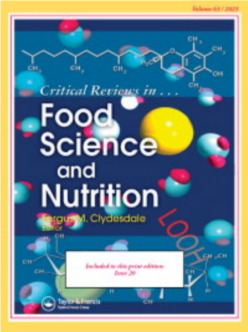


Critical Reviews in Food Science and Nutrition

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

A new trend among plant-based food ingredients in food processing technology: Aquafaba

Erenay Erem, Necattin Cihat Icyer, Nevruz Berna Tatlisu, Mahmut Kilicli, Gizem Hulaga Kaderoglu & Ömer Said Toker

To cite this article: Erenay Erem, Necattin Cihat Icyer, Nevruz Berna Tatlisu, Mahmut Kilicli, Gizem Hulaga Kaderoglu & Ömer Said Toker (2023) A new trend among plant-based food ingredients in food processing technology: Aquafaba, Critical Reviews in Food Science and Nutrition, 63:20, 4467-4484, DOI: 10.1080/10408398.2021.2002259

To link to this article: https://doi.org/10.1080/10408398.2021.2002259

Published online: 11 Nov 2021.

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
2023, VOL. 63, NO. 20, 4467–4484
https://doi.org/10.1080/10408398.2021.2002259

Taylor & Francis
Taylor & Francis Group

Check for updates

REVIEW

A new trend among plant-based food ingredients in food processing technology: Aquafaba

Erenay Erem[a], Necattin Cihat Icyer[b], Nevruz Berna Tatlisu[c], Mahmut Kilicli[a], Gizem Hulaga Kaderoglu[c] and Ömer Said Toker[a]

[a]Department of Food Engineering, Yildiz Technical University, Istanbul, Turkey; [b]Department of Food Engineering, Mus Alparslan University, Mus, Turkey; [c]Department of Food Technology, Istanbul Gelisim University, Istanbul, Turkey

ABSTRACT
In the new century, the most fundamental problem on a global scale is hunger and poverty reduction is one of the primary goals set by the United Nations. Currently, it is necessary to increase agricultural activities and to evaluate all agricultural products rich in nutrients without loss in order to feed the hungry population in the world. Considering that one of the most important causes of hunger in the world is inadequate access to protein content, legumes are one of the most valuable nutritional resources. In order to ensure the sustainability of legumes, alternative new ways of recycling their wastes are sought based on these multiple functions. For this purpose, recycling legume cooking waters to be used as food raw materials in various processes means reducing food waste. Recovery of nutritional components in legumes is also beneficial in vegan and vegetarian diets. In this review study, the importance of legumes in terms of global needs, their importance in terms of nutrition, the methods of obtaining the protein content of legumes, the functional properties of these proteins in the field of food processing, the gains of the evaluation and recovery of legume cooking water (Aquafaba), especially waste, were discussed.

KEYWORDS
Aquafaba; legumes protein; sustainable production; waste recycling

Introduction

The most important issues of our age are cold wars and economic crises that cause poverty and hunger. The lifestyles of societies have been under the influence of economic powers since ancient times. Poverty reduction is at the top of the main mandatory goals of the new century. The Sustainable Development Goals (SDG) set by the United Nations Development Agency (UNDP), in other words the Global Goals, is a universal call to action to end poverty, protect our planet, and ensure that all people live in peace and prosperity. Within this call, 17 main goals were determined, and the first goal is an end to poverty and the second goal is an end to hunger. In this way, the path to the 3rd goal is opened and the way to the goal of healthy and quality life is opened. These basic goals have actually been proven over and over again with every scientific data. For example, the hunger class population is equal to the total population of The United States of America, Canada and the European Union (Ozcicek Dolekoglu 2017). It is predicted that is the main reason for settled life, as a way of getting rid of these effects. Food is produced to feed the hungry population in the world. However, not using resources properly and wasting food are the most important factors that disrupt this balance. It is very important for sustainable production to use all foods, that is, not to create waste products. Increasing agricultural activities and evaluating all agricultural products (e.g. pulses, vegetables and fruits) and taking part in production have the potential to be a way of sustainability. The use of legumes with high protein content, which is one of the reasons for animal food production, is increasingly becoming more prominent (McDermott and Wyatt 2017). The diversity of amino acids found in legumes gives proteins different technological properties. This study aims to emphasize the importance of maximum use of legumes, which have the potential to be used in food processing technology, taking into account the global needs. In addition, it is aimed to emphasize the importance of legumes in terms of rich protein content, their use in food processing, the potential of the demand for legumes to increase agricultural employment, the potential to reduce the demand for animal production due to protein needs, and to examine the gains in waste management.

Global climate changes, increasing population, waste management and pulses

With the increasing world population in the future, it is discussed in world affairs that it will not be easy to access many more useful foods such as pulses. Because, according to the population estimates of the United Nations, the world population is estimated to reach 10 billion by 2050. Furthermore, according to the Food Security and Nutrition report, global hunger has increased in 2019 and is now affecting 820 million people. The fact that this value will

CONTACT Necattin Cihat Icyer n.icyer@alparslan.edu.tr
This article has been corrected with minor changes. These changes do not impact the academic content of the article.

be much higher in 2050 reveals the seriousness of the situation (FAOSTAT (Food and Agriculture Organization of the United Nations Statistics)) 2019). In addition to malnutrition problems caused by global warming and climate changes, serious environmental problems such as water and soil pollution have caused attention to waste management in the food sector. Applications such as recycling waste products as by-products through recycling methods or isolation of components with some nutritional or technological features from waste have become important in the food industry. With recycling from wastes, less waste will be produced, less energy will be needed compared to recycling processes, and thus, the sustainability of food will be contributed (Bigdeloo et al. 2021). Apart from the reduction methods in the food industries, the reduction of household food waste is also effective within the scope of sustainability. Attention to household waste management, even on an individual basis, is an important potential to initiate beneficial changes at global levels (Bigdeloo et al. 2021). As in the food industry, pulses, which are among the products that are considered in domestic waste management, play an important role by providing various services in line with the principles of sustainability with their re- cycling. As a source of quality food and feed, legumes also contribute to the reduction of greenhouse gas emissions as they emit 5-7 times less greenhouse gas per unit area compared to other food products. Thanks to nitrogen fertilizer reduction, they allow carbon retention in the soil and save on fossil energy inputs in the system. Legumes fix atmospheric nitro- gen; releases high quality organic matter into the soil and facilitates the circulation of soil nutrients and water retention (Stagnari et al. 2017). In addition, it has positive effects on soil-related processes such as the chemical and physical properties of the soil, agricultural productivity, soil protection, and reducing the need for chemical fertilizers (Meena and Lal 2018).

In general, the sustainability benefits of legumes can be summarized under the following headings: product diversity with legumes, improving soil health, ensuring economical use of water, high productivity and sustainability. Based on these multiple functions, alternative new ways are sought for the recovery of their waste to ensure the sustainability of legumes (Kumar et al. 2018).

The importance of legumes in terms of production rates and nutrition

Legumes, which are called *Fabaceae*, are members of the *Leguminosae* family. They are grown mostly for their edible seeds. Legumes are essential for human nutrition all over the world with their significant amount of carbohydrate, proteins, and minerals. Therefore, legumes are produced with significant amount in the world (Table 1). Considering that one of the most important problems in today's world where malnutrition is common in various parts of the world is protein-calorie malnutrition, legumes are good sources in this regard (Iqbal et al. 2006). Therefore, legumes are a critical food especially in developing countries such as Africa, Latin America and Asia. While legumes are commonly referred to as "poor man's meat," the label has recently changed to "health foods" that even wealthy people will want to include in their diets (Meena and Lal 2018).

Taking into account the increasing population, global warming and climate changes, it is very important to take measures against the food shortage that awaits us in the future by evaluating food losses and waste, and the correct use of food resources. For this purpose, the recovery of pulse cooking waters, to be used as food raw material in various processes, means reducing a significant amount of food waste, because pulse cooking water is rich in various carbohydrates, proteins, phytochemicals, vitamins, and minerals that pass from pulses to water.

In addition to the importance of the recovery of pulses in waste management, it is also beneficial for vegan and vegetarian nutrition. Today, the increase in vegetarian and vegan consumption preferences has increased the production rates of products for people with this diet. The exponential growth of this market is associated with the consumer's preference for healthy and environmentally friendly food. To this end, plant-based food ingredients and products are increasingly being developed to mimic and replace animal sources such as meat, milk and eggs. In addition, this need is not only due to the difficulties of vegans in finding resources to consume protein. Rather than vegan nutrition and market diversity, it is important to evaluate and sustain alternative new plant resources to meet the protein consumption of carnivores with the increasing population. Consumers are willing to change their orientation, which reduces their carbon footprint, taking into account the factors that cause climate change. This indicates the tendency to consume plant-based foods as an alternative to foods of animal origin (He et al. 2021). In addition, people who are worried about the negative effects of meat and want to access safe food have increased worldwide and started to prefer a vegetarian diet (Alsalman and Ramaswamy 2021). Another reason for the increase of veganism is egg food allergy, which especially affects children (Meurer, de Souza, and Ferreira Marczak 2020). In short, more and more consumers are choosing plant protein sources, allergen-reduced diets, and food products with a reduced carbon footprint.

The demand for legumes, especially lentils and chickpeas, is increasing day by day due to their high protein, dietary fiber and low saturated fat content. Legumes have an important place in vegan diets, especially because they contain phytochemicals. Intense work is being done to develop more plant-based vegetarian products that mimic meat, dairy and egg properties (Shim et al. 2018).

Table 1. Production size of common legumes in the world (FAOSTAT (Food and Agriculture Organization of the United Nations Statistics)), 2019).

Crops	Area harvested (ha)	Production (tonnes)
Beans, dry	33.066.183	28.902.672
Chickpeas	13.718.980	14.246.295
Cow peas, dry	14.447.336	8.903.329
Lentils	4.800.017	5.734.201
Peas, dry	7.166.876	14.184.249
Pigeon peas	5.616.153	4.425.969
Soybeans	120.501.628	333.671.692

The most important plant-based food ingredient in light of global expectations: Proteins

Although legumes have a rich nutritional content, they stand out especially in terms of protein content. Among the most common legumes, chickpeas contain 22 grams and lentils 28 grams (g/100 g) of protein (Du et al. 2014). Legumes including dry beans, chickpeas, broad beans, lentils, and dry peas contain lysine-rich protein (20–30%). Protein content and digestibility of legumes may differ depending on the agricultural practices such as seed characteristics, growing conditions, climate characteristics, soil characteristics, as well as processing methods. The reason for the low digestibility of protein in fermented legumes is the hydrolysis of proteins by the effect of protease enzymes secreted by molds during the fermentation process. Hydrolysis of proteins causes the release of amino acids in different pH environments (Han and Baik 2006). Legumes can be consumed after being cooked (Baojun and Chang 2009). Some precooking processes are effective food processing methods to prevent the deterioration of nutritional components and increase the bioavailability of minerals and proteins (El-Hady and Habiba 2003). The most common industrial processes for legumes that result in loss of most nutritional components are soaking, boiling, steaming and canning (Baojun and Chang 2009). Loss of nutritional components refers to the transport of water-soluble nutrients to the processing water, including water-soluble protein (Seena and Sridhar 2005), vitamins, starch (Rehman and Shah 2005) and others. For this reason, nutritional components such as proteins, carbohydrates and minerals can be found in the soaking and boiling water of legumes.

In terms of food processing technology, isolates and concentrates of pulse proteins offer a range of functionalities such as water binding ability. Pulse proteins can also provide thickening and freeze-thaw stability (crystallization control). However, gums and starches are more typically used for these functions. Pulse proteins can also contribute to browning in the Maillard reaction and can be used for protein supplementation. Protein isolates and concentrates from legumes such as soy, peas, and peanuts contribute to binding and thickening, partly due to their starch and fiber content. Vegetable proteins derived from legumes and their production methods are shown in Table 2.

