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Evaluation of Textural and Microstructural Properties of Vegan Aquafaba Whipped Cream from Chickpeas

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Aquafaba, the viscous by-product liquid from cooking chickpeas or other legumes, is recognized as one of the most common plant-based egg alternatives for forming foam and adding more texture to food products. Recently, canned chickpeas aquafaba, have been suggested as a good choice for replacement egg white in vegan products. In this study, the effects of some processing parameters such as chickpeas/cooking water ratio, pH, sea salt, sugar and xanthan gum on foam capacity, foam stability, viscosity on chickpeas cooking water (aquafaba) were evaluated. Based on the results from the tests, the new recipe of whipping cream was developed, in which the chickpea aquafaba obtained from cooking in chickpeas: cooking water ratio (1:4) with salt content of 0.003 g.ml^{-1}, xanthan gum of 0.00005 g.ml^{-1}, pH of 4 and sucrose content of 0.7 g.ml^{-1} were mixed for 8 min, and then was whipped for 5 min. The results showed that some textural properties of the vegan whipped cream from chickpeas were compared to whipped cream from eggs. The results may be significant to develop new technologies utilizing legume proteins to produce eggless, non-dairy cold desserts.

1. Introduction

Nowadays, limiting the use of animal products along with food self-sufficiency is the trend of many countries around the world, which lead to significant transition toward vegan products in food selection trend (Janssen et al., 2016). Consuming plant–based food products helps reduce the food expense and is suitable for those who suffer from egg/dairy allergies or intolerance. The increase use of plant-based protein is essential to reduce the stress on the farming industry and food-related greenhouse gas emission, which provides many environmental impacts. As the consequence, the rising demand for plant-based protein products in many industrial countries is observed. Dried peas (green pea, lentils, and chickpeas) are the common plant-based egg alternatives. From a nutritional point of view, a combination of plant-based proteins in the right way can provide adequate essential amino acids for requirement of human nutrition. In addition, plant-based protein plays an important role in food processing by creating functional properties through emulsifying capacity, foaming ability, gelling and dough – making capacity (Day, 2013). During cooking or canning legumes, a viscous liquid which is called as aquafaba is obtained and usually is recognized as wastewater of food processing (Mustafa et al., 2018). However, many researches proved that plant-based proteins, especially canned chickpeas aquafaba, have foam forming and stabilizing ability and can be a good choice for replacement egg white in vegan products (Vidal-Valverde et al., 1993). Additionally, Stantiall et al. (2018) also suggests that the characteristics of seeds such as, genotype, chemical and physicochemical composition, as well as cooking methods could affect the chemical composition and functional properties of aquafaba (Stantiall et al., 2018). With the aim of utilizing of discarded peas cooking water (aquafaba) and building a sustainable food system, a new kind of food product, known as aquafaba whipped cream, from the discarded chickpea cooking water (CCW) is developed, which can be used to replace egg white in making cold vegan desserts. In this study, the effects of some factors on the foam properties of aquafaba whipped cream, including pH, salt, xanthan gum, sucrose were studied.

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2. Materials and methods

2.1 Materials

Desi chickpeas (*Cicer arietinum* L.) were obtained by local grocery store (Chan Nguyen food store, Ho Chi Minh City, Vietnam). Sea salt was a product of Visalco Company (Da Nang City, Vietnam). Refined sugar was from Bien Hoa Sugar Joint Stock Company (Dong Nai province, Vietnam) and fresh eggs were supplied by Ba Huan Company (Ho Chi Minh City, Vietnam). The other chemicals used in this study were of food grade.

2.2 Preparation of chickpea cooking water

Dried chickpeas (100 g) were soaked in water (400 mL) for 8 – 10 h. After that, they were cooked in water (material/ water ratio of 1/3, 1/4 and 1/5, w/w) for 45 min. The chickpea cooking water (CCW) was subsequently cooled down to the room temperature (29 ± 3 °C) and was separated from cooked pulses by a stainless steel strainer. The CCW was packed in zipper bags (5 × 7 cm) and stored at -4 °C freezer (Sanyo, Vietnam) until using in further experiments.

