CHEMICAL ENGINEERING TRANSACTIONS
VOL. 89, 2021

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš

ISBN 978-88-95608-87-7; **ISSN** 2283-9216

DOI: 10.3303/CET2189002

Application of Chickpeas Aquafaba with Pre-treatment as Egg Replacer in Cake Production

Thi Minh Nguyet Nguyen[a,*], Nguyen P.b. Ngọc[a], Le Pham Tan Quoc[a], Gia Buu Tran[b]

[a] Institute of Biotechnology and Food Technology, Industrial University of Ho Chi Minh City, 12 Nguyen Van Bao Street, Ward 4, Go Vap District, Ho Chi Minh City, Vietnam
[b] Georgia Cancer Center, Augusta University, USA
nguyenthiminhnguyet@iuh.edu.vn

Aquafaba, the viscous liquid obtained from cooked beans, is a foaming agent to replace egg white, which has been considered a functional ingredient in eggless cake recipes. The study investigated the appropriate conditions for the use of chickpea aquafaba in plant-based bakery processing. The physicochemical properties of cake from aquafaba and control samples (from egg white), such as foaming capacity (FC), foaming stability (FS), weight loss, cake density, volume and colour parameters have been determined. The results showed that the cake sample made from chickpea aquafaba treated with citric acid (pH of 4) – table salt (3,000 μg.mL^{-1}) has a remarkable similarity with the egg white in terms of textural properties. In addition, using xanthan gum also improved FS, hardness, and bubbles size of foaming aquafaba**.** This study suggests the chickpea aquafaba could be considered as an egg white substitute in the plant-based cake production process to contribute to agricultural pollution minimization and to build a shared vision for sustainable food and agriculture.

1. Introduction

According to current statistics, the food system accounts for more than 30 % of the land area, 70 % of available fresh water and 20 % of energy. Sustainable food production for an additional 2.3 billion people will require enormous social transformation and industrial change over the next four decades. Aiking (2011) suggests that livestock products negatively impact the environment, such as biodiversity loss, freshwater depletion, climate change and other issues. Consumers nowadays are getting more conscious of environmental protection and awareness to reduce the pressure on the livestock industry. They are gradually turning to plant food consumption (Janssen et al., 2016), vegan food (Starmer et al., 2018), and replacing progressively animal protein with vegetable protein (Sharif et al., 2018). Besides, the increasing switch to a vegan or plant-based diet has been associated with food allergies. Research proved that most allergies develop at school age, but about 1/3 of allergies persists into adulthood (Tan and Joshi, 2014).

Many food products need to contain bubbles in their structure to provide a pleasant texture or an attractive appearance of products such as bread, waffles, whipped cream, cotton, chocolate mousse, and meringues. Egg whites have excellent surface activity properties and foaming capacity, which are essential parts of the baking processes. There have been many studies looking for ingredients that can potentially replace whole or partial egg in baking products, such as white lupine protein, emulsifier, gum (Arozarena et al., 2001), soy milk (Rahmati and Tehrani, 2015), and milk protein (Tan et al., 2014). A foam system is valuable in food when it is relatively stable over a period of time (Stadelman and Schmeider, 2002). The unique foaming, emulsifying and coagulating properties of egg white proteins play an essential role in food weight and texture (Abu-Ghoush et al., 2010). In addition, Ashwini et al. (2009) have demonstrated that finding a suitable egg substitute is not an easy task. Aquafaba, a viscous liquid separated from any canned beans or extracts of dried beans, has been considered a foaming agent to replace egg white. It is extracted from any canned beans or liquid extracted from the cooking process of dried beans. Aquafaba can be found in canned peas products or easily prepared by boiling legume seeds Aquafaba has many functional properties such as foaming, emulsifying, binding, and thickening, making it a potential candidate for egg white substitutes. These properties of aquafaba vary depending on the chemical composition of the bean, temperature, pressure, cooking time and genotype

Paper Received: 15 May 2021; Revised: 28 August 2021; Accepted: 20 November 2021
Please cite this article as: Nguyen T.M.N., Ngọc N.P., Quoc L.P.T., Tran G.B., 2021, Application of Chickpeas Aquafaba with Pre-treatment as Egg Replacer in Cake Production, Chemical Engineering Transactions, 89, 7-12 DOI:10.3303/CET2189002