The most common processes for preparing pulses for consumption are soaking, boiling, steaming and canning (Serventi 2020). Among these processes, soaking is usually applied before the main processing to shorten the cooking time. There may be differences in soaking time, boiling time, steaming time depending on the type of legumes, growing conditions, storage conditions. Generally, legumes are soaked in a 1:4 weight ratio (pulse:water) for 16 to 24 hours (Han and Baik 2006; Subuola, Widodo, and Kehinde 2011). Many applications and factors are active here. E.g; The hot dipping method, which reduces gas-producing compounds and cooking time, is a short-term process in which 80% of the complex bean sugars can pass into the cooking water. Similarly, presoaking can reduce the nutritional quality of legumes products and affect protein digestibility by transporting nutritional components to the soaking water (Khattab and Arntfield 2009; Subuola, Widodo, and Kehinde 2011). It has been reported that this may be related to the decrease in the effectiveness of factors affecting nutritional components such as polyphenols, protease (trypsin, chymotrypsin) and α-amylase inhibitors (El-Hady and Habiba 2003). Boiling can improve the physical properties of legumes by reducing the effectiveness of inhibitors that adversely affect nutritional components (Subuola, Widodo, and Kehinde 2011). In addition to all these processes, the application of boiling process on legumes may have negative effects on nutritional components. One of the alternative methods used for cooking legumes and preserving nutritional components is steam cooking (Baojun and Chang 2009). In a study investigating the effect of steaming treatment on macronutrients, it was reported that the protein content and protein digestibility significantly affected the heat treatment and application time. Although the decrease in protein content is directly proportional to the autoclaving temperature and time, it has been reported that the protein content of these legumes decreased by 1.3-4.6% after cooking in an autoclave at 121 °C for 10-90 minutes and at 128 °C for 20 minutes (Rehman and Shah 2005). Steaming method creates changes in starch hydrolysis similar to the change in protein content. This effect can be attributed to the fact that the steaming process increases the rate of starch hydrolysis and reduces the content of anti-nutritional factors. The canning procedure includes soaking (25 °C 12 hours), bleaching (85 °C 30 minutes), canned in salt water (1.3% salt and 1.6% sugar) and final heating (121 °C 14 minutes). Of course, small numerical differences in these processes vary according to the type of pulses (Parmar et al. 2016). According to the studies, it has been observed that the protein content increases after the canning process. Likewise, they reported that in some legumes where dietary fiber increase was observed, this was due to the formation of protein-fiber complexes (De Almeida Costa et al. 2006) (Table 3).

Although the purpose of soaking is mainly to speed up the cooking process, there are some methodological differences among researchers: Ghadge, Shewalkar, and Wankhede (2008) soaked whole pigeon peas at an ambient temperature for 10 hours before cooked in pressure cooker for 20 minutes. Stantiall et al. (2018) soaked yellow soybeans in a 1:3.3 weight ratio (pulse: water) for 16 hours at room temperature before boiling. Alsalman and Ramaswamy (2021) soaked dried chickpeas at 40 °C for 2 hours before placed them in a classic pressure cooker to enhance carbohydrate functionality and digestibility by high pressure treatment. Stantiall et al. (2018), applied soaking treatment for 16 hours in a 1:3.3 weight ratio (dry pulse: water) was performed before cooking them in boiling water for haricot beans, garbanzo chickpeas, whole green lentils and split yellow peas. Buhl, Christensen, and Hammershøj (2019) soaked the chickpeas with ultrapure water at a 1:5 ratio (w/v) for 12 hours before the chickpeas were boiled. Han and Baik (2006) soaked legumes (lentils chickpeas, yellow peas, green peas, soybeans) for 3 or 12 hours in distilled water or soaked with ultrasound (47 kilohertz (kHz)) for 1.5 or 3 hours and with high

Table 2. Vegetable proteins derived from legumes and their production methods.

Protein	Legumes type	Methods	Method description	Sources
Broad bean and pea protein	Broad bean and pea seeds	Acid extraction	Protein contents were obtained by direct acidification of the supernatant from the starch extraction (pH 4.4–4.6) obtained from ground broad beans and pea seeds.	(Vose 1980)
Broad bean and pea protein isolates	Broad bean and pea	Ultrafiltration	• Working parameters: • Total ultrafilter area 1.39 m^2. • The process was carried out in a closed loop at 32 L/min liquid extract process feed rate, 25 psig inlet pressure and 15 psig outlet pressure. • The first flow through the membrane is 22.9 L per square meter per hour. • The process took 6–7 hours at 40–45 °C. • Feed stream did not need pre-filtering. • As a result of the protein purification process performed as an alternative by using ultrafiltration technologies, seed N (in the form of isolate) was recovered at the rate of approximately 82%. • Protein isolates prepared by isoelectric precipitation or ultrafiltration were obtained by spray drying.	(Vose 1980)
Broad bean and lentil proteins	Broad bean and lentil legumes	Air classification	• Food products were brought to 8% moisture content before processing. • The products were dehulled and then air aspirated. • Each dehulled product is ground in a pin mill pattern. • Flours transformed into starch and proteins are re-ground and their proteins are separated by air classification.	(Tyler, Youngs, and Sosulski 1981)
Chickpea protein isolates	Chickpea flour	Isoelectric precipitation, Micellar precipitation	• For the micelization procedure, sodium chloride (pH 7.0) was used to extract the proteins from the defatted flour. • The extract obtained was concentrated to half volume by ultrafiltration in a Pellicon device. • Proteins were flocculated by adding water (1: 4 v/v, protein extract: water) at 4 °C, pH 7.0 for micelization. • For isoelectric precipitation, proteins were extracted from degreased flour at pH 8.5 with alkali (0.1 N NaOH) and precipitated by adding acid (0.1 N HCl) to pH 4.5. • Isolates were recovered by centrifugation at 10000xg for 10 minutes and freeze dried.	(Paredes-Lopez, Ordorica-Falomir, and Cbrabes-Trejo 1988; Paredes-Lopez and Ordorica-Falomir 1986)
Chickpea protein isolate	Chickpea	Salt extraction / Micellar precipitation	• Protein was extracted from a 10% (w / v) solution of chickpeas degreased with sodium chloride (0.5 M, pH 7.0) (a chickpea protein isolate containing 87.8% protein was obtained). • After concentrating the extract by ultrafiltration, the protein was flocculated / collected by the addition of water (4 C, pH 7, 1: 4 v/v protein extract: water ratio).	(Paredes-Lopez, Ordorica-Falomir, and Olivares-Vazquez 1991)
Lima bean protein	Lima beans	Acid extraction, Suspension, Extraction	• The flour of ground bean seed was directly suspended in water (flour / water ratio 1:10) at pH 4.5 (8 hours, room temperature). • It was then centrifuged. • A product with 50% protein content was obtained by re-extracting and cleaning processes.	(Ologhobo et al. 1993)
Legume proteins	Five ripe beans variety seeds	Extraction with water	• Seeds were mixed with water at 1–4 C using a 1:10 seed: water ratio. • 16 hours of rest has been carried out. • After this time, the protein concentration in the supernatants ranged from 5.5 to 10 g N / kg seed meal.	(Martin-Cabrejas et al. 1995)
Bean protein	Beans	Salt extraction / Micellar precipitation	• Bean protein was extracted from meal at a ratio of 1:10 (w/v), meal: buffer (0.1 M phosphate and 0.5 M NaCl) at pH 7.6. • After centrifugation, the extract is drained, separated with distilled water. • Freeze-dried to obtain the protein fraction. • Albumin was similarly extracted in distilled water at 4 °C for 1 hour (an enriched fraction with 53–75.7% protein content is provided).	(Marquez, Barros, and Lajolo 1996)

(*Continued*)

Table 2. (*Continued*)

Protein	Legumes type	Methods	Method description	Sources
Protein extracts of various legumes (chickpeas, broad beans, lentils, mung beans, soft peas, peas and winged beans)	Tofu	Heat treatment	• CaSO4 has been used to create protein extracts of legumes referred to as coagulant with or without heat denaturation. • For all legume fractions, a protein concentration of 2.3–3% and the use of 1.5% CaSO4 as coagulant gave the best results for the curd formulation. In addition, the study on the formation of bean curd using protein extracts was studied. • Chickpeas and broad beans have similar textural properties in second place after soybean; For lentil, mung bean and soft pea flour, results were obtained that the moisture content of the curd was significantly higher than for the soy curd.	(Cai, Klamczynska, and Baik 2001)
Specified product proteins	Chickpeas, beans, broad beans, lentils, mung beans and soft peas	Extraction with water	• 200 g of each seed was mixed with 500 mL of water. • Supernatants are extracted using centrifugation. • The extraction was repeated a second time to increase recovery. (The protein contents of the initial extracts ranged from 54% for chickpeas to 67% for soft peas). • After the second extraction, the highest protein content was obtained from broad beans with 65.6%, while the lowest protein content was obtained from chickpea flour with 50.5% protein.	(Cai, Klamczynska, and Baik 2001)
Legume seed protein isolates	Lupine, peas and pods	Isoelectric precipitation, Ultrafiltration	• The legume seeds were ground in a kitchen mill and the resulting flour was processed with petroleum ether (1/3) to extract oil. • The degreased flour is then dispersed in distilled water (1/10); The pH was raised to 9.5 with the aid of 1 N NaOH and stirred at room temperature for 40 minutes using a mechanical stirrer. • Supernatant was collected after centrifugation at 4000 rpm for 20 minutes. It was combined with the supernatant collected from the first centrifuge and the pH was adjusted to 4.5. Precipitated protein was recovered by centrifugation at 4000 rpm for 20 minutes. The pH value was adjusted to 7.0 and was freeze-dried. • Supernatant was concentrated through ultrafiltration membranes followed by freeze drying to have both fractions (globulin and albumin). Protein contents of dried lupine seed protein isolate, pea seed protein isolate, pod protein isolate obtained by isoelectric precipitation and ulfiltration were also indicated in the study.	(Makri, Papalamprou, and Doxastakis 2005)
Lentil protein isolate	Lentil	Combined methods	• Degreased flour (100 g) was mixed with water (1:10) (w / v), adjusted to pH 9.5. • 1.0 M NaOH and stirred at 500 rpm for 1 hour at room temperature. The mixture was kept at 4 ° C overnight to allow protein-free precipitation. • Supernatant was collected after centrifugation at 1600g for 30 minutes at 4 ° C and the pH was adjusted to 4.5 with 0.1 M HCl. • Precipitated protein was collected by centrifugation (1600g, 30 minutes, 4 ° C) and stored at 30 °C until freeze-dried (81.9% protein content was obtained as a result of the processes).	(Bamdad, Goli, and Kadivar 2006; Lee, Htoon, and Paterson 2007)
Legume protein isolates	Legumes seeds	Alkali extraction	• Grinding process has been applied to the products. • Extraction conditions: • pH 8–11, 30–180 min, 25–65 °C • Centrifugation: 4–25 °C • Alkaline extract production • Isoelectric precipitation (pH 4.5) • Centrifugation (4–25 °C) • Finally, protein isolates were obtained by spray drying.	(Boye, Zare, and Pletch 2010)
Soy proteins	Tofu	Extraction, Heat treatment	• Soy milk was extracted from soybeans. • Heating is used to denature soy proteins and inactivate trypsin inhibitors. • A coagulant (e.g. magnesium chloride, calcium sulfate, gluco-delta-lactone) is then added to induce clot formation. • The coagulated soy milk is then split into whey (non-coagulated soy milk) and curdled milk (coagulated soy milk) and the curd is pressed to form tofu.	(Boye, Zare, and Pletch 2010)

(*Continued*)

Table 2. (*Continued*)

Protein	Legumes type	Methods	Method description	Sources
Chickpea protein isolate	Chickpea flour	Isoelectronic precipitation	• Degreased chickpea flour (100 g) (1:10) was mixed with water (w/v), adjusted to pH 9.0 using 1.0 M NaOH. • It was mixed for 45 minutes at 500 rpm at room temperature (20–22 °C). The suspension was then centrifuged at 4500g for 20 minutes at 4 °C using a Sorvall RC-6 Plus centrifuge to collect the supernatant. • The resulting pellet was resuspended in water at a ratio of 1:5 (w/v), adjusted to pH 9.0, mixed for an additional 45 minutes and then centrifuged (4500g, 20 minutes, 4 °C). • Supernatants were pooled and adjusted to pH 4.6 using 0.1 M HCl to precipitate protein. • After processing, the protein was recovered by centrifugation, collected and stored at 30 ° C until freeze dried to allow free flow. As a result of all the processes, the protein content of the isolate was determined as 925.2 g kg-1 by the Kjeldahl method.	(Papalamprou, Doxastakis, and Kiosseoglou 2010)
Soy proteins	Soybean	Bis (2-ethylhexyl) sodium sulfosuccinate (AOT) reverse micelles	• Degreased soybean meal is dispersed in 50 mM phosphate buffer solution (1:15, w/v). The mixture was adjusted to pH 8.5 with 2 M NaOH and the dispersion was stirred at room temperature for 2 hours. • The pH of the supernatant was adjusted to 4.5 to remove insoluble material in high speed centrifugation and the precipitate was collected by centrifugation (10,000 g, 10 minutes at 4 °C). • The precipitate was washed with distilled water and dialyzed three times at 4 °C to remove excess reagents. • Soy protein product, produced by freeze drying.	(Zhao et al. 2018)
Chickpea and kidney bean protein	Chickpeas and kidney beans	High power sonication-based extraction	• Chickpeas and kidney beans were soaked in water for 12 hours and the skins were removed by hand. It was then oven dried at 50 °C for 24 hours. It was milled using a 0.02-inch cavity and 1/16 inch groove mill. • 1 g: 10 mL sample / water ratio, centrifuge tubes were placed in a temperature controlled ice bath and treated at 2.5 W/cm^3 and 4.5 W/cm^3 for 5 minutes. These sonicated samples were then used for extraction of proteins at pH 8.5, 60 °C and stirring for 30 minutes using a magnetic rod on the stir plate. • Samples were centrifuged at 14,000xg for 10 minutes at 15 °C. • Supernatants are collected with a graduated cylinder to measure total volume and protein content measured for extraction yield.	(Byanju et al. 2020)

hydrostatic pressure for 0.5 or 1 hours. They conclude that compared with soaking for 3 hours, soaking pulses with ultrasound for 3 hours in all tested pulses or soaking pulses with high hydrostatic pressure for 1 hours, with exception of soybeans, appeared to be more effective for the reduction of oligosaccharides. Bird et al. (2017) in his studies; chickpea seeds were boiled in water with 1: 1.75 seed to water ratio (CWR) for 90 minutes. Damian, Huo, and Serventi (2018); 126 stated that they obtained approximately 0.6 g of cooking water per gram of dry pulsation as a result of their study to extract cooking water from chickpeas and other pulses.

