biology and life sciences forum

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Proceeding Paper

Aquafaba: A Multifunctional Ingredient in Food Production †

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† 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, 1–15 October 2022; Available online: https://sciforum.net/event/Foods2022.

Abstract: Recently, the 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 great potential for meeting these requests/needs due to its multi-functionality (foaming, emulsifying, gelling, and/or thickening, and the ability/capacity of water- and oil absorption/holding). In this regard, aquafaba generally serves as an egg and/or fat replacer, and an alternative to emulsifiers 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**, *18*, 24. https://doi.org/10.3390/Foods2022-13004

Academic Editor: Arun Bhunia

Published: 30 September 2022

1. Introduction

Nowadays plant-based foods and ingredients have become widespread worldwide not only because of their health benefits but also due to their advantages in environmental sustainability, and ethical issues [1], as replacements for animal food sources such as eggs, milk, and meat [2]. Among these, egg replacement in food products also remains on the agenda. The reasons behind egg replacement are health issues comprising egg allergy, phenylketonuria, high cholesterol concerns together with dietary patterns or religious beliefs, and economic reasons [3]. The reduction or replacement of food ingredients becomes one of the main technical challenges to address in response to public health issues [4]. Although the term 'replacement of food ingredients' is not identified internationally, it refers to 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 with regard to organoleptic, microbial, and functional properties [5]. In this regard, the trends and innovations in bakery products take shape mainly in response to consumer health concerns apart from product enjoyment and industrial feasibility [6]. Therefore, the seeking of new ingredients for the reformulation of food products by partial or total replacement of ingredients is currently on the front burner for researchers and the food industry [7], with the aim of minimizing 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 an alternative to emulsifiers and gelling agents. Aquafaba meets not only the demands of society, but also has positive socioeconomic environmental impacts [12], by minimizing the waste of pulse processing, and thus maintaining food security and sustainability by lowering the greenhouse gas footprint, and saving cost and energy [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 during 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 capable of foaming, emulsifying, gelling, and/or thickening, water- and oil absorption/holding, with a wide pH and temperature range [12]. Recently, its microbiological properties regarding prebiotic activity and inhibition of pathogens have been 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 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 these, low molecular weight proteins ($\leq$25 kDa), are well-known foaming and surface-active attributes. Moreover, it has been 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 in 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 a lipid-soluble aglycone, and are therefore assumed to be a non-ionic surfactant. Therefore, they could reduce interfacial tension and facilitate the formation of 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 it was 93% for aquafaba obtained from the split yellow pea, 97% for whole green lentil aquafaba, 39% for haricot bean aquafaba [19], and 522–638% for lima bean aquafaba [20]. Additionally, the foaming stability of chickpea aquafaba was defined as 7–58% [15], 74–92% [16], 95% [17], and 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 that have a potential to form amphiphilic biopolymers. As such, they can enhance surface properties and thus improve foaming and emulsifying capacities [12]. The emulsifying ability/capacity of chickpea aquafaba has been identified as 3.9–100% [16,18,21,22]; 53% for green lentil aquafaba, 46% for haricot beans aquafaba [21], and 49% for split yellow peas [21] and yellow soybeans aquafaba [19], as summarized in [12]. The emulsifying stability of chickpea aquafaba has been detected as 60–80% [16].

2.3. Gelling Properties

One of the main contributors to the gelling properties of aquafaba is the water adsorption of soluble, low molecular weight carbohydrates. Aquafaba can 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 a limited number of studies on the gelling and thickening facility of aquafaba, but as far as we know, aquafaba made from chickpeas has the highest gelling properties when compared to those from other pulses [12]. Moreover, it has been stated that while uncooked food products such as mousse have comparable gelling properties with egg white, their 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 that is mostly derived from chickpeas is utilized mainly in cakes among bakery products because of its foaming properties for partial and/or total egg replacement, mainly in meringue formulation among confectionary products as an egg white replacer, and in mayonnaise as an egg or fat replacer. However, there is no consensus about its influence on food products, as summarized in Table 1. This could be attributed to different food formulations including different ingredients with different concentrations, in which the composition of aquafaba is affected by genotype and variety, and the growing conditions of pulses, together with parameters of pre- and post-processes.

Table 1. Aquafaba sources, their role, and major findings regarding aquafaba-based food products.