2.3 Preparation of CCW foam

Frozen chickpea cooking water was kept at room temperature (29 ± 3 °C) until completely melted. 100 mL of chickpea aquafaba were put into the bowl. The pH of cooking water was adjusted with citric acid (pH of 3, 4, 5), sea salt (0.002, 0.003, 0.004 $g.ml^{-1}$) was added. Then, the mixture was whipped by mixer (Panasonic MK-GB1WRA, at speed setting 5) for 10 min. The whipped cream made from egg white (EW) via whipping by the same mixer for 3 min was used as the control. The effects of pH and salt concentration on structural properties of foam from CCW were investigated.

2.4 Preparation of whipped cream from CCW

The whipped foam from CCW was mixed with sugar (0.6, 0.7 and 0.8 $g.ml^{-1}$) and xanthan gum (0.00004, 0.00005 and 0.00006 $g.ml^{-1}$). The whipped foam was subsequently mixed for 8 min and whipped for 5 min to obtain the whipped cream from CCW. The whipped cream made from egg white (EW) via whipping by the same mixer for 3 min was used as the control. The effects of sucrose and xanthan gum on foam properties of whipped cream were analysed.

2.5 Textural characteristics analysis

The foam textural characteristics were investigated using procedure by Rahmati et al. (2018) with some slight modifications. After mixing, the foam from chickpeas cooking water was rested for 1 min and filled into the cylindrical mold (diameter of 60 mm, 30 mm of height). The height of the foam was adjusted to have the equal height of mold using a straight tape to brush the surface of the foam. Texture profiles were measured by TPA device (TA-XT Plus, The Brookfield CT3 Texture Analyzer, AMETEK Brookfield, MA, USA) with a cylindrical probe TA4/1000 (diameter of 38.1 mm and height of 20 mm). Probe speed was set at 1 $mm.s^{-1}$, 50 % compression force deformation, compress force of 5 g, speed test of 2 $mm.s^{-1}$. Foam structure properties were performed by hardness index. In addition, the hardness (g), adhesiveness (mJ), cohesiveness, springiness (mm), chewiness (mJ) and gumminess index (g) were determined with a probe speed about 5 $mm.s^{-1}$ (Rosenthal, 2010).

2.6 Determination of foaming capacity (FC) and foaming stability (FS) and overrun

The foaming capacity (FC) and foaming stability (FS) were determined by the method of Makri et al. (2005) with some slight modifications. Briefly, 100 mL of whipped foam were gently moved to the cylinder (500 mL). Foam volume was measured and recorded. The transferring process should not exceed 2 min, foam was kept the room temperature (29 ± 3 °C) for 30 min and the final foam and liquid volume were measured. FC and FS were determined by Eq(1) and Eq(2).

$$\%\ FC=\frac{V_2-V_1}{V_1}\times 100 \quad (1)$$

$$\%\ FS=\frac{V_{30}}{V_2}\times 100 \quad (2)$$

in which, V_2: Volume of foam after homogenization (mL); V_1: Volume of foam before homogenization (mL); V_{30}: Volume of foam after 30 min (mL). The overrun was determined following the Eq(3) (Liu et al., 2019).

$$\%\ Overrun=\frac{(MUW\text{-}MW)}{MW}\times 100 \quad (3)$$

in which, MUW = mass of unwhipped cream with a certain volume; MW = mass of the whipped cream with the certain volume.