Lafarga et al. (2019) boiled chickpeas for 190 minutes with three different CWRs (1: 1.5, 1: 3.25, 1:50) in a stainless-steel pot and carried out their experiments by adjusting the aquafaba pH to different values (3.5, 5.0, 6.5). CWR and pH conditions of optimum aquafaba properties providing the highest functionalities and stability were shared with the results of 1: 1.5 and 3.5, respectively. In addition, He et al. (2019), using less water (1: 1 CWR) and a shorter cooking time (30 minutes) of less than 70-80 kilopascal (kPa) at 115-118 °C to cook seeds 0.7-1.1. liter (It) has been shared that it provides superior functionality by obtaining g of cooking water/chickpea g (dwt).

A new trend among plant-based food ingredients: Aquafaba

In recent years, a food product called "Aquafaba", which has a nutritious content and suitable for a vegan diet, has become popular due to the changing consumption habits. Aquafaba is a combination of two Latin words, aqua for water and faba for the family *Fabaceae*. Appearing as a plant-based emulsifier instead of the egg white traditionally used in bakery products, "Aquafaba" has become very popular. Research and experience show that aquafaba is a

Table 3. Decreasing in nutrients of legumes by some pre-cooking processes.

Nutrients of Legumes	 Soaking	 Boiling	 Steaming	 Canning	Sources
Protein	0.7%		1–5%		(El-Hady and Habiba 2003; Ahmed et al. 2012)
Oligosaccharides	50–75%	60–85%		16%	(Han and Baik 2006; Pedrosa et al. 2015)
Vitamins	10–60%	24–70%		46–65%	(Prodanov, Sierra, and Vidal-Valverde 2004; Słupski 2011)
Phenolics	10–40%	30–50%	25%		(Baojun and Chang 2009; Xu and Chang 2008)
Dietary fiber	5%	30%		16%	(Pedrosa et al. 2015; Rehinan, Rashid, and Shah 2004)
Saponins	8–35%	40%	23%		(Baojun and Chang 2009; Barakat, Reim, and Rohn 2015)

valuable ingredient with functional properties such as foaming, emulsifying and gelling, which can be used in various formulations as an egg and milk alternative in vegan products (Raikos, Hayes, and Ni 2020). This situation encouraged scientists working in the field of food processing to do research on a new plant-based rheological food additive.

The main cooking method of pulses is boiling them that are soaked before, and whose volume increases and swells by taking water (Figure 1). Pulses can be cooked in water and consumed directly or packaged and sold. The water left over during cooking is called aquafaba. Commercially produced aquafaba is obtained by drying this water under suitable processing conditions and delivered to suppliers. In the process of cooking pulses and preparing them for consumption, the addition of mineral salts to the soaking and / or cooking environment can be applied to shorten the cooking time. When the nutritional values of raw and cooked pulses were compared, there was a decrease in the amount of valuable nutritional compounds in cooked pulses (Baojun and Chang 2009). This is because legumes contain many water-soluble components such as protein (albumins, etc.), carbohydrates (sugar, fiber), phenolics, and saponins (Klupšaitė and Juodeikienė 2015). These components that pass into water make pulses cooking water valuable.

According to the literature results in given Table 4, the least dry matter content of pulse cooking water is in haricot bean cooking water as 3.28 g/100g (Stantiall et al. 2018), while the most content is in chickpea cooking water (aquafaba) as 7.89 g/100g (Buhl, Christensen, and Hammershøj 2019). The results show the superiority of aquafaba depending on different processing conditions. This difference may be due to the different processes applied during soaking and cooking as well as the legume variety because while chickpeas were boiled with ultrapure water at a 1:5 ratio (w/v) for 60 minutes, haricot beans were boiled with water (weight ratio 1:1.75 dry pulse: water) for 90 minutes. Hence, it can be said that the water features and processing time can also change the amount of transition.

On the other hand, the most protein content of pulse cooking water is completely green lentils as 1.51 g/100 g, while the least content is in haricot beans as 0.7 g/100 g (Stantiall et al. 2018). This situation can be explained not only the different protein amounts contained in pulses but also with the boiling process parameters. In general, the protein contents of pulses are 18.56% in chickpea, 23% in green lentils, 19.82% in pea and 21.75% in beans (Sarıoğlu and Velioğlu 2018). In another study, the protein contents of pulses are 28.62% in soybeans, 17.86% in lentils, 16.35% in split peas, 15.24 % in black beans, and 14.53% in chickpea, (Rebello, Greenway, and Finley 2014). According to another study, the compositions of protein are 26.1% in lentil, 2.9% in green pea, %24.7 in cowpea and 24% in chickpea (Iqbal et al. 2006). As can be seen, protein contents differences are observed even between the same types.

Therefore, it can be said that among the reasons affecting the difference for protein in the cooking water in pulses, there are also climatic, and harvest-related reasons that affect the protein amount of legume seeds. Therefore, the effects of different processing conditions on how much of the protein present in legumes can pass into the cooking water should be evaluated.

Saponins in pulses cooking water, has important technological property due to its foaming ability as well as its functional property like carcinogenetic as a natural phytochemical (Serventi 2020). The highest level of saponin in cooking water of green lentils as 12% and 4.5% in garbanzo chickpeas in Table 2. On the other hand, the highest percentage saponin content among pulses are soya samples as

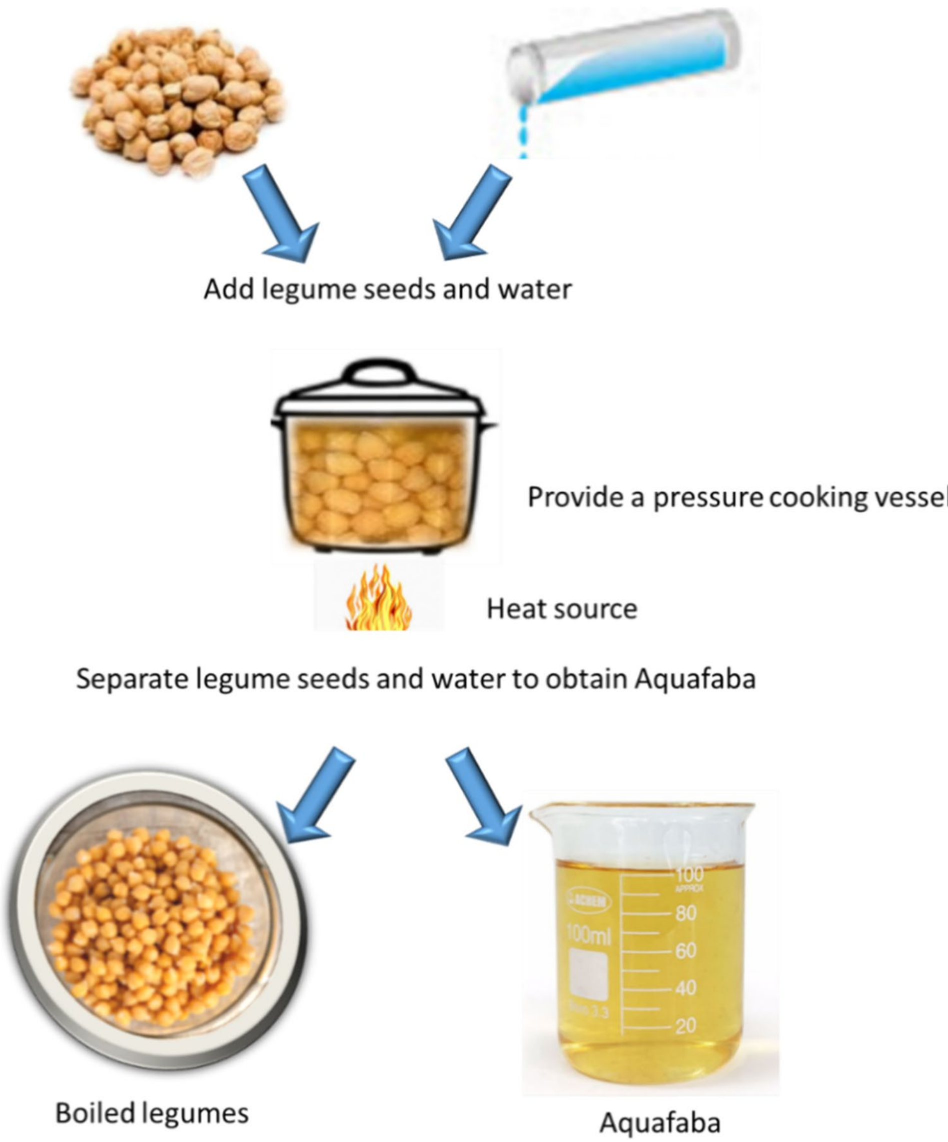


Figure 1. The schematization of aquafaba production.

Table 4. Compositions of legumes cooking water.

Composition (g/100g)	Dry matter (%)	Insoluble CHO (%)	Water-soluble CHO LMW (%)	Water-soluble CHO HMW (%)	Protein (%)	Fat (%)	Ash (%)	Saponins (mg/g)	Reference
Haricot beans	3.28	0.93	0.73	0.16	0.70	<dl	0.75	5.9	(Stantiall et al. 2018)
Garbanzo chickpeas	5.13	2.37	1.20	0.04	0.95	<dl	0.57	4.5	
Whole green lentils	4.69	2.09	0.54	0.07	1.51	<dl	0.48	12	
Split yellow peas	4.41	1.63	1.02	0.09	1.27	<dl	0.40	4.7	
Yellow soybean	5.59	2.46	1.66		0.68	<ql	0.78	6.4	(Serventi et al. 2018)
Aquafaba (chickpea)	7.89	–	–		1.3	–	–	–	(Buhl, Christensen, and Hammershøj 2019)
Aquafaba (chickpea)	5-8	2.4	1.2		0.95-1.5	<dl	0.6	4.5-30	(Mustafa and Reaney 2020)

Abbreviations: CHO, carbohydrates; ql, below quantification limit (0.5% of the dry matter analyzed); LMW and HMW, refer to water-soluble carbohydrates and stand for low molecular weight and high molecular weight, respectively; < dl, below detection limit; -, not mentioned.

6.5 g.kg-1 and haricot bean as 4.1 g.kg-1 (Price, Curl, and Fenwick 1986). Saponins are vulnerable against the heat treatment. For this reason, the rate of cooking water could be less than the rate present in pulses (Mustafa and Reaney 2020). The protease inhibitor interferes with the function of protein-breaking enzymes so protein digestion cannot be completed. Chickpeas are preferred among pulses because they have fewer problems with protease inhibitors. It has been determined that trypsin inhibitory activity follows a decreasing order in the form of soy, beans, broad beans, peas, lentils, and chickpeas (Pekşen and Artık 2005). Microwave cooking and pressure methods can be used to destroy trypsin inhibitors in legumes (Alajaji and El-Adawy 2006). Phytic acid, which is known as myo-inositol hexakis-posphateorinositolhexaphosphate (IP6), is caused by the formation of complex compounds with two or three precious metal ions such as iron, copper, calcium, and zinc, which are difficult to dissolve in water, making their absorption difficult by the body and thus leading to the insufficiency of these elements. It is also known included in pulses and they pass into pulse soaking and cooking water by leaching process. When the cooking process was applied for 45 minutes at 15 °C, it resulted in small losses in the total P and phytate contents in the cooking water, which may be due to the legume seeds reabsorbing the phytate in the cooking water (Urbano et al. 2000).

Functional properties of Aquafaba's protein contents

The methods used during protein separation and purification, extraction of raw materials, isolation of proteins and removal of unwanted contaminants determine the technological properties of aquafaba. In addition to attracting the attention of people with vegan and vegetarian diets with its herbal ingredients, it is preferred because of its foaming, gelling, thickening and emulsifying properties in terms of food technology. Being resistant to food processing applications, having a wide pH and temperature tolerance range increases its functionality (Mustafa and Reaney 2020).

