biology and life sciences forum

MDPI

Proceedings

Aquafaba: A Multifunctional Ingredient in Food Production †

Gamze Nil Yazici *, Tansu Taspinar and Mehmet Sertac Ozer,

Department of Food Engineering, Faculty of Engineering, Cukurova University, 01330 Adana, Turkey
* Correspondence: gnboran@cu.edu.tr
† Presented at "The 3rd International Electronic Conference on Foods: Food, Microbiome, and Health - A Celebration of the 10th Anniversary of Foods' Impact on Our Wellbeing", Online, 01-15 October 2022.

Abstract: Recently, demand of consumers for plant-based foods to replace meat, egg, and dairy products by mimicking their structure with alternatives in many food applications has grown significantly. This tendency is driven by many reasons mainly comprised of allergenicity, different dietary preferences of consumers, and sustainability issues. In this regard, aquafaba has a great potential to meet these requests/needs with its multi functionalities (foaming, emulsifying, gelling, and/or thickening, the ability/capacity of water-, and oil absorption/holding). In this regard, aquafaba takes place in general egg and/or fat replacer, and alternative to emulsifier and gelling agents mainly in baked goods, confectionery/desserts, and mayonnaise.

Keywords: Aquafaba; clean-label; pulse cooking water; egg replacer; emulsifier; fat replacer; plant-based; sustainability; vegan

Citation: Yazici, G. N.; Taspinar, T.; Ozer M. S.. Aquafaba: A Multifunctional Ingredient in Food Production. *Biol. Life Sci. Forum* **2022**, *2*, x. https://doi.org/10.3390/xxxxx

Academic Editor: Firstname Lastname

Published: date

1. Introduction

Nowadays plant-based foods and ingredients become widespread worldwide because of their not only health benefits but also advantages on environmental sustainability, and ethical issues [1], to replace animal sources like eggs, milk, and meat, as well [2]. Among those, egg replacement in food products also remains on the agenda. The reasons behind the egg replacement are health issues comprising egg allergy, phenylketonuria, high cholesterol concerns together with dietary patterns or religious beliefs, and economical reasons [3]. The reduction or replacement of food ingredients becomes one of the main technical challenges to address in therewith public health issues [4]. Although the term 'replacement of food ingredients' is not identified internationally, the replacement of a constituent present in the product to a greater or lesser extent with an alternative that should have the same and/or similar attributes in regards to organoleptic, microbial, and functional properties [5]. In this regard, the trends and innovations in bakery products take shape mainly consumer' health concerns apart from pleasure and industrial feasibility [6]. Therefore, the seeking of new ingredients for reformulation of food products by partial or total replacing ingredients has become a front-burner of researchers and the food industry [7], with aiming to minimize quality deterioration [8].

In this regard, aquafaba, which is generally discarded as food waste [9], a viscous liquid obtained from cooking pulses in water [10], could be a healthy, cruelty-free [11], clean-label, and plant-based multifunctional ingredient for food development, as an egg and/or fat replacer, and alternative to emulsifier and gelling agents. Aquafaba meets not only the demand of society, but also has positive socioeconomic environmental impacts [12], by minimizing waste of pulse processing, and thus maintaining food security and sustainability by lowering greenhouse gas footprint, and saving cost and energy, as well [2]. However, a recent study based on life cycle analysis pointed out that the environmental footprint of vegan mayonnaise made with aquafaba is higher compared to mayonnaise made with egg yolk. This was attributed to high electricity usage while aquafaba processing [11]. Therefore, more studies are needed to clarify this issue in other food products, as well.

2. The Functional Properties of Aquafaba

Aquafaba is a multifunctional ingredient with the ability of foaming, emulsifying, gelling, and/or thickening, water- and oil absorption/holding, with a wide pH and temperature range [12]. Recently, the microbiological properties regarding prebiotic activity and inhibition of pathogens are on the agenda, as well [13]. The aquafaba composition, particle size, and concentration in the formulation, together with process parameters such as temperature, pH, ionic strength, pressure, and some process agents such as salts, acids, bases, and enzymes [12], or the pre-and post-treatment, such as soaking and high pressure, respectively, influence the functionality of aquafaba. The main contributors to aquafaba composition are pulse genotype and variety, and growing conditions [14], and thus mainly their content of protein, water-soluble/insoluble carbohydrates, phenolic compounds, saponins, and coacervates are the main components that are responsible for the functional properties of aquafaba [2].

