyzable tannins	Condensed tannins
	°Brix		% (as acetic acid)	mg/mL	mg/mL	μg GAE/mL	mg/100 mL	mg/100 mL
Free coffee	*1.0^{b} ± 0.00	4.84^{b} ± 0.007	0.700^{a} ± 0.00	3.66^{b} ± 0.004	6.93^{c} ± 0.00	116.59^{b} ± 1.06	390.50^{a} ± 13.43	141.54^{a} ± 17.44
Coffee + chickpea AF powder	1.9^{a} ± 0.14	5.16^{a} ± 0.014	0.673^{ab} ± 0.036	4.21^{a} ± 0.007	7.55^{a} ± 0.03	121.53^{a} ± 2.06	290.00^{b} ± 14.14	99.20^{ab} ± 2.82
Coffee + navy bean AF powder	2.0^{a} ± 0.00	5.07^{a} ± 0.014	0.602^{b} ± 0.007	4.09^{a} ± 0.013	7.39^{b} ± 0.01	115.37^{b} ± 1.63	300.00^{ab} ± 10.00	87.87^{b} ± 6.59

[*] Different letters within the rows indicate significant difference at ($p \leq 0.05$) as calculated by Tukey's test.

tannins during pasteurization either by hydrolyzing them to tannic acid or by polymerizing and becoming insoluble in water. Also, the reduction might be due to the formation of complexes with AF proteins (Alsalman et al., 2020). Condensed tannins are the primary cause of the product's sensory features, mainly astringency and bitterness (Ju et al., 2021). Thus, instant coffee made with AF contains fewer tannins and may have a less bitter taste.

3.4. *Foaming attributes*

The quality of aerated food products is assessed using two criteria: foamability and foam stability. Foamability refers to the continuous phase's air inclusion capability, whereas foam stability refers to its ability to retain gas for a set period (Lima et al., 2024). Fig. 1A depicts the foamability of the AF liquid of the two investigated legumes. The volume created from 50 mL of canned chickpea and navy bean was 215 mL and 195 mL, indicating a foam expansion of 430 % and 390 %, respectively. This could be attributed to the greater protein content of chickpea AF powder compared to navy beans (Table 1). Shim et al. (2018) studied the foaming attribute of AF from commercially canned chickpeas, which ranged from 400 to 500 %, whereas Golzi et al. (2023) found a range of 230–354 % in navy bean AF powder. Fig. 1B further demonstrates that the foam of navy bean remained consistent for 3 h; however, the volume of chickpea AF liquid decreased after 1.5 h and lost 62.5 % of its original volume after 3 h. In agreement, Shim et al. (2018) discovered that after 1 h, the liquid was separated from all canned chickpea foam except one brand. After a further 14 h, the foam disappeared from all samples except the brand with resistant foam. Regarding the navy bean, Tabtabaei et al. (2019) discovered that dry-enriched navy bean protein concentrates had greater foam expansion and stability than wet navy bean protein isolates. They attributed the remarkable whip-ability and foam stability to the high solubility. That may explain the current study's findings regarding the foamability of chickpea AF, which has a greater WAI than navy bean AF (Table 2). The high WAI value could be attributed to the greater availability of the polar amino acids on the surface of the proteins. That may attract a disproportionate amount of water, thereby dehydrating other components in the fractions. In addition, protein samples with higher protein content not only had more small protein particles but also contained smaller starch fragments, contributing to higher WAI values (Pelgrom et al., 2013), as also demonstrated in chickpea AF. On the other hand, the foam stability of AF navy bean is mostly related to its carbohydrate content (Table 1). Polysaccharides can stabilize foams and emulsions using a different mechanism. Once disseminated in water, they increase bulk viscosity and enhance stability against coalescence. When combined with proteins, they can interact with them via hydrophobic, hydrogen bonding, and electrostatic interactions, resulting in a synergistic impact (Miquelim et al., 2010).