(Mustafa et al., 2018). The quality and composition of canned chickpea aquafaba depend on the soaking and cooking time/ time of soaking and cooking process. (Shim et al., 2018). One of the beans whose aquafaba has good foaming ability is Chickpea, and aquafaba from commercially canned chickpeas has been studied in recent years (Mustafa et al., 2018). The evaluation of the textural and microstructural properties of whipped cream from chickpea aquafaba was obtained by the traditional cooking method (Nguyet et al., 2021). Up to the present time, there is no research on using manual chickpea aquafaba in baking plant-based cake. This study aimed to determine: i) Effects of the different treatments on foaming capacity, foaming stability, hardness and bubble size of foaming aquafaba and (ii) Properties of cakes with the different treatments of chickpea cooking water as an application for eggless baking processes.

2. Materials and methods

2.1 Materials and chemicals

Dried chickpeas (*Cicer arietinum* L.) provided from Chan Nguyen nutritious food store (Vietnam) (100 g of dried chickpeas contain 269 calories, 45 g of carbohydrates, 4 g of fat, 15 g of protein and 13 g of fibre) and baking materials, including flour (Meizan company, Vietnam), yellow sugar (Bien Hoa company, Vietnam), salt (Visalco company, Vietnam), colza oil (Tuong An company, Vietnam) were obtained from local grocery stores. All other chemicals used in this study were of food grade.

2.2 Aquafaba and whipping preparation

The first step was to soak dried chickpeas in tap water for ten hours and drained them afterwards. Then, drained chickpeas were cooked with beans/water ratio of 1/4 (w/w) on the electric stove (Sunhouse SH6150) for 40 min at 800 W. After that, the mixture was cooled at room temperature, and the beans were removed. The initial pH value of the solution was approximately 6.2. On the other hand, soluble protein and saponin concentrations, total soluble solid content of the chickpeas aquafaba were characterized. The soluble solid content was briefly measured using an ATAGO Master Refractometer Manual 0-30, while the soluble protein concentration was determined using the Bradford method. The saponin concentration of aquafaba was evaluated using Dong and Gu (2001) method.

Whipping preparation: For whipping, 100 mL of aquafaba was whipped at approximately 720 rpm by a stirrer (Panasonic MK-GB1WRA, China) for 3 min. Anhydrous citric acid was diluted with water to produce the 6.5 M citric acid solution used for pH adjustment. 1 g anhydrous xanthan gum (98 % purity) was put into 99 mL of distilled water. The mixture was placed into a blender and mixed for 2 min to produce the 1 % xanthan gum solution. Treatment 1: The pH of 4 (adjusted by citric acid) and salt content of 3,000 $\mu g.mL^{-1}$. Treatment 2: included Treatment 1 and added xanthan gum of 50 $\mu g.mL^{-1}$ (Nguyet et al., 2021).

2.3 Batter preparation and baking procedure

The cakes used in this study were prepared based on two recipes, one recipe using 100 mL aquafaba (as egg replacement) and the other recipe using 100 mL of egg white (control sample). First, the cake batter was prepared by adding 50 g of fine sugar. Then, the mixture was stirred by a stirrer (Panasonic MK-GB1WRA, China) at approximately 720 rpm for 2 min. After that, 30 g of canola oil were added into the mixture, and the mixture was whipped for 1 min (Mixture 1). Next, 60 g of wheat flour and 1.5 g of baking powder were added to mixture 1, and the mixture was subsequently whipped with level 1 (approximately 520 rpm) for 1 min. Finally, the obtained cake batter was baked in an oven (Southstar NFC-8D, China) at 150 °C for 30 min. After baking, the cake was cooled at room temperature for 30 min to carry out the following survey.