2.7 Determination of colour parameters

Colour parameters (L^*-lightness, a^*- redness, and b^*-yellowness) were measured by Konica Minolta CR410 device (Tokyo, Japan) (Petzold et al., 2019). Foam of whipping cream was filled Minolta cuvette and the whiteness index (WI) was calculated by the Eq(4) by Mohamad et al. (2015).

$$WI=100-\sqrt{(100-L^*)^2+a^{*2}+b^{*2}}. \quad (4)$$

2.8 Microscope observation

The foam was observed using a fluorescence microscope model Olympus BX 53 (Tokyo, Japan) to determine shape and size of dispersed objects. The dimensions of 30 representative foam bubbles were measured by DSS Imagetech software (Delhi, India) and the average foam bubble size was determined.

2.9 Statistical analysis

All experiments were performed in triplicates and analysed by the one-way analysis of variance (ANOVA) method and significant differences among the means from triplicate analyses at ($p < 0.05$) were determined by Fisher's least significant difference (LSD) procedure using Statgraphics Centurion XVI software (Statpoint Technologies Inc., Warrenton, Virginia, USA). The data were expressed in the form of a mean ± standard deviation (SD).

3. Results and discussion

3.1 Effect of chickpeas: water ratio on the foaming capacity (FC) and foaming stability (FS) of CCW

The effect of chickpeas: water ratio on the FC and FS of CCW was presented in Table 1. The data showed that the FC and FS value at ratio of 1/3 and 1/5 were significantly lower than that of ratio of 1/4. At the ratio of 1/3, the low level of water strongly affects the quality of received chickpea cooking water. Cooking chickpeas for 45 min with a low level of water (ratio of 1/3) makes chickpeas tender and quickly broken; causing starch granules easily disperse in cooking water and break the foam membranes, which in turn leads to decrease in FC and FS. On the contrary, CCW at the ratio of 1/5 has a lower FC and FS compared to the ratio of 1/4 due to the low concentration of foaming agents. The ratio of 1/4 is considered to be the most suitable ratio to obtain the highest values of FC and FS.

Table 1: Foaming ability and foaming stability of different chickpeas/water ratios

No	Chickpeas/water ratio (w/w)	FC (%)	FS (%)
1	1/3	510.00 ± 17.30[a]	81.17 ± 1.15[a]
2	1/4	610.67 ± 10.10[b]	85.55 ± 1.18[b]
3	1/5	504.71 ± 20.0[a]	82.10 ± 0.99[a]

[a.b] Different letters in same column indicate significant differences among different treatments ($p < 0.05$).

3.2 Physical properties of CCW foam

As shown in Table 2, egg white has higher FC (684.00 ± 5.29 %) and FS (98.67 ± 0.58 %) than CCW does (FC of CCW is 620.67 ± 8.08 % and FS of CCW is 85.67 ± 0.51 %). Dried chickpea contains significant amounts of albumin (8 – 12 %) and globulins (53 – 60 %) (Day, 2013) which might be responsible for the formation of foam. It has been proved that chickpeas contains saponins, which are considered to play an important role in forming foam and famous for theirs bioactivity (Singh et al., 2017). These compounds have been extracted and dispersed in cooking water, which enhances FC and FS of CCW foam. Besides that, lower viscosity index of CCW compared to EW (2.57 ± 0.20 versus 20.89 ± 1.93 cP, $p<0.05$) might be an explanation for the lower values of FC and FS of CCW.

The color analysis showed that L^* index of EW was higher than that of CCW because the color of EW foam tended to be white. White index (WI) of EW foam was significantly lower than CCW foam. The b^* index of CCW tended to be green while a^* index of CCW tended to be redder than EW. Note that, overrun (OR) of EW and CCW were not statistically different (Table 2). According to Liu et al. (2019), the increase volume of foam after being whipped is mainly due to the air level incorporated into the foam (Liu et al., 2019). The results suggested that the air level added to EW was similar that of CCW.