Aside from scent, color, and taste in coffee-based beverages, the presence of rich, persistent foam is a significant quality factor for coffee drinkers (Shankaran & Chinnaswamy, 2019). Coffee foam is a coarse, bibasic dispersion made up of coffee liquid and spherical, tiny gas bubbles enclosed by a lamella. The coffee foam plays many roles, apart from providing an aesthetic appeal; it collects volatile coffee odors and

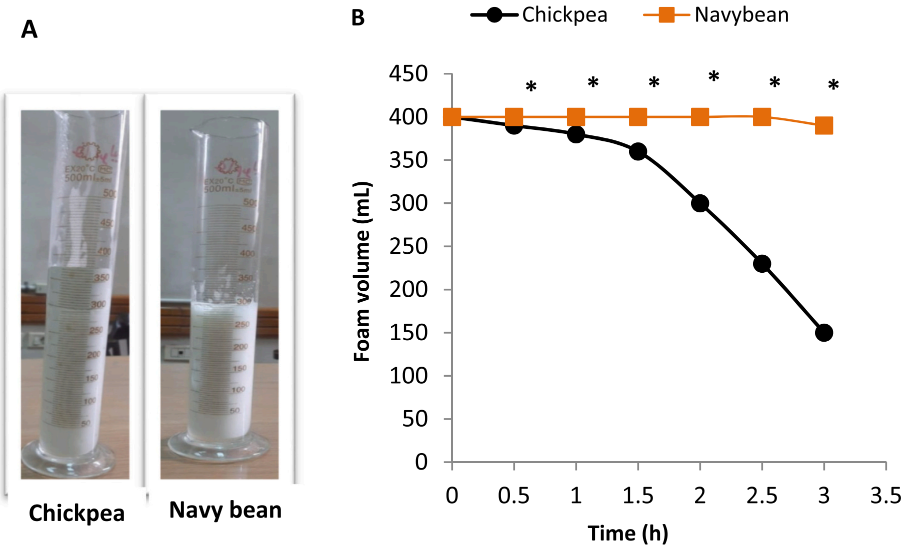


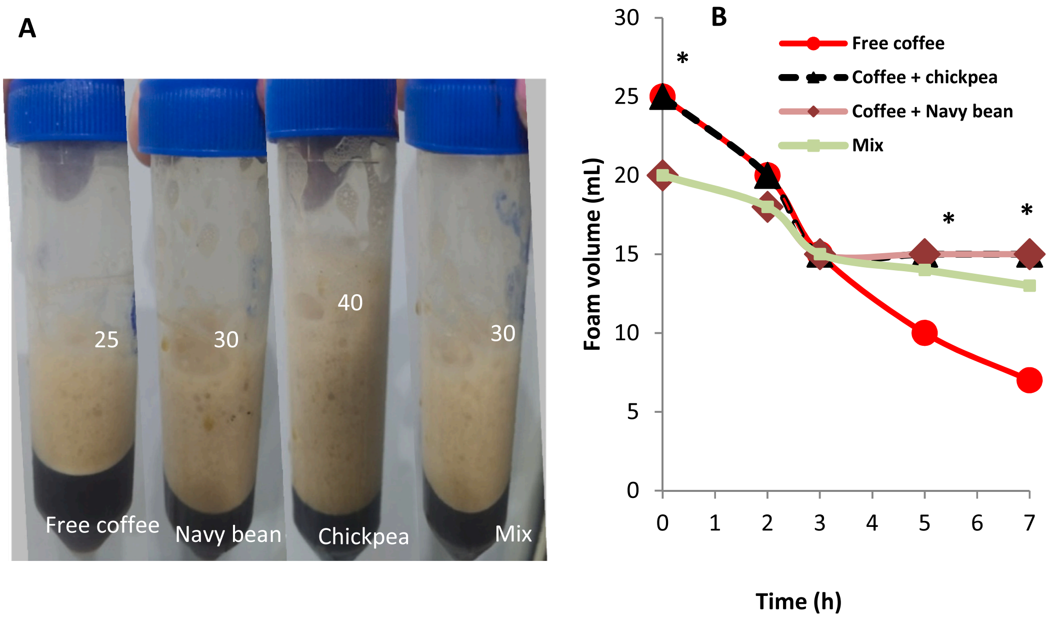
Fig. 1. Foam capacity (A) and stability (B) of chickpea and navy bean aquafaba.
* Indicate statistically significant differences between the samples (p-value ≤ 0.05).

functions as an insulator to keep the coffee temperature stable for longer periods (Illy & Viani, 2005). Therefore, the AF powder of chickpea and navy bean was evaluated as a foam booster in instant coffee, which has not previously been tried.