2.1. Foaming Properties

The foaming attributes of aquafaba are mainly associated with the content of low molecular weight proteins, especially albumin, polysaccharides, and saponin [14]. Among those, low molecular weight proteins (≤25 kDa), are well-known foaming and surface-active attributes. Moreover, it was revealed that there is a positive correlation (r^2 = 0.95) between the protein content of aquafaba and its foaming ability/capacity [2]. In general, the adsorption of protein at the gas and/or aqueous phase interface reduces interfacial energy, which enables the encapsulation of more bubbles and gives rise to the formation of more foam. The role of polysaccharides on foam stability is materialized by decreasing creaming and increasing viscosity. In this regard, the cross-links between polysaccharides and proteins may have a key role in foam stability [12]. Saponins have an amphiphilic structure including both a water-soluble glycoside and lipid-soluble aglycone, therefore assumed as a non-ionic surfactant. Therefore, they could reduce interfacial tension and facilitate forming foam and smaller droplets throughout the homogenization process. In this regard, they could be utilized as a foaming and/or emulsifying agent in the food industry [2]. The foaming ability/capacity of chickpea aquafaba was determined as nearly 40-290% [15], 182-480% [16], 127% [17], 162-324% [18]; whereas 93% aquafaba obtained from the split yellow pea, 97% in whole green lentil, 39% in haricot bean [19], 522-638% in lima bean [20]. Additionally foaming stability of chickpea aquafaba was defined as 7-58% [15], 74-92% [16], 95% [17], 3-93% [18].

2.2. Emulsifying Properties

The emulsifying properties of aquafaba are attributed to their content of protein, oligo- and polysaccharide, phenolic, and saponin. Among those, the factors which influence the emulsifying capacity of aquafaba regarding proteins and polysaccharides are not only molecular shape and charge, together with the ratio of hydrophobic to hydrophilic groups, but also the Maillard reaction which causes structural change by forming covalent complexes between those molecules have a potential to form amphiphilic biopolymers. Therefore they could enhance surface properties and, thus, improve foaming and emulsifying capacities [12]. The emulsifying ability/capacity of chickpea aquafaba was identified as 3.9-100% [21], [18], [22], [16]; 53% green lentils, 46% in haricot beans [21], 49% in split yellow peas [21], and yellow soybeans [19], as summarized in [12]. The emulsifying stability of chickpea aquafaba was detected as 60-80% [16].

2.3. Gelling Properties

One of the main contributors to gelling properties of aquafaba is water adsorption of soluble, low molecular weight carbohydrates. Aquafaba could form a weak hydrogel structure because of not only the content of water-soluble- carbohydrates and protein, as well as fiber mainly composed of cellulose and pectin but also their interactions [2]. There is limited study in the literature regarding the gelling and thickening facility of aquafaba, but as far as we know, aquafaba made from chickpea has the highest gelling properties when compared to those from other pulses [12]. Moreover, it was stated that while uncooked food products like mousse have comparable gelling properties with egg white, the gelling ability is poor in cooked products such as bread or meringue due to their low dry matter content which is mainly composed of insoluble fiber [2].

3. Using Aquafaba in Food Products

Aquafaba which was mostly derived from chickpea is utilized in mainly cakes among bakery products because of especially its foaming properties for partial and/or total egg replacement, mainly meringue formulation among confectionary products as an egg white replacer, and mayonnaise as an egg-or fat replacer. However, there is no consensus about the influence on food products, as summarized in Table 1. This could be attributed to different food formulations including different ingredients with different concentrations, the composition of aquafaba which is affected by genotype and variety, and growing conditions of pulses, together with parameters of pre- and post-processes.

Table 1. The aquafaba sources, their role, and major findings in aquafaba- based food products.