Aquafaba has technological features such as water and oil holding capacity, emulsion stabilizer, foaming, gelling and thickening (Mustafa and Reaney 2020). The technological features of Aquafaba in food processing are related to its oil and water holding capacity. It has been determined that the oil holding capacity of aquafaba prepared from legumes is higher than the water holding capacity. In the same study, it was shared that aquafaba obtained from garbanzo chickpeas has a significantly higher oil holding capacity (3.22 g/g) compared to other beans (Damian, Huo, and Serventi 2018).

The emulsion properties of the proteins and carbohydrates contained in Aquafaba depend on the molecular structure and the ratio of hydrophobic groups to hydrophilic groups (De Kanterewicz et al. 1987). Dranca and Oroian (2018) reported that heating chickpea seeds in water causes many compounds to be transported to the cooking water (aquafaba), and reactions that cause structural changes such as Maillard reactions of proteins and carbohydrates coming into the cooking water occur. Luo et al. (2011) reported that the solubility and emulsification properties of aquafaba are directly related to the content of phenolic compounds, and the saponin content is also effective in stabilization. Another factor contributing to the emulsification properties of Aquafaba is that it contributes to the formation of more stable protein-oil-water emulsions with its low protein and dry matter content (Zayas 1997). In the study conducted by Mustafa et al. (2018), emulsion stability varied between 60% and 80% (Shim et al. 2018). The reason for these and similar variations was attributed to differences in legume brands, legume varieties, aquafaba composition and canning conditions (Sánchez-Vioque et al. 1999). The emulsification properties of Aquafaba are affected by the applied food processing methods. It has been shared that soaking, cooking and dehydration processes reduce the emulsifying capacity of chickpea flour (Aguilera et al. 2009a, Ma et al. 2011). Therefore, studies should be conducted considering many processing parameters in order to improve the emulsifying properties of aquafaba.

There are factors such as surface tension, surface elasticity, surface viscosity and separation pressure that determine the stabilization of foaming feature, which is another technological feature of Aquafaba (Mustafa and Reaney2020). The foaming properties of Aquafaba in food processing are directly related to its low molecular weight proteins, polysaccharides and saponin content (Mustafa et al. 2018; Singh et al. 2008). It has been understood that aquafaba may partly explain the differences in foaming capacity due to changes for albumin, a low molecular weight protein. In addition, crosslinking between polysaccharides and proteins can also make a significant contribution to aquafaba foam stability. Saponins, which contribute to the emulsifying feature, increase the foaming capacity of aquafaba by also affecting this feature (Güçlü-Ustündağ and Mazza 2007). Similarly, Mustafa et al. (2018) reported that the difference in foaming capacity and stability of chickpea aquafaba obtained from different sources may be due to the composition of aquafaba. While the moisture content and viscosity of aquafaba were positively correlated in the study; these factors were not associated with the foam volume increase. The information that aquafaba obtained from canned commercial chickpeas without salt and disodium ethylene diamine tetra acetic acid (EDTA) produces foams that are more viscous and more stable than canned chickpeas containing these additives. In addition to the findings obtained, it was revealed that aquafaba proteins are largely thermosoluble hydrophilic species and by nuclear magnetic resonance (NMR) analysis the foam mainly polysaccharides, sucrose and protein content. As a general result of the study; It has been stated that the quality of aquafaba is affected by the processes used in canned food production (Mustafa et al. 2018). Other important factors contributing to Aquafaba's foaming ability are its starch and oil content. The presence of unsaturated fatty acids reduces foam volume and stability (Behera et al. 2014). In general, it is thought that chickpea variety, growing conditions, type and amount of protein content, processing conditions and added additives cause changes in the functional properties of aquafaba in terms of food processing technology (Fernández-Quintela et al. 1997). Its negative effect on the foaming capacity by causing low foaming may be due to the long cooking time of aquafaba. In the study where this information was shared, aquafaba was used to cook up to 90 minutes (Mustafa et al. 2018). It has been reported that aquafaba produced from salted and unsalted chickpeas has similar foaming capacity and foaming stability (Mustafa et al. 2018; Shim et al. 2018). In another study; considering that the foam obtained from egg white increases with the addition of temperature and salt, it can be predicted that the foam stability will be increased with the pretreatments to be applied to chickpea (Behera et al. 2014; Raikos, Campbell, and Euston 2007).

Thickeners and gelling additives play an important role in the development of foam formation and emulsion properties. While protein isolates that fulfill these functions in legumes vary between 6-18% at a minimum level; 0.6% for gelatin and 3% for egg albumin (Mazumdar, Durgalla, and Gaur 2016). When heat treatments such as dry and wet heating, boiling and autoclaving were applied to legumes such as soy, peanut, cowpea and chickpea, the obtained flour reduced its gelling ability. However, when processes such as roasting and boiling are applied directly to different types of legume flour, it has been observed that the gelling properties are improved (Bencini 1986; Ma et al. 2011). It was concluded that the application of heat in complex structures under specified conditions promotes the Maillard reaction (Aguilera et al. 2009b; Handa and Kuroda 1999). Aquafaba's gelling hydrogels; Proteins are formed because of polysaccharide and protein-polysaccharide interactions. Water-soluble polysaccharides in Aquafaba's structure contribute to its gelling properties. Compared to other legumes, chickpea has higher gelling properties than other legumes. There are still not enough studies on the gelling properties of Aquafaba (Mustafa and Reaney 2020; Serventi et al. 2018).

There are many factors that affect the technological features of the aquafaba mentioned above. Some of the factors affecting the technological properties of Aquafaba are the legume variety and production conditions, soaking, processing techniques, auxiliary substances such as enzymes, acids, bases and salts, protein content and carbohydrate content (Mustafa and Reaney 2020). The different genotypes of chickpea varieties have revealed important differences in their physicochemical and functional characteristics. It is understood that chickpea composition and seed behaviors are affected during storage and industrial processing, that is, environmental conditions also affect quality and performance characteristics. Likewise, significant differences were found in the chemical composition of different chickpea types. It has been found that the transition rate of molecules from seed to cooking water or aquafaba can be influenced by differences in genotype and environment. In addition, it was concluded that aquafaba composition may affect physiochemical and functional properties, and based on this result, it is stated that desired aquafaba functionality properties will enable the determination of new chickpea genotypes.

Application areas of Aquafaba in food technology

Bird et al. (2017) used chickpea ingredients (flour, paste, soaking water and cooking water) to improve structure of gluten-free bread. Replacing some of the tap water used in the formulation with chickpea cooking water created a softer texture. Large holes were observed in the control sample structure observed with scanning electron microscopy. It may have caused the gases produced by fermentation to escape without being kept in the structure, causing it to have a harder structure. On the other hand, using chickpea cooking water gave a more homogeneous and smooth structure with a small hole. Significant amounts of insoluble fiber and protein found in chickpea cooking water were associated with this condition.

Textural changes have been reported with the incorporation of cooking water from soybean processing into gluten-free crackers (Serventi et al. 2018). They found some significant textural changes. The control sample hardened twice on the second day of storage compared to day 0, while the sample using soybean cooking water was not hardened on the second day of storage, but rather softened. This was due to the high rate of moisture absorption. Yellow soybean cooking water has 1.54 g/g water absorption and 2.68 g/g oil absorption capacity due to presence of soluble and insoluble carbohydrates. Researchers recommended freeze-dried soybean cooking water could be added also to the bakery products such as cakes and soft cookies with controlling consistent time and temperature of operation.

Mustafa et al. (2018) prepared sponge cake with using either egg white or aquafaba which was derived from canned chickpea. Hardness, chewiness, springiness, cohesiveness, and resilience values of aquafaba cake crumb were found lower than egg white cake. Chewiness, springiness, and cohesiveness values were significantly different. It was indicated that with adding xanthan gum could improve those properties. Due to the simple carbohydrates and monomers amounts were higher in aquafaba compared to egg whites, the crust color of the cake made with aquafaba was found to be significantly darker result of caramelization and maillard reactions. Researchers were concluded that aquafaba had a possible to replace to replace egg white in vegan or egg-free cake formulations.

Developed vegan mayonnaise with using legume cooking water and investigated some quality parameters. Canning water of aquafaba was used instead of egg white thanks to emulsifying capacity. The most important factors of obtaining good quality and stability foam and emulsion were pH and boiling conditions. If they optimize, it is easy to develop nearly equal sensorial and textural same products which made of animal base proteins. After investigation of water-oil holding, emulsion and foam capacity of proteins extracted from different legumes such as cowpeas, chickpeas, soybeans, runner beans, peas lentils and beans in another study, it was concluded that plant derived proteins can be strong alternative of animal derived proteins for using a thickening agent in liquids (Lafarga et al. 2020).

Aslan and Ertaş (2020) used chickpea aquafaba at different levels in cake formulation due to its foaming capacity like egg. For this reason, different proportions of aquafaba (0-25-50-75-100%) were used with eggs and added to cake formulations. According to their results of the foaming capacity measured before cake making, the foaming stability of the concentration prepared with 25% aquafaba and 75% egg was found to be 253.33%, the highest value compared to the others. At the concentration containing 100% aquafaba with the lowest foam capacity (126.67%), the foam stability was found to be 94.74% with the highest value. While the density, pH, ash, and protein content (%) of the cake dough decreased as the aquafaba concentration increased, the maximum dry matter content was found in the sample containing 75% aquafaba and the least dry matter content was found in the cake dough containing only eggs. Baking loss and firmness of cake samples values differences found insignificant. The researchers stated that aquafaba would be a good alternative for vegan users in terms of both cost and nutrition.

Aquafaba is also used as a supplement to bakery products due to its resistant starch content, instead of egg whites in various recipes (Sajilata, Singhal, and Kulkarni 2006, He et al. 2021). Other applications are; It is the use of meringue (Stantiall et al. 2018), sponge cake (Mustafa et al. 2018) and vegan mayonnaise (Raikos, Hayes, and Ni 2020) as an emulsifier that takes the role of egg white in the development of products. Since soy milk contains approximately 26% protein on a dry basis, legume-based cheese can also be used as a legume-based milk substitute similar to the production of sauce and the taste of the developed product is not affected (Buhl, Christensen, and Hammershøj 2019; Gugger, Galuska, and Tremaine 2016). Aquafaba, which has various usage forms, affects the cake product quality by using vegetable proteins as egg substitutes (Meurer, de Souza, and Ferreira Marczak 2020). In addition to affecting the cake product quality, it is used as a good egg substitute for some products such as vegan mayonnaise, butter, chocolate. In addition, many chefs include aquafaba in their whipped cream, ice cream and many dessert recipes. One of the scientifically conducted studies has attracted attention by vegan people. In this study, it was reported that aquafaba is included in mayonnaise, cheese and cake recipes thanks to its foaming and emulsification properties (Meurer, de Souza, and Ferreira Marczak 2020). Aquafaba can be used as a rheological additive for those who prefer a vegan diet. In addition, because legumes are rich in lysine protein, they can play an alternative role to animal proteins (He et al. 2021).

Commercial products made from Aquafaba

In addition to scientific research, different commercial products containing aquafaba have also been produced by various companies. The target audience of these products, which were produced for use in products containing eggs or milk, was mostly vegan customer segment. Aquafaba was offered for sale in the form of liquid in a milk carton to use directly (Egg Alternative Aquafaba - Love OGGS® no date (Egg Alternative Aquafaba - Love OGGS n.d.)) as well as in the powder form which could be mixed with water to use for different recipes such as cake, ice-cream, cookies, brownies, muffins and dressing (Vor Aquafaba Powder 7 ounce (oz) — Vörn.d.). Aquafaba was used as the main ingredient in the powder mixture produced for meringue, the main component of which is egg in fact, in order to gain foam production. It has been produced with target of vegan customers to take the form easily as a result of mixing with water for the production of meringues (Vor Vegan Meringue Powder 6 oz — Vörn.d.). On the other hand aquafaba was used in the mayonnaise which is an emulsion of oil in water (Naked Byron Foods Vegan Mayonnaise 435 g (Cold) – Vegan Grocery Storen.d.; Veggie-Naise, Vegan Béarnaise Sauce | Needl n.d.). While egg yolk is generally used as an emulsifier (Cornelia, Siratantri, and Prawita 2015), the proteins in aquafaba had taken that role in these vegan mayonnaises. Hence, aquafaba had excellent commercial product potential for vegan customers. Those commercial products of aquafaba were summarized in Table 5.

Developing the functional properties of Aquafaba with innovative technologies

Ultrasound treatment

Ultrasound is a series of high-frequency sound waves that start at 16 kHz. Meurer, de Souza, and Ferreira Marczak (2020) used ultrasound pretreatment in their study about chickpea cooking water. After their investigation found that treatment have positive effect on foaming expansion because the expansion increased from 259% to 548%. This could be attributed to the protein solubility increasing from 863 (μg/mL) in the untreated sample to 980 μg/mL in the treated by ultrasound at 50% power for 30 minutes sample. The application of ultrasound has also improved many other features. Between the sample of foams that was not treated with ultrasound and the sample treated by ultrasound at 100% power for 10 minutes, the L value increased by about 7 values and reached a value very close to egg white. The hardness, consistency and adhesiveness values of foams improved after the ultrasound applications. In general, it has been stated that the use of ultrasound improves the foaming and emulsifying properties of aquafaba to the extent that it can be used as an egg substitute.