2.4 Determination of the properties of the foam

Foaming capacity (FC) and foaming stability (FS) were determined by the method of Makri et al. (2005) with slight modification. In brief, 100 mL of whipped foam were gently moved to a cylinder (500 mL). Foam volume was noted. The foam transferring process was done within 2 min; then the foam was stored for 30 min. The foam and the final liquid volume were then noted. The FC and FS of foam were calculated. According to Rahmati and Tehrani (2015) procedure, the textural properties were determined at 720 rpm for 3 min, then added to a 60 mm diameter, 30 mm high cylindrical mould. The structural properties of the foam were determined by TPA (Texture profile analysis) method using the Brookfield CT3 Texture Analyzer (US) and a cylindrical probe TA4/1000 (diameter of 38.1 mm, thickness of 20 mm). Transducer velocity was set as 1 mm/s with 50 % compression force compared to the original, and compression repeated 2 times (compression force of 5 g). The velocity before testing was 2 mm/s. The structural properties of the foam are expressed as Hardness values.

2.5 Determination of the properties of cake

The properties of cake were evaluated by cake density, volume increase, and weight loss. They were calculated according to the Eq(1) – (3):

$$Cake\ density\ (kg.m^{-3}) = \frac{W_{cake}\ (kg)}{V_{cake}\ (m^3)} \tag{1}$$

$$Volume\ increase\ (\%) = \frac{V_{cake} - V_{batter}}{V_{batter}} \times 100 \tag{2}$$

$$Weight\ loss\ (\%) = \frac{W_{batter} - W_{cake}}{W_{batter}} \times 100 \tag{3}$$

where W_{cake} and V_{cake} are weight and volume of cake after baking, V_{cake} and V_{bater} are volumes of cake and batter, W_{batter} and W_{cake} are weight of batter and cake after baking. Moisture content was measured by the method of AOAC-934.06.

The textural properties of the cake were based on the method previously described by Nguyet et al. (2020): the cakes were cut into cubes (2×2×2 cm). The velocity of the transducer was set as 5 mm/s with a compression force of 50 % deformation compared to the original and compression twice. The compression force was 5 g, the TA4/1000 Cylinder (38.1 mm in diameter and 20 mm in thickness) was used.

The colour parameters of crust and crumb of cake were measured by colourimeter (Minolta CR410, Japan), including L^*, a^* and b^* value. The cake's crust was measured at 3 points on the surface and 7 points around the cake. Each cake was cut a slice of 1.5 cm of thickness from the tip to the bottom of the cake, was measure 5 positions on each side of the slice. In addition, the browning index value (BI) was calculated by Eq(4) and (5) (Cruz-Solorio, 2018):

$$BI = 100 - \frac{x - 0.31}{0.17} \tag{4}$$

$$x = \frac{a^* + 1.75L^*}{5.647L^* + a^* - 3.012b^*} \tag{5}$$

2.6 Statistical analysis

All tests were performed in triplicates, and the results were represented as mean ± standard deviation. The differences among the treated groups were determined by the one-way analysis of variance (ANOVA) method and Fisher's least significant difference procedure via the Statgraphics Centurion XV software (Statpoint Technologies Inc. Virginia, USA).

3. Results and discussion

3.1 Effect of the different treatments on foaming capacity, foaming stability, hardness and bubble size of foaming aquafaba

The protein and saponin concentration of aquafaba were 27.897 ± 2.340 $mg.L^{-1}$ and 0.466 ± 0.056 ppm. The total soluble solid content of aquafaba was 5.2 ± 0.1 %, and the initial pH of aquafaba was 6.2. FC, hardness and bubble size foam of acid-salt chickpeas and egg white were not significantly different. There have been several studies on adjusting pH and salt addition to improve foaming properties (Nguyen et al., 2021). Table 1 showed the highest foaming ability of the aquafaba solution with pH adjustment and table salt. Nguyet et al. (2021) proved that the chickpea aquafaba had suitable textural properties treated with a salt content of 3,000 $\mu g.mL^{-1}$, xanthan gum of 50 $\mu g.mL^{-1}$, and pH of 4 (adjusted by citric acid). This data has been used to process for further investigation of the cake. These results showed that both pH and salt concentration affect the foaming properties of chickpea cooking water with the specific data that NaCl addition increases FC and FS to a degree but then decreases. These results are contrary to the publication of Buhl et al. (2019), in which the foaming ability of aquafaba is not affected when the NaCl concentration increases or the pH value of canned chickpea water changes. The addition of polysaccharides will have beneficial effects on FC and FS. However, in this study, xanthan gum does not increase FC but promotes FS. This result can be explained by the increase in viscosity of the aqueous phase and the formation of adhesive films, which leads to the increase of FS. Determination of the properties of cakes with the different treatments.