End product	Aquafaba source(s)	Role of aquafaba	Major findings	References
Cake	Chickpea (Commercially canned)	Egg white replacer	Moisture↓, pH↓^, Baking loss↑^, Height↓, Volume index↓, Colour(crust): L*↓, a*↑, b*↑^, Texture(crumb): hardness↓^, chewiness↓, springiness↓, cohesiveness↓, resilience↓^	[16]
Cake	Chickpea	Egg replacer	**Batter:** pH↓, Specific gravity↓; **Cake:** Volume index↓, Symmetry index↓, Baking loss↔, Colour(crumb): L*↑, a*↓, b*↓, Texture: firmness↑	[17]
Cake	Lima bean	Egg replacer	Specific volume↔, Baking loss↓, Colour(crust):L*↓, a*↔, b*↓, Texture: hardness↓, chewiness,↓, springiness↓, cohesiveness↓	[20]
Gluten-free bread	Chickpea	Hydrocolloid alternative for texture improvement	**Dough:** Peak viscosity↔, Breakdown↔, Final viscosity↔, Setback↓, Peak time↑; **Bread:** Moisture↔, Baking loss↔, Height↔, Specific volume↔, Colour: L*↔ a*↑, b*↓, Texture: hardness↓	[24]
Gluten-free bread	Haricot beans, garbanzo chickpeas, whole green lentils, split yellow peas yellow soybeans	Emulsifier	**Dough**: Peak viscosity↔, Breakdown↔(except yellow soybean), Final viscosity↔, Setback↑(except haricot beans, whole green lentils), Peak time↔(except yellow soybean); **Bread**: Moisture↔, Specific volume↑, Colour: L*↓(except split yellow peas), b*(except garbanzo chickpea, split yellow peas), Texture: hardness↑(except garbanzo chickpea, split yellow peas), chewiness↓, springiness↔, cohesiveness↓	[25]
Gluten-free cracker	Yellow soybeans	Emulsifier	Moisture (0.day)↓, Moisture (2.day)↑, Colour: L*↔, b*↑, Texture: hardness (0.day)↔, hardness (2.day)↓	[19]*
Meringue	Chickpea	Egg replacer	Colour: L*↓, Texture: hardness↓, consistency↓, adhesiveness↓	[22]

		Haricot beans, garbanzo chickpeas, whole green lentils, split yellow peas	Egg white replacer	Moisture↓, Height↔(except haricot beans), Specific volume↑(except haricot beans), Colour: L*↔, a*↔(haricot beans, split yellow peas), b*↔(haricot beans, split yellow peas), Texture: hardness↔(garbanzo chickpea, whole green lentils); hardness↑(haricot beans, split yellow peas), extensibility↓, Sensory: appearance↓(except split yellow peas), taste↓(except split yellow peas), texture↓ (except split yellow peas), overall preference↔	[26]
		Chickpea	Egg white replacer	Colour: L*↔, b*↔, Sensory^: flavor↓, texture↑, overall acceptance↓, acceptability index↓	[18]
	Mousse	Garbanzo chickpeas, split yellow peas	Egg white replacer	Sensory: color ↔, glossiness↔, aroma↔, sweetness↔, smoothness↔, flavor↑, overall preference↑	[21]
	Macaron	Chickpea (Commercially canned)	Egg white replacer	Height increase↓^, Width,↓^, Yield↓^, Sensory^ (just for regarding 5 scores): taste↓, texture↓, appearance↓	[29]
	Mayonnaise	Chickpea (Commercially canned)	Egg replacer, fat replacer	Colour: L*(0.day and 28.day)↔, a*(0.day and 28.day), b*↓^(0.day and 28.day), Texture: firmness↓, adhesive force↓, adhesiveness↓, cohesiveness↔	[30]
		Chickpea	Egg white replacer	Colour: L*↓, a*↔, b*↑, Sensory*: flavor↓, texture↓, overall acceptance↓, acceptability index↓	[18]
		Chickpea	Egg replacer	pH↔, Brix↑^, Viscosity↑^, Texture: firmness↑, consistency↑, cohesiveness↔, Sensory: appearance↑, color↑, aroma↔, taste↔, Bacterial load↓^	[31]
		Chickpea	Egg replacer, emulsifier	pH↓, Emulsion stability↓, Heating stability(freeze-dried)↑, Heating stability(spray-dried)↔, Colour: L*↓, b*↓	[32]
	Non-dairy yoghurt	ND	Gelling agent	pH↑, Titrable acidity↑, WHC↑, Syneresis↓, Texture: hardness↑, adhesiveness↑, gumminess↑, chewiness↑^, Viable counts of *S. thermophilus* and *L. bulgaricus*↑	[33]
	Whipped cream	Chickpea	Egg white replacer	Average diameter↑, Texture: hardness↓, adhesiveness↔, cohesiveness↑, springiness↑, gumminess↓, chewiness↑	[34]
	Non-dairy ice-cream	Chickpea, split yellow pea	Emulsifier	Colour: L*↔, a*↑(chickpea), a*↔(split yellow pea), b*↑(chickpea), b*↔(split yellow pea), Texture: hardness↑^, Sensory: color ↔, creaminess↔, sweetness↔, overall acceptability↓(chickpea), overall acceptability↔(split yellow pea)	[35]*