High pressure treatment

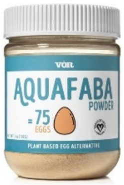
Alsalman and Ramaswamy (2021) investigated carbohydrate functionality and digestibility of aqueous aquafaba (chickpea) by high-pressure treatment. It was indicated that high pressure treatment and concentration of aquafaba increased consistency coefficient as well as strengthened gel structure by increasing complex modules. They found that digestibility of starch and crystallinity was increased with applying treatment. Applying pressure during 50 minutes of cooking in chickpeas reduces the protein solubility, while cooking with pressure shortens the boiling time. Autoclaving is used as a more effective method with higher pressure and water vapor temperature above 120 °C.

In this context, it is understood that it is very important to use less water and energy to produce larger scale aquafaba in environmentally friendly processes. In accordance with this purpose; It has been suggested that more use of other methods such as hydrolytic enzymes, ultrasound or microwave assisted extraction will increase the yield of aquafaba and further strengthen its functional properties.

Possible modification methods

Pulse cooking water (aquafaba) contain a remarkable amount of protein and its amount stated in different studies as 1.3-1.5

Table 5. Commercial products making from Aquafaba.



Aquafaba Powder by Vör Foods was stated that 198 g of powder was equivalent to 74 eggs so it can be used with adding water to make different receppies. (Vor Aquafaba Powder 7oz — Vör, n.d.)

Vegan Cocktail Foamer, contained aquafaba, by Vör Foods could be used to creates egg free foam to beverages (Vor Faba Foamer | Vegan Cocktail Foamer — Vör, n.d.).

Vegan Meringue Powder by Vör Foods was contained aquafaba powder, sugar, corn starch and cream of tartar. It was useful for meringue and butter cream recipes with mixed in water (Vor Vegan Meringue Powder 6oz — Vör, n.d.).

Egg Alternative Aquafaba by Oggs was contained 18 kcal energy from %100 aquafaba (water and chickpea extract) per 100 ml. It was useful to make different recipes (ice-cream, cake, cookie, donuts, brownies, muffins, ext.) (Egg Alternative Aquafaba - Love OGGS®, Egg Alternative Aquafaba - Love OGGS® n.d.).

Vegan Mayonnaise by Naked Byron Foods was contained sunflower oil, pure olive oil, lemon juice, apple cider vinegar, coconut sugar, sea salt, mustard, mustard powder (Naked Byron Foods Vegan Mayonnaise 435g (Cold) – Vegan Grocery Store, n.d.).

Vegan Béarnaise Sauce made with aquafaba was riched omega 3 was stated as vegan, gluten-free and delicious (Veggie-Naise, Vegan Béarnaise Sauce | Needl n.d.)

% (Serventi 2020), 0.95% (Stantiall et al. 2018), 1% (Bird et al. 2017) and 1.3% (Buhl, Christensen, and Hammershøj 2019) for chickpea; 0.68% for yellow-soybean; 1.27% for yellow peas; 1.51% for green lentils (Serventi et al. 2018). Lots of different functional properties could attribute to these protein content of aquafabas: high emulsifying activity and stability with protein and fiber (Damian, Huo, and Serventi 2018), developing of stable foam with combination of protein and saponins (Serventi et al. 2018), provide thickening properties (Serventi et al. 2018). To develop these important functional properties or create new properties, different modification process could be applied. The modification techniques applied to different vegetable proteins were given at Table 6. The main purpose of modification of plant proteins is applying of different processing stresses which include temperature, pressure, freezing, pH, electric field, solvent force. Important functional effects can be achieved by applying chemical, physical, and biological modifications to aquafabas.

Home use possibilities of Aquafaba's

Around the world, almost 1.3 billion tons of food is wasted in the food production chain every year from farm to fork. It is known that around 33% of these wastes are generated

Table 6. Modification techniques of different plant derived protein.

Modification technique	Applied product	Effects on functionality	Reference
Physical modification approaches			
Heat treatment	Lentil and chickpea	Increasing of available starch contents of soaked pulses, and decreasing of resistant starch contents	(Aguilera et al. 2009b)
	Pulse flours (lentil, chickpea, pea)	Increasing gelling, fat binding and water holding capacity in boiled flours	(Ma et al. 2011)
	Soy protein	Modifying foaming properties to use in aerated food system	(Shao, Lin, and Kao 2016)
	Cowpea protein	Water holding capacity increased (higher values: 30 min at 70 °C)	(Peyrano, Speroni, and Avanza 2016)
	Chickpea	Loss of vitamin B in microwave cooking was less than in autoclaving and boiling	(Alajaji and El-Adawy 2006)
Pulsed electric field	Chickpea	Reduction of water absorption and the relative water uptake	(Mahajan and Pandey 2014)
	Pea	Developing mass transfer processes	(Baier, Bußler, and Knorr 2015)
Cold atmospheric pressure plasma, Pulsed ultraviolet light, and Gamma-irradiation	Soy protein	Reduction of the immunoreactivity in the soluble protein fraction	(Meinlschmidt et al. 2016)
Ultrasound treatment	Chickpea	Decreasing of soaking and cooking times	(Yildirim, Öner, and Bayram 2013)
	Soy protein	During cavitation, changes occurred in flow behavior due to unfolding of protein chains. Increasing of protein solubility	(Hu et al. 2013)
	Black bean protein	Becoming smaller of big particles due to broking up of low soluble protein aggregates along cavitation.	(Jiang et al. 2014)
	Faba bean protein	Improving the surface and foaming properties	(Martínez-Velasco et al. 2018)
High pressure treatment	Lentil protein	Improving the degree of hydrolysis with accelerating the enzymatic hydrolysis reaction to improve functional antioxidant hydrolysates	(Ahmed et al. 2019)
	Pea protein	Enhancing of air bubble encapsulation and foam formation; preserving the organoleptic and nutritional properties	(Chao, Jung, and Aluko 2018; Sim, Karwe, and Moraru 2019)
	Aquafaba	Increasing viscosity and gel structure, enhancing starch digestibility, improving emulsion capacity and stability	(Alsalman et al. 2020)
Extrusion	Yellow pea protein and chickpea	Increasing on digestibility of indispensable amino acids to production of high-quality protein foods	(Devi et al. 2020)
	Mung bean protein	Improving strong gel forming, generation of small aggregates with improving solubility and digestibility, producing desirable foam and emulsion at optimized feed moisture	(Hossain Brishti et al. 2021)
	Lentil	Increasing of nutritional value with reducing of protein antinutritional factors, increasing of acceptability of sensory evaluation	(Rathod and Annapure 2016)
Chemical modification approaches			
Acylation	Mung bean protein	Decreasing of antinutritional factors; increasing water and oil absorption capacity, improvement on emulsification activity and stability	(El-Adawy 2000)
	Red kidney bean protein	Increasing of protein solubility, inducing of structural unfolding, increasing in conformational flexibility to improvement emulsifying property	(Yin et al. 2010)
	Soy protein	Increasing of oil binding capacity, surface hydrophobicity and, emulsion stability	(Matemu et al. 2011)
Glycation	Chickpea	Increasing of solubility, emulsion activity index; improving of emulsion stability	(Alshareef 2018)
	Cowpea protein	Increasing of carbohydrate content in isolate	(Campbell, Euston, and Ahmed 2016)
	Soy protein	Making stronger of antioxidant effect of proteins	(Feng et al. 2021)
Phosphorylation	Soybean protein	Improving of emulsifying and foam activity, increasing of protein digestibility, water, and fat absorption	(Sánchez-Reséndiz et al. 2018)
	Pea protein	Improving of solubility, emulsifying property, and stability, foaming property, and oil absorption capacity.	(Liu et al. 2020)
Biological modification approaches			
Enzymatic	Pea protein	Degradation of high molecular weight peptides, improving protein solubility and foaming capacity	(Arteaga et al. 2020)
	Kidney bean	Reducing of the allergenicity	(Kasera et al. 2015)
	Faba bean protein	Increasing of solubility, improving better foaming, oil holding, emulsifying capacity	(Eckert et al. 2019)
Fermentation	Pea protein-enriched flour	Improving of water and oil binding properties	(Kumitch et al. 2020)
	Chickpea flour	Increasing of water absorption index, protein digestibility; improving of water holding capacity, fat absorption capacity and emulsifying properties	(Xiao et al. 2015)
	Soy protein	Increasing of water and oil binding capacity, protein solubility and especially foaming capacity	(Meinlschmidt et al. 2016)
Other modification approaches			
Complexation	Pea protein	Increasing solubility with high methoxy pectin	(Pillai et al. 2020)
	Soybean protein	Improving digestibility and nutritional quality with anthocyanin-rich black rice extracts	(Zhang et al. 2006)
	Flaxseed	Increasing of antioxidant capacity with phenolic	(Guimarães Drummond E Silva et al. 2017)
Amyloid fibrillization	Cowpea protein	Improving of rheological properties	(Li et al. 2021)
	Soy Protein	Providing of rheological properties	(Wang et al. 2020)
	Pea Protein	Increasing of aggregate size	(Munialo et al. 2014)

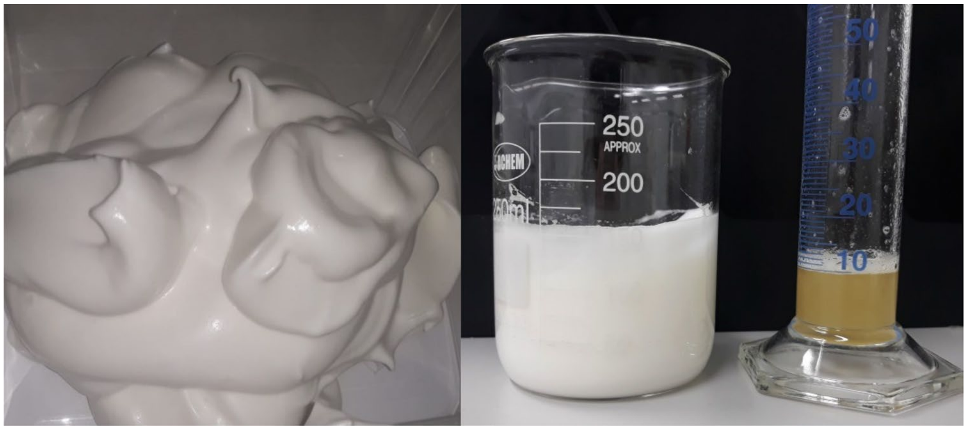


Figure 2. Display of chickpea cooking water foaming capacity when mixed with sugar at a ratio of 1:1.

as a result of household consumption. For this reason, the use of legume cooking water, which are food waste, in the industry, as well as the use of them at home with preparing different foods gain importance in terms of food waste management and ecological balance too.

Pulses are foods that are widely consumed around the world. They are important to consume as affordable meat alternative for their high nutritional value. They consumed by the whole world population because they are a good source of plant protein and other nutrients, such as vitamins B, calcium, potassium, zinc, and antioxidants. Hence, people from all around the world cook pulses in their meals. The best cooking method of pulses is boiling in water to make different recipes. Pulses' remaining water after cooking can have different uses even in domestic consumption. It can be used in recipes like bread, mayonnaise, cake, ice cream, meringue, macaroon, or cookie rather than pouring into sinks. Classic kitchen tools can be transformed into important products that can benefit from the valuable properties of pulses' cooking water. Furthermore, pulse-cooking waters such as chickpeas generally do not have a predominant taste and smell. For this reason, it can be an organoleptic ally powerful option apart from technologically option for egg in various recipes for individuals who do not like the taste of eggs and are uncomfortable with their odor.

Pulse boiling waters with its foaming ability provide different possibilities to home-produced pulse cooking waters. Pulses consumers can easily foam the remaining water at home after cooking. By whisking it with sugar, a stable cream can be obtained with a volume. Figure 2 shows the foam structure with a volume of 150 ml formed by whisking 10 ml of chickpea cooking water for 6 minutes. Thanks to this foaming ability, pulse-cooking water can gain a structure like cake cream when mixed with sugar. This cream is economical as it can be prepared with only 2 ingredients; it is low calorie and vegan since it does not contain animal food. It can be used in cupcakes decorations or baked and consumed as meringues or macaroons. A hand mixer is sufficient for its preparation. Hence, it can be easily preferred in home production and consuming pulses cooking water can reduce household food waste.

In recipes where eggs are included, to produce products such as cakes and soft cookies pulse-cooking waters can be whipped to obtain the volume to the structure without egg added. An evaluation area can be created for pulse cooking water for the production of many gluten-free products and vegan food in home kitchens. Hence, the amount of household food waste is reduced, it contributes to the home economy and healthy new tastes can be created for both children and adults.