The foam qualities were tested after being added to instant coffee at a concentration of 1 % dry weight or as a blend with a concentration of 0.5 % of each in order to assess the foamability and stability of AF powder. The foam characteristics of the instant coffee beverage varied greatly among samples (Fig. 2A), even though it was examined after pasteurization. The chickpea-added coffee sample had the maximum foam volume, followed by the navy bean sample, whereas the capacity for free coffee foam was 25 mL. Instant coffee with an equal ratio of chickpea and navy bean AF powder (0.5 %) has a foamability that is similar to coffee with navy bean AF alone ($p > 0.05$).

The foam stability was also significantly different between the samples (Fig. 2B). The free instant coffee's foam stability was steady for 1 h before dropping by 72 % to its lowest volume after 7 h. Interestingly, although having a lower volume than free coffee and coffee with chickpea, the coffee with navy bean AF maintained foam stability for 7 h, losing only 25 % of its volume. Chickpea-added coffee and mixed samples lost 40 % and 35 % of their initial volume, respectively, in the same period. The prepared coffee samples with tap water exhibited significantly higher foamability in all samples (Fig. 2C) than that prepared with distilled water. That may be due to the presence of certain compounds in tap water, such as nitrogen and phosphorus, which also cause the foamy tap water phenomenon (Domo'n et al., 2024).

There are many reasons explaining the foamability and stability of both AF liquid and powder. AF chickpea foamability in both liquid and powder forms was superior to that of a navy bean, although foam stability was the inverse. These data pertain to the protein and carbohydrate content because they are related to both foamability and foam stability. Chickpea AF has greater protein content than navy beans, whereas navy bean AF powder contains more sugar (Table 1). Because proteins are more hydrophobic due to the makeup of their side chains, they contribute significantly to foaming (Miquelim et al., 2010), while foam stability depends on the polysaccharide content that interacts with proteins, especially in espresso coffee (Nunes & Coimbra, 1998). This could explain the foam stability of instant coffee-added navy bean AF. Stantiall et al. (2018) evidenced the higher foaming ability of the AF liquid of Garbanzo chickpeas than navy beans (58 % vs. 37 %), but there was no information provided regarding the differences in foaming stability. In addition, there are no reports on their foaming qualities when combined with coffee.



C

Water type	Foam capacity (mL)			
	Free coffee	Navy bean	Chickpea	Mix
Distilled water	†25.00^{Bc} ± 0.00	30.16^{Bb} ± 0.28	40.33^{Ba} ± 0.28	†30.33^{Bb} ± 0.28
Tap water	26.16^{Ac} ± 0.28	31.16^{Ab} ± 0.28	41.50^{Aa} ± 0.5	31.50^{Ab} ± 0.00

Fig. 2. Foam capacity (A) and stability (B) of instant coffee beverage with additional chickpea and navy bean aquafaba powder (1 %, dw/v) or their mix (0.5 % each, dw/v). (C) Comparison of foamability of different samples prepared by distilled water or tap water.
* Indicates statistically significant differences between the samples (p-value ≤ 0.05). †Superscript letters indicate significant differences between rows, while subscript letters between columns (p-value ≤ 0.05).