↓ indicates increment is statistically different; ↑ indicates decrease is statistically different.; ↔ indicates increment or decrease is not statistically different; WHC: water holding capacity, ND: not defined, x: Results were compared according to increase in fat replacement ratio, y: Results were compared according to increase in soaking time, z: Results were given for 28. day of storage, ^ Results were not given statistically, *The soaking water of different pulses used in corresponding food formulation.

4. Conclusion

Aquafaba is a new era for researchers and food manufacturers because of its nutritional and functional properties which allow use in a wide range of food products. Moreover, it gives an opportunity to reduce environmental load, by recycling by-products into value-added food ingredients. Therefore, it is a promising clean-label and eco-friendly ingredient for sustainable food production and a circular economy. However, there are restrictions on the quality standardization of aquafaba and applied food products for industrialization and commercialization, because of several factors affecting the composition of aquafaba. In addition, although some researchers focused on drying aquafaba regarding low aw and thus increase shelf life, more studies are needed for the optimization of different drying methods and process parameters are important for industrialization, as well. Moreover, although the amount and activity of the anti-nutritional compound of aquafaba are generally lower than raw seeds, more studies should affirm this issue. Future studies should also head for the application of aquafaba to more food products and its effects on the quality of end products, even regarding gluten-free and non-dairy food products.