Table 2 showed that the viscosity of the cake batter made from Treatment 2 chickpeas aquafaba was higher (2853.18 Cps) than Treatment 1 and Non-treatment but still lower than the batter made from the foam of egg white (4488.00 Cps). This is due to the high viscosity of xanthan gum, leading to an increase in the foam and batter viscosity, and increasing the viscosity of the batter. In addition, the cake from the chickpeas solution treated with acid - salt had the highest expansion (17.35 %), but it was not statistically different from the cake from egg white (16.09 %). Cakes from Non-treatment or treated with xanthan gum had lower expansion (8.63 % and 8.41 %) (Table 2). Untreated chickpeas aquafaba has low FC and FS, so the foam was significantly broken during the folding process, which led to the collapsing structure of the cake after baking.

Table 1: Comparison of the effect of different treatments on foaming capacity (FC), foaming stability (FS), hardness and bubble size of foaming aquafaba

Samples	FC (%)	FS (%)	Hardness (g)	Bubble size (µm)
Non-treatment	$520.67^{a} \pm 9.02$	$85.56^{a} \pm 1.45$	$41.50^{a} \pm 1.80$	$589.04^{c} \pm 369.62$
Treatment 1	$685.33^{c} \pm 8.33$	$93.70^{b} \pm 0.31$	$78.50^{b} \pm 3.91$	$216.04^{a} \pm 84.60$
Treatment 2	$627.33^{b} \pm 17.21$	$99.13^{c} \pm 0.93$	$83.23^{c} \pm 0.87$	$369.62^{b} \pm 199.76$
Egg white	$684.00^{c} \pm 5.29$	$98.64^{c} \pm 0.15$	$76.50^{b} \pm 1.50$	$177.16^{a} \pm 79.89$

Different lowercase letters in the same column denote significant differences (*p*<0.05).

Table 2: Physicochemical properties of cake with the different treatments

Parameter	Non-treatment	Treatment 1	Treatment 2	Egg white
Viscosity (Cps) of batter	$1,126.40^{a} \pm 53.77$	$1,167.41^{a} \pm 83.14$	$2,853.18^{b} \pm 64.06$	$4,488.00^{c} \pm 190.75$
Cake density (kg.m^{-3})	$548.32^{d} \pm 4.17$	$436.73^{b} \pm 3.40$	$468.50^{c} \pm 2.75$	$410.67^{a} \pm 1.92$
Volume increase (%)	$8.63^{a} \pm 1.10$	$17.35^{b} \pm 0.08$	$8.41^{a} \pm 0.45$	$16.09^{b} \pm 0.39$
Weight loss (%)	$9.27^{a} \pm 0.61$	$18.52^{c} \pm 0.46$	$14.03^{b} \pm 0.71$	$21.67^{d} \pm 0.28$
Moisture (%)	$31.00^{c} \pm 0.22$	$25.73^{a} \pm 0.19$	$27.66^{b} \pm 0.42$	$25.82^{a} \pm 0.10$

Different lowercase letters in the same row denote significant differences (*p*<0.05).

Although FC and FS of foam treated with xanthan gum are pretty effective, the batter volume is large). The main reason for using the protein-polysaccharide complex as a foam stabilizer is its high surfactant capacity, the ability to increase the viscosity of dispersed media, and form thick gel-like adsorbent layers (Ye, 2008). Due to its high viscosity, the adhesion increases sharply, and the water cannot escape from the batter during the baking process; hence the expansion is poor. Egg whites are also highly viscous, but their nature is protein denatured by heat, while the nature of xanthan gum is a very stable polysaccharide with temperature (Lopes et al., 2015). The weight loss of the cake samples made with egg white reached the highest value (21.67 %), followed by the cake made with aquafaba treated with acid-salt (18.52 %), the cake made with aquafaba treated with xanthan gum (14.03 %) and the untreated cake made with aquafaba (9.27 %). The weight loss mainly depends on the evaporation of water during the baking process. Therefore, an increase in the moisture evaluation can lead to a decrease in the weight of a cake. Similarly, the cake density from the egg white and the acid-salt treatment was also small (410.67 kg.m^{-3} versus 436.73 kg.m^{-3}).