On the other hand, pulses cooking waters such as chickpea cooking water can form high emulsions thanks to the protein it contains. Thus, it can easily form emulsions. With this feature, it can be used in homes as vegan mayonnaise with a successful consistency by homogenizing it with the help of a household mixer with using liquid oil and aquafaba. It has attracted attention as it can be used at home in different recipes. One of the studies carried out in this context, Mustafa et al. (2018) examined the factors affecting the functional properties of aquafaba recovered from commercially canned chickpeas. As a result of the study, it was suggested to home users to choose a store-bought canned chickpea product without salt or EDTA, which gives the most concentrated results (Mustafa et al. 2018). For the use of aquafaba as an egg substitute, Grizio and Specht (2018) stated the use of 1 tablespoon of aquafaba per egg yolk, 2 tablespoons per egg white and 3 tablespoons of aquafaba per whole egg.

Conclusion

Correct use of resources is one of the most fundamental solutions in the fight against hunger. Current developments such as global climate change, increasing population, food shortage, and food waste require the ideal management of waste obtained from food. Improving the agricultural production of legumes rich in nutrients in the fight against hunger offers a great potential solution to food shortages. Pulses are among the most important nutritional sources that benefit the industry and sustainable production and consumption due to their nutritional richness, the creation of multiple by-products in the process stages, their functional and technological features, and the diversity of use in foods. Pulses are among the most popular food products due to their high protein content, low cost, general acceptability and functional properties that can be used in food processing. For this purpose, recycling of pulse cooking water (aquafaba) in food processing means significantly reducing food waste. The fact that aquafaba is rich in carbohydrates, proteins, phytochemicals, vitamins and minerals further reinforces its future importance. Aquafaba's achievements in food processing also mean it will be a powerful alternative to substitutes of animal origin.

Acronyms and Abbreviations

C:	Celsius
CWR:	seed to water ratio
dwt:	deadweight tonnage
EDTA:	ethylenediaminetetraacetic acid
ext.:	extract
ha:	area harvested
IP6:	inositol hexaphosphate
kDa:	kilodalton
kHz:	kilohertz
kPa:	kilopascal
lt:	liter
μg/mL:	microgramme by milliliter
n.d:	no date
NMR:	nuclear magnetic resonance
oz:	ounce
ql:	below quantification limit (0.5% of the dry matter analyzed)
SDG:	the sustainable development goals
UNDP:	the united nations development agency
w/v:	weight by volume
< dl:	below detection limit; -, not mentioned

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The author(s) reported there is no funding associated with the work featured in this article.

ORCID

Erenay Erem http://orcid.org/0000-0002-1607-2610
Necattin Cihat Icyer http://orcid.org/0000-0002-3190-9669
Nevruz Berna Tatlisu http://orcid.org/0000-0001-7460-1560
Mahmut Kilicli http://orcid.org/0000-0002-6885-0277
Gizem Hulaga Kaderoglu http://orcid.org/0000-0001-6722-1519
Ömer Said Toker http://orcid.org/0000-0002-7304-2071

References

Aguilera, Y., M. A. Martín-Cabrejas, V. Benítez, E. Mollá, F. J. López-Andréu, and R. M. Esteban. 2009a. Changes in carbohydrate fraction during dehydration process of common legumes. *Journal of Food Composition and Analysis* 22 (7–8):678–83. doi: 10.1016/j.jfca.2009.02.012.

Aguilera, Y. R. M., V. Esteban, E. Benítez, M. Mollá, and A. Martín-Cabrejas. 2009b. Starch, functional properties, and microstructural characteristics in chickpea and lentil as affected by thermal processing. *Journal of Agricultural and Food Chemistry* 57 (22):10682–8. doi: 10.1021/jf902042r.

Ahmed, S. A., I. A. M. Ahmed, M. Eltayeb, and S. O. Ahmed. 2012. Effect of sodium chloride concentration on the functional properties of selected legumes flour. *African Journal of Food, Agriculture, Nutrition and Development* 12 (6):6701–14.

Ahmed, J., M. Mulla, N. Al-Ruwaih, and Y. A. Arfat. 2019. Effect of high pressure treatment prior to enzymatic hydrolysis on rheological, thermal, and antioxidant properties of lentil protein isolate. *Legume Science* 1 (1):e10. doi: 10.1002/leg3.10.

Alajaji, S. A., and T. A. El-Adawy. 2006. Nutritional composition of chickpea (Cicerarietinum L.) as affected by microwave cooking and other traditional cooking methods. *Journal of Food Composition and Analysis* 19 (8):806–12. doi: 10.1016/j.jfca.2006.03.015.

Alsalman, F. B., M. Tulbek, M. Nickerson, and H. S. Ramaswamy. 2020. Evaluation and optimization of functional and antinutritional properties of aquafaba. *Legume Science* 2 (2):1–15. doi: 10.1002/leg3.30.

Alsalman, F. B., and H. S. Ramaswamy. 2021. Changes in carbohydrate quality of high-pressure treated aqueous aquafaba. *Food Hydrocolloids* 113 (October):106417. doi: 10.1016/j.foodhyd.2020.106417.

Alshareef, M. A. 2018. Physicochemical properties of glycated chickpea (*Cicerarietinum L.*) protein. *Journal of Pure & Applied Sciences* 17 (1):248–249. doi: 10.51984/jopas.v17i1.97.

Arteaga, V. G., M. A. Guardia, I. Muranyi, P. Eisner, and U. Schweiggert-Weisz. 2020. Effect of enzymatic hydrolysis on molecular weight distribution, techno-functional properties and sensory perception of pea protein isolates. *Innovative Food Science & Emerging Technologies* 65:102449. doi: 10.1016/j.ifset.2020.102449.

Aslan, M., and N. Ertaş. 2020. Possibility of using "chickpea aquafaba" as egg replacer in traditional cake formulation. *Harran Tarım ve Gıda Bilimleri Dergisi* 24 (1):1–8. doi: 10.29050/harranziraat.569397.

Baier, A. K., S. Bußler, and D. Knorr. 2015. Potential of high isostatic pressure and pulsed electric fields to improve mass transport in pea tissue. *Food Research International* 76:66–73. doi: 10.1016/j.cej.2015.05.007.

Bamdad, F., A. H. Goli, and M. Kadivar. 2006. Preparation and characterization of proteinous film from lentil (*Lens Culinaris*): Edible film from lentil (*Lens Culinaris*). *Food Research International* 39 (1):106–11. doi: 10.1016/j.foodres.2005.06.006.

Baojun, X., and S. K. C. Chang. 2009. Phytochemical profiles and health-promoting effects of cool-season food legumes as influenced by thermal processing. *Journal of Agricultural and Food Chemistry* 57 (22):10718–31. doi: 10.1021/jf902594m.

Barakat, H., V. Reim, and S. Rohn. 2015. Stability of saponins from chickpea, soy and faba beans in vegetarian, broccoli-based bars subjected to different cooking techniques. *Food Research International* 76 (1):142–9. doi: 10.1016/j.foodres.2015.03.043.

Behera, M. R., S. R. Varade, P. Ghosh, P. Paul, and A. S. Negi. 2014. Foaming in micellar solutions: Effects of surfactant, salt, and oil concentrations. *Industrial & Engineering Chemistry Research* 53 (48):18497–507. doi: 10.1021/ie503591v.

Bencini, M. C. 1986. Functional properties of drum dried chickpea (*Cicerarietinum L.*) flours. *Journal of Food Science* 51 (6):1518–21. doi: 10.1111/j.1365-2621.1986.tb13849.x.

Bigdeloo, M., T. Teymourian, E. Kowsari, S. Ramakrishna, and A. Ehsani. 2021. Sustainability and circular economy of food wastes: Waste reduction strategies, higher recycling methods, and improved valorization. *Materials Circular Economy* 3 (1):4. doi: 10.1007/s42824-021-00017-3.

Bird, L. G., C. L. Pilkington, A. Saputra, and L. Serventi. 2017. Products of chickpea processing as texture improvers in gluten-free bread. *Food Science and Technology International = Ciencia y Tecnologia de Los Alimentos Internacional* 23 (8):690–8. doi: 10.1177/1082013217717802.

Boye, J., F. Zare, and A. Pletch. 2010. Pulse proteins: Processing, characterization, functional properties and applications in food and feed. *Food Research International* 43 (2):414–31. doi: 10.1016/j.foodres.2009.09.003.

Buhl, T. F., C. H. Christensen, and M. Hammershøj. 2019. Aquafaba as an egg white substitute in food foams and emulsions: Protein composition and functional behavior. *Food Hydrocolloids* 96 (October 2018):354–64. doi: 10.1016/j.foodhyd.2019.05.041.

Byanju, B., M. M. Rahman, M. P. Hojilla-Evangelista, and B. P. Lamsal. 2020. Effect of high-power sonication pretreatment on extraction and some physicochemical properties of proteins from chickpea, kidney bean, and soybean. *International Journal of Biological Macromolecules* 145:712–21. doi: 10.1016/j.ijbiomac.2019.12.118.

Cai, R., B. Klamczynska, and B. K. Baik. 2001. Preparation of bean curds from protein fractions of six legumes. *Journal of Agricultural and Food Chemistry* 49 (6):3068–73. doi: 10.1021/jf0013398.

Campbell, L., S. R. Euston, and M. A. Ahmed. 2016. Effect of addition of thermally modified cowpea protein on sensory acceptability and textural properties of wheat bread and sponge cake. *Food Chemistry* 194:1230–7. doi: 10.1016/j.foodchem.2015.09.002.

Chao, D., S. Jung, and R. E. Aluko. 2018. Physicochemical and functional properties of high pressure-treated isolated pea protein. *Innovative Food Science & Emerging Technologies* 45:179–85. doi: 10.1016/j.ifset.2017.10.014.

Cornelia, M., T. Siratantri, and R. Prawita. 2015. The utilization of extract durian (*Duriozibethinus L.*) seed gum as an emulsifier in vegan mayonnaise. *Procedia Food Science* 3:1–18. doi: 10.1016/j.profoo.2015.01.001.

Damian, J. J., S. Huo, and L. Serventi. 2018. Phytochemical content and emulsifying ability of pulses cooking water. *European Food Research and Technology* 244 (9):1647–55. doi: 10.1007/s00217-018-3077-5.

De Almeida Costa, G. E., K. Da Silva Queiroz-Monici, S. M. Pissini Machado Reis, and A. C. De Oliveira. 2006. Chemical composition, dietary fibre and resistant starch contents of raw and cooked pea, common bean, chickpea and lentil legumes. *Food Chemistry* 94 (3):327–30. doi: 10.1016/j.foodchem.2004.11.020.

De Kanterewicz, R. J., B. E. Elizalde, A. M. R. Pilosof, and G. B. Bartholomai. 1987. Water-oil absorption index (WOAI): A simple method for predicting the emulsifying capacity of food proteins. *Journal of Food Science* 52 (5):1381–3. doi: 10.1111/j.1365-2621.1987.tb14087.x.

Devi, S., A. Varkey, H. Dharmar, R. R. Allen, R. R. Holt, L. H. Allen, M. S. Sheshshayee, T. Preston, C. L. Keen, and A. V. Kurpad. 2020. Amino acid digestibility of extruded chickpea and yellow pea protein is high and comparable in moderately stunted South Indian children with use of a dual stable isotope tracer method. *The Journal of Nutrition* 150 (5):1178–85. doi: 10.1093/jn/nxaa004.

Dranca, F., and M. Oroian. 2018. Extraction, purification and characterization of pectin from alternative sources with potential technological applications. *Food Research International (Ottawa, ON)* 113:327–50. doi: 10.1016/j.foodres.2018.06.065.

Du, S. K., H. Jiang, X. Yu, and J. Lin Jane. 2014. Physicochemical and functional properties of whole legume flour. *LWT - Food Science and Technology* 55 (1):308–13. doi: 10.1016/j.lwt.2013.06.001.

Eckert, E., J. Han, K. Swallow, Z. Tian, M. Jarpa Parra, and A. L. Chen. 2019. Effects of enzymatic hydrolysis and ultrafiltration on physicochemical and functional properties of faba bean protein. *Cereal Chemistry* 96 (4):725–41. doi: 10.1002/cche.10169.

Egg Alternative Aquafaba - Love OGGS. n.d. Accessed May 29, 2021. https://www.loveoggs.com/product-oggs-aquafaba-egg-alternative/

El-Adawy, T. A. 2000. Functional properties and nutritional quality of acetylated and succinylatedmung bean protein isolate. *Food Chemistry* 70 (1):83–91. doi: 10.1016/S0308-8146(00)00079-0.

El-Hady, E. A. A., and R. A. Habiba. 2003. Effect of soaking and extrusion conditions on antinutrients and protein digestibility of legume seeds. *LWT - Food Science and Technology* 36 (3):285–93. doi: 10.1016/S0023-6438(02)00217-7.