Funding: This study was funded by CUKUROVA UNIVERSITY, TURKEY by FBA-2021-14058 project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Boukid, F.; Gagaoua, M. Vegan egg: A future-proof food ingredient? *Foods*. **2022**, *11*, 161. https://doi.org/10.3390/foods11020161.
2. He, Y.; Meda, V.; Reaney, M.J.T.; Mustafa, R. Aquafaba, a new plant-based rheological additive for food applications. *Trends Food Sci. Technol*. **2021**, *111*, 27–42. *https://doi.org/*10.1016/j.tifs.2021.02.035.
3. Yazici, G.N.; Ozer, M.S. A review of egg replacement in cake production: Effects on batter and cake properties. *Trends Food Sci. Technol.* **2021**, *111*, 346–359. https://doi.org/10.1016/j.tifs.2021.02.071.
4. Hutchings, S.C.; Low, J.Y.Q.; Keast, R.S.J. Sugar reduction without compromising sensory perception. An impossible dream? *Crit. Rev. Food Sci. Nutr*. **2019**, *59*, 2287–2307. https://doi.org/10.1080/10408398.2018.1450214.
5. Suna, S.; Çopur, Ö.U. A new approach: Replacement and alternative foods for food industry. In *Alternative and Replacement Foods,* 1st ed.*;* Alina Maria, H., Alexandru Mihai, G., Eds.; Elsevier Inc., 2018; Volume 17, pp. 1-30. doi:/10.1016/C2016-0-00621-6.
6. Martínez-Monzó, J.; García-Segovia, P.; Albors-Garrigos, J. Trends and innovations in bread, bakery, and pastry. *J. Culin. Sci. Technol.* **2013**, *11*, 56–65. *https://doi.org/*10.1080/15428052.2012.728980.
7. Di Monaco, R.; Miele, N.A.; Cabisidan, E.K.; Cavella, S. Strategies to reduce sugars in food. *Curr. Opin. Food Sci*. **2018**, *19*, 92–97. https://doi.org/10.1016/j.cofs.2018.03.008.
8. Peng, X.; Yao, Y. Carbohydrates as fat replacers. *Annu. Rev. Food Sci. Technol.* **2017**, *8*, 331–351. https://doi.org/10.1146/annurev-food-030216-030034.
9. Aslan, M.; Ertaş, N. Foam drying of aquafaba: Optimization with mixture design. *J. Food Process. Preserv*. **2021**, *45*, e15185. https://doi.org/10.1111/jfpp.15185.
10. He, Y.; Shim, Y.Y.; Mustafa, R.; Meda, V.; Reaney, M.J.T. Chickpea cultivar selection to produce aquafaba with superior emulsion properties. *Foods*. **2019**, *8*, 1–16. https://doi.org/10.3390/foods8120685.
11. Saget, S.; Costa, M.; Styles, D.; Williams, M. Does circular reuse of chickpea cooking water to produce vegan mayonnaise reduce environmental impact compared with egg mayonnaise? *Sustain*. **2021**, *13*, 4726. *https://doi.org/*10.3390/su13094726.
12. Mustafa, R.; Reaney, M.J.T. Aquafaba, from food waste to a value-added product. In *Food Wastes and By-products: Nutraceutical and Health Potential*, 1st ed.; Rocio Campos-Vega, B., Dave, O., Haydé Azeneth,V.-C., Eds.; John Wiley & Sons Ltd., 2020; pp. 93–126. https://doi.org/10.1002/9781119534167.
13. Serventi, L. Gao, C., Chen, M., Chelikani, V. Cooking water functional properties. In *Upcycling Legume Water: From Wastewater to Food Ingredients,* 1st ed.*;* Springer, 2020; pp.87-103. https://doi.org/10.1007/978-3-030-42468-8.
14. Erem, E.; Icyer, N.C.; Tatlisu, N.B.; Kilicli, M.; Kaderoglu, G.H.; Toker, Ö.S. A new trend among plant-based food ingredients in food processing technology: Aquafaba. *Crit. Rev. Food Sci. Nutr*. **2021**, *0*, 1–18. https://doi.org/10.1080/10408398.2021.2002259.
15. Alsalman, F.B.; Tulbek, M.; Nickerson, M.; Ramaswamy, H.S. Evaluation and optimization of functional and antinutritional properties of aquafaba. *Legum. Sci.* **2020**, *2*, 1–15. https://doi.org/10.1002/leg3.30.
16. Mustafa, R.; He, Y.; Shim, Y.Y.; Reaney, M.J.T. Aquafaba, wastewater from chickpea canning, functions as an egg replacer in sponge cake. *Int. J. Food Sci. Technol*. **2018**, *53*, 2247–2255. *https://doi.org/*10.1111/ijfs.13813.
17. Aslan, M.; Ertaş, N. Possibility of using "chickpea aquafaba" as egg replacer in traditional cake formulation. *Harran Tarım ve Gıda Bilim. Derg*. **2020**, *24*, 1–8. https://doi.org/10.29050/harranziraat.569397.
18. Lafarga, T.; Villaró, S.; Bobo, G.; Aguiló-Aguayo, I. Optimisation of the pH and boiling conditions needed to obtain improved foaming and emulsifying properties of chickpea aquafaba using a response surface methodology. *Int. J. Gastron. Food Sci.* **2019**, *18*, 100177. https://doi.org/10.1016/j.ijgfs.2019.100177.
19. Serventi, L.; Wang, S.; Zhu, J.; Liu, S.; Fei, F. Cooking water of yellow soybeans as emulsifier in gluten-free crackers. *Eur. Food Res. Technol.* **2018**, *244*, 2141–2148. https://doi.org/10.1007/s00217-018-3122-4.