As a result, these two cakes' weight was lighter than the cake from foam untreated and added xanthan gum. Cake samples were preliminarily analyzed for nutritional content. Table 2 showed that the nutrition indicators were quite similar to egg white cakes and acid-salt cake. Although egg cake's protein and lipid contents are higher than those of chickpeas cake, the energy from chickpeas cake is not significantly different from that of egg cake. Due to its good water retention during baking, cakes made from untreated chickpeas or added xanthan gum have a higher moisture content (31.00 % versus 27.66 %) compared to the rest of the cakes. Based on the above analysis, the study noted similarities in physical and chemical properties between the egg white and Treatment 1 of aquafaba cakes.

3.2 Colour parameters analysis of cakes made via different treatments

Table 3 showed that the chickpeas cake batter had a higher brightness (L^*) than the egg. After the baking process, the brightness of the Non-treatment samples (the crust) was significantly reduced (from 90.22 to 60.09). The remaining three samples (cakes made using Treatment 1, Treatment 2, and egg white) had more colour stability. The Non-treatment sample showed a weak foam structure. Thus, there was no guarantee of expansion during the baking process. Besides, the caramelization reactions or Maillard reactions on the crust resulted in the darkening of the cake. The browning index (BI) on the crust and the crumb were quite similar in all samples. The significant difference in $\triangle E^*$ between the samples is clearly shown in the inequality of colour when comparing the four cake samples side by side. From the cross-sections of the four cake samples (Figure 1), it was found that the egg white cake had a finer and denser structure. The cake, which was made using chickpeas aquafaba, has large gaps created by air holes. Besides, there is no clear demarcation boundary between the crust and crumb in the cake from untreated aquafaba (Figure 1a), but the crust is clearly visible in the remaining three samples (Figure 1b, 1c, 1d). Based on colour analysis, it can be inferred that cakes made using aquafaba and egg white are fundamentally different.

Table 3: Colour parameters of cake with the different treatments

`		Non-treatment	Treatment 1	Treatment 2	Egg white
Colour values (Batter)	L^*	$90.22^d \pm 1.31$	$65.97^b \pm 0.05$	$75.51^c \pm 0.50$	$62.15^a \pm 0.35$
	a^*	$-0.39^a \pm 0.05$	$-0.17^c \pm 0.01$	$-0.40^a \pm 0.03$	$-0.29^b \pm 0.04$
	b^*	$2.95^c \pm 0.35$	$2.29^b \pm 0.02$	$2.03^a \pm 0.01$	$2.16^{ab} \pm 0.02$
	ΔE^*	$88.11^d \pm 1{,}31$	$63.85^b \pm 0.05$	$73.29^c \pm 0.47$	$60.03^a \pm 0.35$
Colour values (The crust)	L^*	$60.09^a \pm 2.62$	$66.86^b \pm 1.15$	$76.76^d \pm 0.38$	$68.77^c \pm 1.98$
	a^*	$9.27^c \pm 0.84$	$7.27^b \pm 0.89$	$2.22^a \pm 0.14$	$9.49^c \pm 1.22$
	b^*	$35.90^d \pm 0.72$	$34.61^c \pm 1.06$	$25.24^a \pm 0.51$	$33.34^b \pm 0.76$
	ΔE^*	$66.57^a \pm 1.50$	$72.54^b \pm 0.58$	$77.97^d \pm 0.41$	$74.00^c \pm 1.40$
	BI	$99.02^a \pm 0.08$	$99.22^b \pm 0.06$	$99.59^c \pm 0.01$	$99.25^b \pm 0.06$
Colour values (The crumb)	L^*	$64.20^a \pm 3.86$	$67.07^b \pm 2.43$	$73.09^c \pm 2.97$	$80.42^d \pm 1.10$
	a^*	$3.00^c \pm 0.27$	$2.70^c \pm 0.46$	$1.34^b \pm 0.42$	$0.79^a \pm 0.37$
	b^*	$25.84^b \pm 0.82$	$25.71^b \pm 0.92$	$22.72^a \pm 0.97$	$23.21^a \pm 1.00$
	ΔE^*	$67.22^a \pm 1.29$	$68.95^b \pm 2.00$	$73.73^c \pm 2.82$	$80.92^d \pm 0.87$
	BI	$99.46^a \pm 0.06$	$99.50^a \pm 0.05$	$99.6^b \pm 0.03$	$99.66^b \pm 0.02$

Different lowercase letters in the same row denote significant differences (p<0.05).