Table 2: Physical properties of egg white and CCW

Physical properties	Egg white (EW)	Chickpeas cooking water (CCW)
Foaming capacity (%)	684.00 ± 5.29^{b}	620.67 ± 8.08^{a}
Foaming stability (%)	98.67 ± 0.58^{b}	85.67 ± 0.51^{a}
Overrun (%)	117.71 ± 1.22^{a}	110.87 ± 1.11^{a}
L^*	89.29 ± 0.26^{b}	87.61^{a} ± 2.35^{a}
a^*	- 0.52 ± 0.09^{a}	-1.07^{b} ± 0.06^{b}
b^*	10.54 ± 2.35^{b}	4.66^{a} ± 0.21^{a}
White index (WI) of foam	84.82 ± 1.16^{a}	86.68 ± 2.14^{b}
Viscosity [cP]	20.89 ± 1.93^{b}	2.57 ± 0.20^{a}

^{a,b} Different letters in each row indicate significant differences among different treatments ($p < 0.05$)

3.3 Effects of pH and sea salt on textural properties of foam

The effect of pH on foam properties of CCW was presented in Table 3. In general, the shift of pH makes changes in the hydration ability of protein, which affects functional characteristics of food products such as foaming ability. As shown in Table 3, FC, FS and hardness index at pH of 4 are significantly higher than others. According to Sánchez-Vioque et al. (1999), the repulsive forces between protein molecules at pH near protein iso-electric point (pI of 4.3) are not sufficient to inhibit the formation of protein aggregates, and aggregated proteins adsorb at the gas-liquid interface (Sánchez-Vioque et al., 1999). Due to aggregation of protein and increase of hardness of foam, the CCW foam in pH of 4 is more stable than others. As a result, pH 4 was chosen for further experiments.

Table 3: Effect of pH on textural properties of foam

Foam properties	pH		
	3	4	5
FC (%)	636.00 ± 7.21^{b}	650.33 ± 6.51^{c}	610.67 ± 7.57^{a}
FS (%)	86.61 ± 0.35^{a}	91.55 ± 0.51^{c}	87.82 ± 0.15^{b}
Hardness (g)	24.67 ± 1.52^{a}	29.8 ± 2.75^{b}	25.67 ± 0.58^{a}

^{a,b,c} Different letters in each row indicate significant differences among different treatments ($p < 0.05$)

Adding sea salt in CCW makes changes ionic concentration, which alters the effect of ionic strength (Na^+, Cl^-) on water absorption of protein. In addition, these ions also have an impact on the foam membrane. At the suitable ion concentration, electrostatic interactions formed between protein and Na^+, Cl^- is strong enough to form the stable foam with higher hardness index. The results in Table 4 showed that FC (671.33 ± 5.85 %) and FS (93.64 ± 1.72 %) of CCW were significantly enhanced and tended to be similar to EW foam characteristics (684.00 ± 5.29 % and 98.67 ± 0.58 %). At pH 4 and sea salts concentration of 0.3 %, hardness index of CCW increased sharply as compared to non-adjusted CCW foam, but it is still lower than that of EW foam (34.00 ± 2.65 g versus 69.12 ± 6.29 g).

Table 4: Effect of salt contents on textural properties of foam

Foam properties	Salt content ($g.ml^{-1}$)		
	0.002	0.003	0.004
FC (%)	649.67 ± 4.93^{b}	671.33 ± 5.85^{c}	643.33 ± 3.01^{b}
FS (%)	88.18 ± 0.74^{b}	93.64 ± 1.72^{c}	88.09 ± 1.18^{ab}
Hardness (g)	25.00 ± 1.00^{a}	34.00 ± 2.65^{b}	22.00 ± 2.00^{a}

^{a,b,c} Different letters in each row indicate significant differences among different treatments ($p < 0.05$)

3.4 Effects of sucrose and xanthan gum on textural properties of foam cream

Proteins possess both hydrophilic and hydrophobic characters; when proteins combine polysaccharides, proteins play a role as surface-active biopolymers through altering of hydrogen bonds and electrostatic attractive, electrostatic repelling forces in the mixtures between two biopolymers. Sucrose is the sweetener used in dessert products and incorporates with xanthan gum as surfactants to form better structure properties of foam cream. According to Rahmati et al. (2018), probable interactions between legume proteins and xantham gum could produce multilayers O/W emulsions (Rahmati et al., 2018). The interactions between biopolymer protein-polysaccharides such as hydrogen bonds, electrostatic attractive and electrostatic repelling forces could also stabilize the O/W emulsions (Lam and Nickerson, 2013). The results from Table 5 showed that suitable concent of sucrose (0.7 g.ml-1) increased the FC, FS, hardness, chewiness, gumminess as compared to others. This concentration has been chosen for further experiments.