FAOSTAT (Food and Agriculture Organization of the United Nations Statistics). 2019. World Food and Agriculture Statistical Pocketbook 2019. ISBN 978-92-5-131849-2. Rome. http://www.fao.org/3/ca6463en/ca6463en.pdf

Feng, C., H. Wei, D. Yang, B. Feng, Z. Ma, S. Han, Q. Zou, and H. Shi. 2021. ORS Pred: An optimized reduced scheme-based identifier for antioxidant proteins. *Proteomics* 21 (15):2100017. doi: 10.1002/pmic.202100017.

Fernández-Quintela, A., M. T. Macarulla, A. S. Del Barrio, and J. A. Martínez. 1997. Composition and functional properties of protein isolates obtained from commercial legumes grown in northern Spain. *Plant Foods for Human Nutrition (Dordrecht, Netherlands)* 51 (4):331–41. doi: 10.1023/A:1007936930354.

Ghadge, N. P., S. V. Shewalkar, and D. B. Wankhede. 2008. Effect of processing methods on qualities of instant whole legume: Pigeon pea (Cajanuscajan L.). *Agricultural Engineering International: CIGR Ejournal* X:1–8.

Grizio, M., and L. Specht. 2018. *Plant-based egg alternatives: Optimizing for functional properties and applications*. The Good Food Institute. Accessed August 16, 2021. https://gfi.org/images/uploads/2018/06/Plantbasedeggalternatives.pdf.

Güçlü-Ustündağ, O., and G. Mazza. 2007. Saponins: Properties, applications and processing. *Critical Reviews in Food Science and Nutrition* 47 (3):231–58. doi: 10.1080/10408390600698197.

Gugger, E. T., P. Galuska, and A. Tremaine. 2016. Legume-based dairy substitute and consumable food products incorporating same. United States Patent Publication No. WO/2016/172570 AI, filed April 22, 2016, and issued October 27, 2016. https://patentimages.storage.googleapis.com/cb/e2/91/36648ec060f3e1/WO2016172570A1.pdf.

Guimarães Drummond E Silva, F., B. Miralles, B. Hernández-Ledesma, L. Amigo, A. H. Iglesias, F. G. Reyes Reyes, and F. M. Netto. 2017. Influence of protein-phenolic complex on the antioxidant capacity of flaxseed (Linum usitatissimum L.) products. *Journal of Agricultural and Food Chemistry* 65 (4):800–9. doi: 10.1021/acs.jafc.6b04639.

Han, I. H., and B. K. Baik. 2006. Oligosaccharide content and composition of legumes and their reduction by soaking, cooking, ultrasound, and high hydrostatic pressure. *Cereal Chemistry Journal* 83 (4):428–33. doi: 10.1094/CC-83-0428.

Handa, A., and N. Kuroda. 1999. Functional improvements in dried egg white through the Maillard reaction. *Journal of Agricultural and Food Chemistry* 47 (5):1845–50. doi: 10.1021/jf9811018.

He, Y., V. Meda, M. J. T. Reaney, and R. Mustafa. 2021. Aquafaba, a new plant-based rheological additive for food applications. *Trends in Food Science & Technology* 111 (February):27–42. doi: 10.1016/j.tifs.2021.02.035.

He, Y., Y. Y. Shim, R. Mustafa, V. Meda, and M. J. T. Reaney. 2019. Chickpea cultivar selection to produce aquafaba with superior emulsion properties. *Foods* 8 (12):685. doi: 10.3390/foods8120685.

Hossain Brishti, F., S. Y. Chay, K. Muhammad, M. Rashedi Ismail-Fitry, M. Zarei, S. Karthikeyan, F. Caballero-Briones, and N. Saari. 2021. Structural and rheological changes of texturized mung bean protein induced by feed moisture during extrusion. *Food Chemistry* 344:128643. doi: 10.1016/j.foodchem.2020.128643.

Hu, H., J. Wu, E. C. Y. Li-Chan, L. Zhu, F. Zhang, X. Xu, G. Fan, L. Wang, X. Huang, and S. Pan. 2013. Effects of ultrasound on structural and physical properties of soy protein isolate (SPI) dispersions. *Food Hydrocolloids* 30 (2):647–55. doi: 10.1016/j.foodhyd.2012.08.001.

Iqbal, A., I. A. Khalil, N. Ateeq, and M. Sayyar Khan. 2006. Nutritional quality of important food legumes. *Food Chemistry* 97 (2):331–5. doi: 10.1016/j.foodchem.2005.05.011.

Jiang, L., J. Wang, Y. Li, Z. Wang, J. Liang, R. Wang, Y. Chen, W. Ma, B. Qi, and M. Zhang. 2014. Effects of ultrasound on the structure and physical properties of black bean protein isolates. *Food Research International* 62:595–601. doi: 10.1016/j.foodres.2014.04.022.

Kasera, R., A. B. Singh, S. Lavasa, K. N. Prasad, and N. Arora. 2015. Enzymatic hydrolysis: A method in alleviating legume allergenicity. *Food and Chemical Toxicology* 76:54–60. doi: 10.1016/j.fct.2014.11.023.

Khattab, R. Y., and S. D. Arntfield. 2009. Nutritional quality of legume seeds as affected by some physical treatments 2. antinutritional factors. *LWT - Food Science and Technology* 42 (6):1113–8. doi: 10.1016/j.lwt.2009.02.004.

Klupšaitė, D., and G. Juodeikienė. 2015. Legume: Composition, protein extraction and functional properties. A review. *Chemical Technology* 66 (1):5–12. doi: 10.5755/j01.ct.66.1.12355.

Kumar, N., K. K. Hazra, C. P. Nath, C. S. Praharaj, and U. Singh. 2018. Grain legumes for resource conservation and agricultural sustainability in South Asia. In *Legumes for soil health and sustain-*

able management, ed. R. S. Meena. Singapore: Springer. doi: 10.1007/978-981-13-0253-4_3

Kumitch, H. M., A. K. Stone, M. T. Nickerson, D. R. Korber, and T. Tanaka. 2020. Effect of fermentation time on the physicochemical and functional properties of pea protein-enriched flour fermented by *Aspergillusoryzae* and *Aspergillusniger*. *Cereal Chemistry* 97 (2):416–28. doi: 10.1002/cche.10257.

Lafarga, T., C. Álvarez, S. Villaró, G. Bobo, and I. Aguiló-Aguayo. 2020. Potential of pulse-derived proteins for developing novel vegan edible foams and emulsions. *International Journal of Food Science & Technology* 55 (2):475–81. doi: 10.1111/ijfs.14286.

Lafarga, T., S. Villaró, G. Bobo, and I. Aguiló-Aguayo. 2019. Optimisation of the pH and boiling conditions needed to obtain improved foaming and emulsifying properties of chickpea aquafaba using a response surface methodology. *International Journal of Gastronomy and Food Science* 18:100177. doi: 10.1016/j.ijgfs.2019.100177.

Lee, H. C., A. K. Htoon, and J. L. Paterson. 2007. Alkaline extraction of starch from Australian lentil cultivars matilda and digger optimized for starch yield and starch and protein quality. *Food Chemistry* 102 (3):551–9. doi: 10.1016/j.foodchem.2006.03.042.

Li, T., L. Wang, X. Zhang, H. Geng, W. Xue, and Z. Chen. 2021. Assembly behavior, structural characterization and rheological properties of legume proteins based amyloid fibrils. *Food Hydrocolloids* 111:106396. doi: 10.1016/j.foodhyd.2020.106396.

Liu, Y., D. Wang, J. Wang, Y. Yang, L. Zhang, J. Li, and S. Wang. 2020. Functional properties and structural characteristics of phosphorylated pea protein isolate. *International Journal of Food Science & Technology* 55 (5):2002–10. doi: 10.1111/ijfs.14391.

Luo, Z., B. S. Murray, A. Yuso, M. R. A. Morgan, M. J. W. Povey, and A. J. Day. 2011. Particle-stabilizing effects of flavonoids at the oil-water interface. *Journal of Agricultural and Food Chemistry* 59 (6):2636–45. doi: 10.1021/jf1041855.

Ma, Z., J. I. Boye, B. K. Simpson, S. O. Prasher, D. Monpetit, and L. Malcolmson. 2011. Thermal processing effects on the functional properties and microstructure of lentil, chickpea, and pea flours. *Food Research International* 44 (8):2534–44. doi: 10.1016/j.foodres.2010.12.017.

Mahajan, T. S., and O. P. Pandey. 2014. Effect of electric field (at different temperatures) on germination of chickpea seed. *African Journal of Biotechnology* 13 (1):61–7. doi: 10.5897/AJB2013.13345.

Makri, E., E. Papalamprou, and G. Doxastakis. 2005. Study of functional properties of seed storage proteins from indigenous European legume crops (Lupin, Pea, Broad Bean) in admixture with polysaccharides. *Food Hydrocolloids* 19 (3):583–94. doi: 10.1016/j.foodhyd.2004.10.028.

Martin-Cabrejas, M. A., R. M. Esteban, K. W. Waldron, G. Maina, G. Grant, S. Bardocz, and A. Pusztai. 1995. Hard-to-cook phenomenon in beans: Changes in antinutrient factors and nitrogenous compounds during storage. *Journal of the Science of Food and Agriculture* 69 (4):429–35. doi: 10.1002/jsfa.2740690405.

Martínez-Velasco, A., C. Lobato-Calleros, B. E. Hernández-Rodríguez, A. Román-Guerrero, J. Alvarez-Ramirez, and E. J. Vernon-Carter. 2018. High intensity ultrasound treatment of faba bean (Vicia faba L.) protein: Effect on surface properties, foaming ability and structural changes. *Ultrasonics Sonochemistry* 44:97–105. doi: 10.1016/j.ultsonch.2018.02.007.

Marquez, U. M. L., R. M. C. Barros, and F. M. Lajolo. 1996. Chemically determined total and available methionine in beans (*Phaseolus vulgaris L.*) and isolated protein fractions. *Food Chemistry* 55 (2):179–84. doi: 10.1016/0308-8146(95)00071-2.

Matemu, A. O., H. H. Kayahara, S. Murasawa, S. Katayama, and S. Nakamura. 2011. Improved emulsifying properties of soy proteins by acylation with saturated fatty acids. *Food Chemistry* 124 (2):596–602. doi: 10.1016/j.foodchem.2010.06.081.

Mazumdar, D. S., P. Durgalla, and P. M. Gaur. 2016. Utilization of pulses-value addition and product development. In *Pulses for sustainable food and nutrition security in SAARC region*, ed. R. Gurungand and S. M. Bokhtiar, 65–98. Dhaka: SAARC Agriculture Centre. ISBN 978-984-34-1521-9

McDermott, J., and A. J. Wyatt. 2017. The role of pulses in sustainable and healthy food systems. *Annals of the New York Academy of Sciences* 1392 (1):30–42. doi: 10.1111/nyas.13319.

Meena, S. R., and R. Lal. 2018. Legumes and sustainable use of soils. *Legumes for Soil Health and Sustainable Management*, ed. R. S. Meena. Singapore, Springer. doi: 10.1007/978-981-13-0253-4_1

Meinlschmidt, P., E. Ueberham, J. Lehmann, U. Schweiggert-Weisz, and P. Eisner. 2016. Immunoreactivity, sensory and physicochemical properties of fermented soy protein isolate. *Food Chemistry* 205:229–38. doi: 10.1016/j.foodchem.2016.03.016.

Meurer, M. C., D. de Souza, and L. D. Ferreira Marczak. 2020. Effects of ultrasound on technological properties of chickpea cooking water (aquafaba). *Journal of Food Engineering* 265:109688. doi: 10.1016/j.jfoodeng.2019.109688.

Munialo, C. D., A. H. Martin, E. Van Der Linden, and H. H. De Jongh. 2014. Fibril formation from pea protein and subsequent gel formation. *Journal of Agricultural and Food Chemistry* 62 (11):2418–27. doi: 10.1021/jf4055215.

Mustafa, R., Y. He, Y. Y. Shim, and M. J. T. Reaney. 2018. Aquafaba, wastewater from chickpea canning, functions as an egg replacer in sponge cake. *International Journal of Food Science & Technology* 53 (10):2247–55. doi: 10.1111/ijfs.13813.

Mustafa, R., and M. J. T. Reaney. 2020. Aquafaba, from food waste to a value-added product. In *Food wastes and by products: nutraceutical and health potential*, eds. R. Campos-Vega, B. D. Oomah, H. A. Vergara-Castañeda, 93–126. New York, NY, USA: Wiley Online Library. doi: 10.1002/9781119534167.ch4.

Naked Byron Foods Vegan Mayonnaise 435g (cold) – Vegan Grocery Store. n.d. Accessed May 29, 2021. https://www.crueltyfreeshop.com.au/products/nakedbyronfoodsveganmayonnaise435gcold

Ologhobo, A. D., D. F. Apata, A. Oyejide, and O. Akinpelu. 1993. Toxicity of raw limabeans (Phaseolus lunatus L.) and limabean fractions for growing chicks. *British Poultry Science* 34 (3):505–22. doi: 10.1080/00071669308417606.