20. Nguyen, T.M.N.; Nguyen, T.P.; Tran, G.B.; Le, P.T.Q. Effect of processing methods on foam properties and application of lima bean (*Phaseolus lunatus* L.) aquafaba in eggless cupcakes. *J. Food Process. Preserv.* **2020**, *44*, 1–11. *https://doi.org/*10.1111/jfpp.14886.
21. Damian, J.J.; Huo, S.; Serventi, L. Phytochemical content and emulsifying ability of pulses cooking water. *Eur. Food Res. Technol.* **2018**, *244*, 1647–1655. *https://doi.org/*10.1007/s00217-018-3077-5.
22. Meurer, M.C.; de Souza, D.; Ferreira Marczak, L.D. Effects of ultrasound on technological properties of chickpea cooking water (aquafaba). *J. Food Eng.* **2020**, *265*, 109688. https://doi.org/10.1016/j.jfoodeng.2019.109688.
23. He, Y., Rana, M., Shim, Y.Y., Reaney, M. Aquafaba replaces egg white in sponge cake. In 2nd International Conference on Food Chemistry & Nutrition, Vancauver, Canada, 24-24 July 2017.
24. Bird, L.G.; Pilkington, C.L.; Saputra, A.; Serventi, L. Products of chickpea processing as texture improvers in gluten-free bread. *Food Sci. Technol. Int*. **2017**, *23*, 690–698. https://doi.org/10.1177/1082013217717802.
25. Huang, S.; Liu, Y.; Zhang, W.; Dale, K.J.; Liu, S.; Zhu, J.; Serventi, L. Composition of legume soaking water and emulsifying properties in gluten-free bread. *Food Sci. Technol. Int.* **2018**, *24*, 232–241. https://doi.org/10.1177/1082013217744903.
26. Stantiall, S.E.; Dale, K.J.; Calizo, F.S.; Serventi, L. Application of pulses cooking water as functional ingredients: The foaming and gelling abilities. *Eur. Food Res. Technol.* **2018**, *244*, 97–104. https://doi.org/10.1007/s00217-017-2943-x.
27. Starmer, D.; Coate, K.; Terry, P. The Effects of creating a vegan alternative to hard meringues by substituting aquafaba for egg whites. *J. Acad. Nutr. Diet.* **2018**, *118*, A51. https://doi.org/10.1016/j.jand.2018.06.197.
28. Beeber, M.; Panitz, A.; Traynor, C.; Zanville, K.; Ghatak, R.; Bhaduri, S.; Navder, K. The effect of cannellini bean puree with aquafaba as a fat replacer on the physical, textural, and sensory acceptability of chocolate mousse. *J. Acad. Nutr. Diet*. **2019**, *119*, A47. https://doi.org/10.1016/j.jand.2019.06.131.
29. Horner, D.; Huneycutt, E.; Ross, B.B. Aquafaba and flax seed gel as a substitute for egg whites in french macaron cookies. *J. Nutr. Diet. Pract.* **2019**, *3*, 1–8.
30. Raikos, V.; Hayes, H.; Ni, H. Aquafaba from commercially canned chickpeas as potential egg replacer for the development of vegan mayonnaise: Recipe optimisation and storage stability. *Int. J. Food Sci. Technol*. **2019**, *55*, 1935–1942. https://doi.org/10.1111/ijfs.14427.
31. Muhialdin, B.J.; Mohammed, N.K.; Cheok, H.J.; Farouk, A.E.A.; *Meor Hussin, A.S. Reducing microbial contamination risk and improving physical properties of plant-based mayonnaise produced using chickpea aquafaba. *Int. Food Res. J.* **2021**, *28*, 547–553.
32. He, Y.; Purdy, S.K.; Tse, T.J.; Tar'an, B.; Meda, V.; Reaney, M.J.T.; Mustafa, R. Standardization of aquafaba production and application in vegan mayonnaise analogs. *Foods.* **2021**, *10*, 1978. *https://doi.org/*10.3390/foods10091978.
33. Raikos, V.; Juskaite, L.; Vas, F.; Hayes, H.E. Physicochemical properties, texture, and probiotic survivability of oat-based yogurt using aquafaba as a gelling agent. *Food Sci. Nutr*. **2020**, *8*, 6426–6432. https://doi.org/10.1002/fsn3.1932.
34. Minh Nguyet, N.T.; Tan Quoc, L.P.; Buu, T.G. Evaluation of textural and microstructural properties of vegan aquafaba whipped cream from chickpeas. *Chem. Eng. Trans*. **2021**, *83*, 421–426. https://doi.org/10.3303/CET2183071.
35. Serventi, L. Yang, Y., Bian, Y. Cooking water applications. In U*pcycling Legume Water: From Wastewater to Food Ingredients*, 1st ed.; Springer, 2020; pp.105-120. https://doi.org/10.1007/978-3-030-42468-8.