3.5. LC-Q-Orbitrap-HRMS analysis

The Q-Exactive Orbitrap/MS instrument was configured to perform full MS/vDIA scans in both positive and negative ion modes. A comprehensive mass scan was performed as the initial stage, which served multiple purposes: it screened for target compounds, qualitatively analyzed them, and allowed for the examination of unknown substances. The AF powder of chickpeas and navy beans was examined in this study. The analysis included nine protein compounds, ten saccharide compounds, eight phenolic compounds, and seven saponin compounds. The objective was to comprehensively compare the chemical profiles of these two AF variants and thoroughly characterize their compositions. The relative abundance of the discovered substances, which included proteins, saccharides, phenols, and saponins, in each AF type was determined by looking at their peak area (Supplementary 1), which was derived from the HRMS data and recorded in Table 5 for comparative analysis. A higher peak area indicates a higher relative abundance of the corresponding compound in the AF sample.

In the protein compound screening, albumin-2, defensins, glutenin, legumin, lipoxygenase, non-specific lipid transfer proteins, thaumatin, and vicilin were more abundant in chickpeas than in navy bean AF powder. Conversely, phaseleosin was more prevalent in navy bean AF powder than in chickpeas. The total of these protein types was higher in chickpea AF powder than in navy bean powder, aligning with the results shown in Table 1. These results are consistent with findings by Stantiall et al. (2018), who reported a protein content of 0.95 g/100 g in garbanzo chickpea cooking water that was higher than that of haricot beans (0.70 g/100 g). The breaking of pulse hulls during the cooking process facilitates protein release into the water. Choden et al. (2023) also found distinct bands in SDS-PAGE in chickpea AF, including albumin, glutelin, vicilin, and legumin. There are no reports on the protein types of navy bean AF, just those found in navy bean seeds (Jafari et al., 2016).

Table 5 also depicts that the total polysaccharides screened are higher in navy bean AF powder than in chickpea AF powder. Arabinogalactobiose, arabinose, diagalacturonic acid, galactose, galacturonic acid, glucose, maltose, maltotriose, trigalacturonic acid, and xylose were found in greater peak areas in navy bean compared to chickpea AF. On the other hand, diagalacturonic acid and trigalacturonic acid were not detected in chickpea AF powder. These observations are in agreement with the polysaccharide content in the seeds of both legumes reported in a previous study (Begum et al., 2023).

Screening for phenolic compounds revealed that chickpea AF contained a higher quantity of the screened phenolic compounds than navy bean AF, consistent with the Folin-Ciocalteu analysis results (Table 1). Navy bean AF contained higher levels of chlorogenic, ferulic, and gallic acids compared to chickpea AF. The opposite was seen for caffeic, coumaric, and sinapic acids, as well as quercetin and kaempferol. These variances are most likely attributable to genetic polymorphisms between chickpeas and navy beans. Chickpeas may naturally synthesize higher levels of these compounds as part of their defense mechanisms or metabolic pathways.

As shown in Table 5, data from saponin compound screening showed that navy bean AF had a greater concentration of these compounds than chickpea AF, except for soyasaponins I. The quantities of hederagenin glycosides, lablaboside C, kaikasaponin, oleanolic acid, zanhic acid diglycosides, and aglycone were higher in navy bean AF than in chickpea, which aligned with the results of total saponin content. Soyasaponin I, on the other hand, was more prevalent in chickpea AF. Low molecular-weight components such as saponins, known for their foaming capabilities, may have helped develop a larger foam volume, enhancing foam capacity values (Choden et al., 2023). Here, the high saponin content of navy bean AF may explain its foam stability. The LC-

Table 5
Comparison between aquafaba powder of chickpea and navy bean by LC-Q-Orbitrap High-Resolution Mass Spectrometry.