Ozcicek Dolekoglu, C. 2017. Gıda kayıpları, israf ve toplumsal çabalar. *Tarım Ekonomisi Dergisi* 23 (2):179–86. doi: 10.24181/tarekoder.364946.

Papalamprou, E. M., G. I. G. I. Doxastakis, and V. Kiosseoglou. 2010. Chickpea protein isolates obtained by wet extraction as emulsifying agents. *Journal of the Science of Food and Agriculture* 90 (2):304–13. doi: 10.1002/jsfa.3816.

Paredes-Lopez, O., and C. Ordorica-Falomir. 1986. Production of safflower protein isolates: Composition, yield and protein quality. *Journal of the Science of Food and Agriculture* 37 (11):1097–103. doi: 10.1002/jsfa.2740371107.

Paredes-Lopez, O., C. Ordorica-Falomir, and A. Cbrabes-Trejo. 1988. Production of safflower protein isolates: Phvsicochemical characterization. *Lebensm.Wiss.u.-Technol* 21:328. doi: 10.1111/j.1365-2621.1991.tb05367.x.

Paredes-Lopez, O., C. Ordorica-Falomir, and M. R. Olivares-Vazquez. 1991. Chickpea protein isolates: Physicochemical, functional and nutritional characterization. *Journal of Food Science* 56 (3):726–9. doi: 10.1111/j.1365-2621.1991.tb05367.x.

Parmar, N., N. Singh, A. Kaur, A. S. Virdi, and S. Thakur. 2016. Effect of canning on color, protein and phenolic profile of grains from kidney bean, field pea and chickpea. *Food Research International (Ottawa, ON)* 89 (Pt 1):526–32. doi: 10.1016/j.foodres.2016.07.022.

Pedrosa, M. M., C. Cuadrado, C. Burbano, M. Muzquiz, B. Cabellos, B. Olmedilla-Alonso, and C. Asensio-Vegas. 2015. Effects of industrial canning on the proximate composition, bioactive compounds contents and nutritional profile of two Spanish common dry beans (*Phaseolus vulgaris L.*). *Food Chemistry* 166:68–75. doi: http://dx.doi.org/10.1016/j.foodchem.2014.05.158.

Pekşen, E., and C. Artık. 2005. Anti besinse lmaddeler ve yemeklik baklagillerin besleyici değerleri. *Ondokuz Mayıs Üniversitesi Ziraat Fakültesi Dergisi* 20 (2):110–20.

Peyrano, F., F. Speroni, and M. V. Avanza. 2016. Physicochemical and functional properties of cowpea protein isolates treated with temperature or high hydrostatic pressure. *Innovative Food Science & Emerging Technologies* 33:38–46. doi: 10.1016/j.ifset.2015.10.014.

Pillai, P. K., B. E. L. Morales-Contreras, L. Wicker, and M. T. Nickerson. 2020. Effect of enzyme de-esterified pectin on the electrostatic complexation with pea protein isolate under different mixing conditions. *Food Chemistry* 305:125433. doi: 10.1016/j.foodchem.2019.125433.

Price, K. R., C. L. Curl, and G. R. Fenwick. 1986. The saponin content and sapogenol composition of the seed of 13 varieties of legume. *Journal of the Science of Food and Agriculture* 37 (12):1185–91. doi: 10.1002/jsfa.2740371206.

Prodanov, M., I. Sierra, and C. Vidal-Valverde. 2004. Influence of soaking and cooking on the thiamin, riboflavin and niacin contents of legumes. *Food Chemistry* 84 (2):271–7. doi: 10.1016/S0308-8146(03)00211-5.

Raikos, V., L. Campbell, and S. R. Euston. 2007. Rheology and texture of hen's egg protein heat-set gels as affected by pH and the addition of sugar and/or salt. *Food Hydrocolloids* 21 (2):237–44. doi: 10.1016/j.foodhyd.2006.03.015.

Raikos, V., H. Hayes, and H. Ni. 2020. Aquafaba from commercially canned chickpeas as potential egg replacer for the development of vegan mayonnaise: Recipe optimisation and storage stability. *International Journal of Food Science & Technology* 55 (5):1935–42. doi: 10.1111/ijfs.14427.

Rathod, R. P., and U. S. Annapure. 2016. Effect of extrusion process on antinutritional factors and protein and starch digestibility of lentil splits. *Lwt - Food Science and Technology* 66:114–23. doi: 10.1016/j.lwt.2015.10.028.

Rebello, C. J., F. L. Greenway, and J. W. Finley. 2014. A review of the nutritional value of legumes and their effects on obesity and its related co-morbidities. *Obesity Reviews* 15 (5):392–407. doi: 10.1111/obr.12144.

Rehinan, Z., M. M. Rashid, and W. H. Shah. 2004. Insoluble dietary fibre components of food legumes as affected by soaking and cooking processes. *Food Chemistry* 85 (2):245–9. doi: 10.1016/j.foodchem.2003.07.005.

Rehman, Z. U., and W. H. Shah. 2005. Thermal heat processing effects on antinutrients, protein and starch digestibility of food legumes. *Food Chemistry* 91 (2):327–31. doi: 10.1016/j.foodchem.2004.06.019.

Sajilata, M. G., R. S. Singhal, and P. R. Kulkarni. 2006. Resistant starch - A review. *Comprehensive Reviews in Food Science and Food Safety* 5 (1):1–17. doi: 10.1111/j.1541-4337.2006.tb00076.x.

Sánchez-Reséndiz, A., S. Rodríguez-Barrientos, J. Rodríguez-Rodríguez, B. Barba-Dávila, S. O. Serna-Saldívar, and C. Chuck-Hernández. 2018. Phosphoesterification of soybean and peanut proteins with sodium trimetaphosphate (STMP): Changes in structure to improve functionality for food applications. *Food Chemistry* 260:299–305. doi: 10.1016/j.foodchem.2018.04.009.

Sánchez-Vioque, R., A. Clemente, J. Vioque, J. Bautista, and F. Millán. 1999. Protein isolates from chickpea (*Cicerarietinum L.*): Chemical composition, functional properties and protein characterization. *Food Chemistry* 64 (2):237–43. doi: 10.1016/S0308-8146(98)00133-2.

Sarıoğlu, G., and Y. S. Velioğlu. 2018. Baklagillerin bileşimi. *Akademik Gıda* 16 (4):483–96. doi: 10.24323/akademik-gida.505547.

Seena, S., and K. R. Sridhar. 2005. Physicochemical, functional and cooking properties of under explored legumes, Canavalia of the southwest coast of India. *Food Research International* 38 (7):803–14. doi: 10.1016/j.foodres.2005.02.007.

Serventi, L. 2020. *Upcycling legume water: From wastewater to food ingredients*. Switzerland: Springer. doi: 10.1007/978-3-030-42468-8.

Serventi, L., S. Wang, J. Zhu, S. Liu, and F. Fei. 2018. Cooking water of yellow soybeans as emulsifier in gluten-free crackers. *European Food Research and Technology* 244 (12):2141–8. doi: 10.1007/s00217-018-3122-4.

Shao, Y. Y., K. H. Lin, and Y. J. Kao. 2016. Modification of foaming properties of commercial soy protein isolates and concentrates by heat treatments. *Journal of Food Quality* 39 (6):695–706. doi: 10.1111/jfq.12241.

Shim, Y. Y., R. J. Mustafa, K. Shen, M. J. T. Ratanapariyanuch, and M. J. T. Reaney. 2018. Composition and properties of aquafaba: Water recovered from commercially canned chickpeas. *Journal of Visualized Experiments* 2018 (132):14. doi: 10.3791/56305.

Sim, S. Y., M. V. Karwe, and C. I. Moraru. 2019. High pressure structuring of pea protein concentrates. *Journal of Food Process Engineering* 42 (7):e13261. doi: 10.1111/jfpe.13261.

Singh, G. D., A. A. Wani, D. Kaur, and D. S. Sogi. 2008. Characterisation and functional properties of proteins of some Indian chickpea (*Cicerarietinum*) cultivars. *Journal of the Science of Food and Agriculture* 1243 (September 2007):1237–43. doi: 10.1002/jsfa.

Stagnari, F., A. Maggio, A. Galieni, and M. Pisante. 2017. Multiple benefits of legumes for agriculture sustainability: An overview. *Chemical and Biological Technologies in Agriculture* 4 (2):4–7. doi: 10.1186/s40538-016-0085-1.

Stantiall, S. E., K. J. Dale, F. S. Calizo, and L. Serventi. 2018. Application of pulses cooking water as functional ingredients: The foaming and gelling abilities. *European Food Research and Technology* 244 (1):97–104. doi: 10.1007/s00217-017-2943-x.

Subuola, F., Y. Widodo, and T. Kehinde. 2011. Processing and utilization of legumes in the tropics. In *Trends in vital food and control engineering*, ed. A. A. Eissa, 71–84. United Kingdom: IntechOpen Limited. https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection-in-biometrics.

Słupski, J. 2011. Effect of freezing and canning on the content of vitamin C in immature seeds of five cultivars of common bean (*Phaseolus vulgaris L.). Acta Scientarium Polonorum. Technologia Alimentaria* 10 (2):199–208.

Tyler, R. T., C. G. Youngs, and F. W. Sosulski. 1981. Air classification of legumes. I. Seperation efficiency, yield, and composition of the starch and protein fractions. *Cereal Chemistry* 58 (2):144–8.

Urbano, G., M. P. López-Jurado, C. Aranda, E. Vidal-Valverde, E. Tenorio, and J. Porres. 2000. The role of phytic acid in legumes: Antinutrient or beneficial function? *Journal of Physiology and Biochemistry* 56 (3):283–94. doi: 10.1007/BF03179796.

Veggie-Naise, Vegan Béarnaise Sauce | needl. n.d. Accessed May 29, 2021. https://needl.co/app/p/veggiebel/54331/veggienaise_vegan_b_arnaise_sauce2

Vor Vegan Meringue Powder 6oz — Vör. n.d. Accessed May 29, 2021. https://www.vorfoods.com/aquafaba/vor-vegan-meringue-powder-6oz

Vose, J. R. 1980. Production and functionality of starches and protein isolates from legume seeds (field peans and horsebeans). *Cereal Chemistry* 57 (6):406–10.

Wang, S., J. G. Yang, D. Shao, H. Qu, L. Zhao, L. Yang, Y. Zhu, H. He, H. Liu, and D. Zhu. 2020. Soy protein isolated-soy hull polysaccharides stabilized O/W emulsion: Effect of polysaccharides concentration on the storage stability and interfacial rheological properties. *Food Hydrocolloids* 101:105490. doi: 10.1016/j.foodhyd.2019.105490.

Xiao, Y., G. Xing, X. Rui, W. Li, X. Chen, M. Jiang, and M. Dong. 2015. Effect of solid-state fermentation with Cordycepsmilitaris SN-18 on physicochemical and functional properties of chickpea (*Cicerarietinum L.*) flour. *Lwt - Food Science and Technology* 63 (2):1317–24. doi: 10.1016/j.lwt.2015.04.046.

Xu, B., and S. K. Chang. 2008. Total phenolics, phenolic acids, isoflavones, and anthocyanins and antioxidant properties of yellow and black soybeans as affected by thermal processing. *Journal of Agricultural and Food Chemistry* 56 (16):7165–75. doi: 10.1021/jf8012234.

Yildirim, A., M. D. Öner, and M. Bayram. 2013. Effect of soaking and ultrasound treatments on texture of chickpea. *Journal of Food Science and Technology* 50 (3):455–65. doi: 10.1007/s13197-011-0362-8.

Yin, S. W., C. H. Tang, Q. B. Wen, X. Q. Yang, and D. B. Yuan. 2010. The relationships between physicochemical properties and conformational features of succinylated and acetylated kidney bean (*Phaseolus vulgaris L.*) protein isolates. *Food Research International* 43 (3):730–8. doi: 10.1016/j.foodres.2009.11.007.

Zayas, J. F. 1997. Foaming properties of proteins. In *Functionality of proteins in food*, 260–309. Switzerland: Springer. doi: 10.1007/978-3-642-59116-7_6.

Zhang, M. W., B. J. Guo, R. F. Zhang, J. W. Chi, Z. C. Wei, Z. H. Xu, Y. Zhang, and X. J. Tang. 2006. Separation, purification and identification of antioxidant compositions in black rice. *Agricultural Sciences in China* 5 (6):431–40. doi: 10.1016/S1671-2927(06)60073-4.

Zhao, X., X. Zhang, H. Liu, G. Zhang, and Q. Ao. 2018. Functional, nutritional and flavor characteristic of soybean proteins obtained through reverse micelles. *Food Hydrocolloids* 74:358–66. doi: 10.1016/j.foodhyd.2017.08.024.