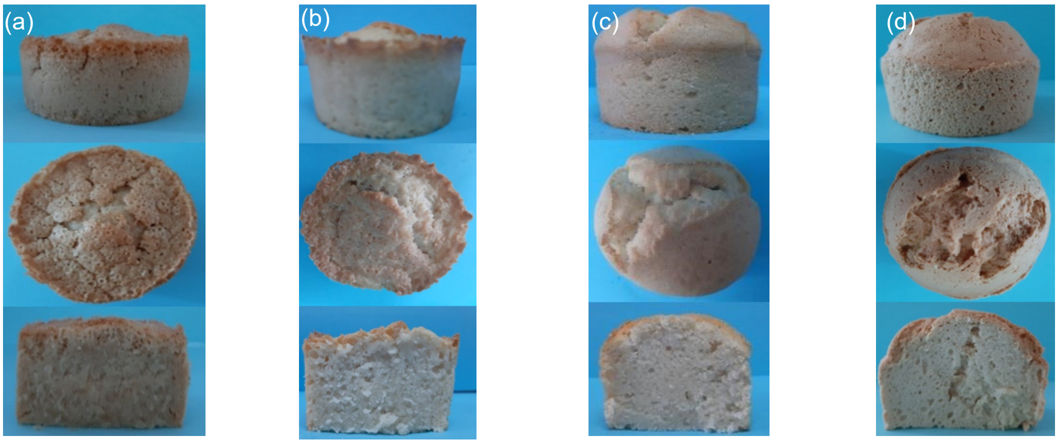

Figure 1: Cake with the different treatments (a) Non-treatment; (b) Treatment 1; (c) Treatment 2; (d) Egg white

3.3 Textural properties of cakes made via different treatments

Table 4 demonstrated that the textural parameters of the cake, including hardness, cohesiveness, springiness, gumminess, and chewiness of the cake made from egg white and the one made from Treatment 1 were not significantly different.

Table 4: Textural properties of cake with the different treatments

Parameter	Non-treatment	Treatment 1	Treatment 2	Egg white
Hardness 1 (g)	$404.90^b \pm 70.10$	$428.67^b \pm 75.87$	$238.33^a \pm 47.66$	$358.00^b \pm 36.01$
Hardness 2 (g)	$333.17^b \pm 41.25$	$382.50^b \pm 67.95$	$214.00^a \pm 42.87$	$334.50^b \pm 31.01$
Cohesiveness	$0.53^a \pm 0.07$	$0.71^b \pm 0.03$	$0.68^b \pm 0.03$	$0.74^b \pm 0.01$
Springiness (mm)	$7.30^a \pm 0.86$	$8.59^{bc} \pm 0.28$	$7.99^{ab} \pm 0.53$	$9.04^c \pm 0.06$
Gumminess (g)	$189.17^a \pm 47.05$	$303.43^b \pm 46.43$	$161.00^a \pm 30.88$	$262.80^b \pm 22.00$
Chewiness (mJ)	$13.47^a \pm 3.56$	$25.65^b \pm 4.74$	$12.53^a \pm 1.64$	$23.72^b \pm 2.14$

Different lowercase letters in the same row denote significant differences (p<0.05).

These results were similar to that of textural properties of cakes made from aquafaba treated with acid-salt and egg white. This shows that the textural properties sharply influence the structural properties of the cake.

4. Conclusions

Chickpea aquafaba is a complicated mixture which contains many components. In order to create foam with properties that can replace eggs in baking, the aquafaba needs to be adjusted. The results showed that the cake sample made from chickpeas aquafaba treated with citric acid (pH of 4), table salt (3,000 $\mu g.mL^{-1}$) has a remarkable similarity with the one made from egg white in terms of textural properties. The obtained results showed that aquafaba could use as a replacer for egg white in vegan bakery processing.

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