Group	Compound	Precursor ion	Area		Ionization mode
			Chickpea	Navy bean	
Proteins	Albumin-2	1001.03846	1,047,530	275,888	Positive
	Defensins	1001.0000	3,063,911	113,165	Positive
	Glutenin	1002.9688	1,132,049	111,227	Positive
	Legumin	575.2834	364,505	54,804	Positive
	Lipoxygenase	567.3192	138,249	113,717	Positive
	Non-Specific lipid transfer proteins	890.3333	976,970	21,243	Positive
	Phaseleosin	639.6721	58,741	115,870	Positive
	Thaumatin	1048.8095	412,360	81,825	Positive
	Vicilin	870.4785	966,496	241,587	Positive
Saccharides	Arabinogalactobiose	335.0949	184,667	1,938,650	Positive
	Arabinose	151.06160	50,297,912	65,578,710	Positive
	Diagalacturonic acid	369.0457	–	818,250	Negative
	Galactose	203.05320	3,544,765	245,784,756	Positive
	Galacturonic acid	193.0348	1,255,050	54,460,567	Negative
	Glucose	203.0528	32,873,813	2,037,575,055	Positive
	Maltose	365.1054	90,874,901	17,944,536,575	Positive
	Maltotriose	527.1580	20,521,701	826,254,260	Positive
	Trigalacturonic acid	545.0566	–	398,745	Negative
	Xylose	173.0422	570,952	5,976,735	Positive
Phenols	Caffeic acid	181.049536	1,164,002	316,405	Positive
	Chlorogenic acid	355.102514	175,594	4,862,668	Positive
	Coumaric acid	165.055400	176,381,876	2,709,866	Positive
	Ferulic acid	195.065186	274,004	7,999,034	Positive
	Gallic acid	171.028801	34,549	83,920	Positive
	Kaempferol	287.055014	584,200	57,712	Positive
	Quercetin	303.049929	145,720	11,478	Positive
	Sinapic acid	225.70638	1,479,341	558,798	Positive
Saponins	Hederagenin glycosides	911.5053	405,052	1,164,910	Positive
	Lablaboside C	1045.5584	101,587	58,360,514	Positive
	Kaikasaponin	941.5110	96,587	97,425,632	Positive
	Oleanolic acid	909.4897	179,337	4,169,564	Positive
	Soyasaponins I	941.5104	8,971,893	1,481,775	Positive
	Zanhic acid aglycone	487.3423	16,881	699,300	Positive
	Zanhic acid diglycosides	899.4897	231,449	1,544,580	Positive

HRMS data could explain the synergistic effect of the compounds detected in each AF powder and its foam capacity and stability.

4. Conclusion

The findings showed that there are notable differences in the chemical, physical, and functional properties of the dried AF powder of chickpeas and navy beans. Chickpea AF powder demonstrated its capacity to improve the foam of instant coffee, whereas navy bean powder demonstrated superior foam stability in this popular beverage. Their protein, carbohydrate, and saponin contents are primarily responsible for these variations. The LC-Q-Orbitrap-HRMS profile verified the variations of organic substances such as proteins, sugars, phenolic compounds, and saponins between these AF powders. The high percentage of proteins in chickpea AF powder as well as sugars and saponin in navy bean AF powder, as shown by LC-Q-Orbitrap-HRMS, partially explain the phenomenon of the high foam capacity of AF chickpea and the superior foam stability of navy bean, either as foam or after addition to instant coffee. Chickpea AF powder also has higher concentrations of the health-promoting polyphenols: caffeic, coumaric, and sinapic acids, as well as kaempferol and quercetin, than navy bean powder. The limitations of this study include the aroma of aquafaba, which may change the aroma of coffee at higher concentrations; therefore, we recommend the addition of flavors such as vanillin when it added to coffee. Additionally, the high value of hygroscopicity, especially of navy bean AF powder, requires special storage conditions away from humid environments, as well as the inclusion of anti-caking chemicals such as calcium carbonate. Finally, AF powder appears to be a viable plant-based alternative to coffee creamer, as it reduces acidity and tannin content but does not affect whitening. It may benefit those with casein allergies and can be sold as a non-dairy coffee foam enhancer. Additionally, it serves as a vegan option to improve coffee quality and, at the same time, add unique nutrients like phenolics and protein to the diet.

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CRediT authorship contribution statement

Heba Sayed Mostafa: Writing – review & editing, Writing – original draft, Visualization, Resources, Investigation, Formal analysis, Data curation, Conceptualization. **Omar Khaled:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation.

Declaration of competing interest

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2024.101961.

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