	End Product	Aquafaba Source(s)	Role of Aquafaba	Major Findings	References
BAKERY PRODUCTS	Cake	Chickpeas (commercially canned)	Egg white replacer	Moisture↓, pH↓^, Baking loss↑^, Height↓, Volume index↓, Color (crust): L*↓, a*↑, b*↑^, Texture (crumb): hardness↓^, chewiness↓, springiness↓, cohesiveness↓, resilience↓^	[16]
BAKERY PRODUCTS	Cake	Chickpeas	Egg replacer	**Batter:** pH↓, Specific gravity↓; **Cake:** Volume index↓, Symmetry index↓, Baking loss↔, Color (crumb): L*↑, a*↓, b*↓, Texture: firmness↑	[17]
BAKERY PRODUCTS	Cake	Lima beans	Egg replacer	Specific volume↔, Baking loss↓, Color (crust): L*↓, a*↔, b*↓, Texture: hardness↓, chewiness,↓, springiness↓, cohesiveness↓	[20]
BAKERY PRODUCTS	Gluten-free bread	Chickpeas	Hydrocolloid alternative for texture improvement	**Dough:** Peak viscosity↔, Breakdown↔, Final viscosity↔, Setback↓, Peak time↑; **Bread:** Moisture↔, Baking loss↔, Height↔, Specific volume↔, Color: L*↔ a*↑, b*↓, Texture: hardness↓	[23]
BAKERY PRODUCTS	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↑, Color: L*↓ (except split yellow peas), b* (except garbanzo chickpea, split yellow peas), Texture: hardness↑ (except garbanzo chickpeas, split yellow peas), chewiness↓, springiness↔, cohesiveness↓	[24]
BAKERY PRODUCTS	Gluten-free cracker	Yellow soybeans	Emulsifier	Moisture (0.day)↓, Moisture (2.day)↑, Color: L*↔, b*↑, Texture: hardness (0.day)↔, hardness (2.day)↓	[19] *

Table 1. *Cont.*

	End Product	Aquafaba Source(s)	Role of Aquafaba	Major Findings	References
CONFECTIONERY/DESSERTS	Meringue	Chickpeas	Egg replacer	Color: 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), Color: *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↔	[25]
		Chickpeas	Egg white replacer	Color: *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]
	Macaroon	Chickpeas (commercially canned)	Egg white replacer	Height increase↓^, Width,↓^, Yield↓^, Sensory^ (just for regarding 5 scores): taste↓, texture↓, appearance↓	[26]
OTHER FOOD PRODUCTS	Mayonnaise	Chickpeas (commercially canned)	Egg replacer, fat replacer	Color: *L** (0.day and 28.day)↔, *a** (0.day and 28.day), *b**↓^ (0.day and 28.day), Texture: firmness↓, adhesive force↓, adhesiveness↓, cohesiveness↔	[27]
		Chickpeas	Egg white replacer	Color: *L**↓, *a**↔, *b**↑, Sensory*: flavor↓, texture↓, overall acceptance↓, acceptability index↓	[18]
		Chickpeas	Egg replacer	pH↔, Brix↑^, Viscosity↑^, Texture: firmness↑, consistency↑, cohesiveness↔, Sensory: appearance↑, color↑, aroma↔, taste↔, Bacterial load↓^	[28]
		Chickpeas	Egg replacer, emulsifier	pH↓, Emulsion stability↓, Heating stability(freeze-dried)↑, Heating stability(spray-dried)↔, Color: *L**↓, *b**↓	[29]
	Non-dairy yoghurt	ND	Gelling agent	pH↑, Titrable acidity↑, WHC↑, Syneresis↓, Texture: hardness↑, adhesiveness↑, gumminess↑, chewiness↑^, Viable counts of *S. thermophilus* and *L. bulgaricus*↑	[30]
	Whipped cream	Chickpeas	Egg white replacer	Average diameter↑, Texture: hardness↓, adhesiveness↔, cohesiveness↑, springiness↑, gumminess↓, chewiness↑	[31]
	Non-dairy ice-cream	Chickpeas, split yellow peas	Emulsifier	Color: *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)	[32] *

↓ 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 days of storage, ^ Results were not given statistically, * The soaking water of different pulses used in corresponding food formulation.

4. Conclusions

Aquafaba is a new frontier for researchers and food manufacturers because of its nutritional and functional properties which allow its use in a wide range of food products. Moreover, it presents an opportunity for reducing the 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 have focused on drying aquafaba, with regard to its low aw value, and thus increasing shelf life, more studies are needed for the optimization of different drying methods, while process parameters are important for industrialization. Moreover, although the amount and activity of the anti-nutritional compounds of aquafaba are generally lower than those of raw seeds, more studies should affirm this finding. Future studies should also aim for the application of aquafaba to more food products and examine its effects on the quality of end products, even regarding gluten-free and non-dairy food products.

Author Contributions: Conceptualization, G.N.Y. and T.T.; writing—original draft preparation, G.N.Y.; writing—review and editing, G.N.Y., T.T. and M.S.O.; project administration, M.S.O.; funding acquisition, M.S.O. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by Cukurova University, Turkey, as part of the FBA-2021-14058 project.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

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