Table 5: Effects of sucrose on textural properties of CCW whipped cream (pH of 4 and 0.3 % sea salts)

Foam properties	Sucrose (g.ml^{-1})		
	0.6	0.7	0.8
FC (%)	669.33 ± 11.01^{b}	688.67 ± 10.26^{c}	636.67 ± 7.02^{a}
FS (%)	92.03 ± 0.98^{ab}	96.04 ± 2.36^{c}	90.05 ± 1.19^{a}
Hardness (g)	27.83 ± 1.04^{a}	33.67 ± 0.76^{b}	27.17 ± 1.04^{a}
Adhesiveness (mJ)	0.73 ± 0.04^{ab}	0.82 ± 0.02^{b}	0.70 ± 0.07^{a}
Cohesiveness	1.29 ± 0.10^{a}	1.49 ± 0.14^{a}	1.33 ± 0.10^{a}
Springiness (mm)	2.52 ± 0.08^{ab}	2.84 ± 0.14^{b}	2.46 ± 0.20^{a}
Gumminess (g)	34.07 ± 0.81^{a}	44.53 ± 1.47^{b}	34.73 ± 2.06^{a}
Chewiness (mJ)	0.86 ± 0.09^{a}	1.17 ± 0.11^{b}	0.88 ± 0.12^{a}

^{a,b,c} Different letters in each row indicate significant differences among different treatments ($p < 0.05$)

On the other hand, xanthan is an anionic gum which is widely used in food industry due to its unique properties. Xanthan gum is stable in acidity and alkaline environment. Xanthan gum is able to increase the viscosity of liquid, which improves properties of foam cream (Long et al., 2013). Sucrose and xanthan gum has significant effects on foam properties. The concentration of sucrose (0.7 g.ml^{-1}) and xanthan gum (0.00005 g.ml^{-1}) is perfectly suitable for stabilizing the foam products (Table 5 and Table 6). Nowadays, there is no published report of using sucrose and xanthan gum in processing emulsions from chickpeas cooking water. The results suggest that using sucrose and xanthan gum together has high potential in improvement of CCW foam cream properties and can be used as a good replacement for eggs in making non-dairy and eggless cold desserts.

Table 6: Effects xanthan gum on textural properties of CCW whipped cream (pH of 4, 0.003 g.ml^{-1} sea salts and sucrose content of 0.7 g.ml^{-1})

Foam properties	Xanthan gum content (g.ml^{-1})		
	0.00004	0.00005	0.00006
FC (%)	761.33 ± 22.03^{b}	947.33 ± 12.70^{c}	942.00± 7.21^{c}
FS (%)	98.67 ± 0.51^{b}	100.00 ± 0.00 ^{b}	100.00± 0.00^{b}
Hardness (g)	33.67 ± 1.04^{b}	39.67 ± 0.58^{c}	26.83 ± 1.26^{a}
Adhesiveness (mJ)	0.83 ± 0.03^{a}	0.94 ± 0.03^{b}	0.83 ± 0.04^{a}
Cohesiveness	1.20 ± 0.12^{a}	1.42 ± 0.04 ^{ab}	1.54 ± 0.15^{a}
Springiness (mm)	2.27^{a} ± 0.48	3.09 ± 0.18^{b}	2.79 ± 0.18^{ab}
Gumminess (g)	42.27± 2.84^{a}	48.87± 3.17^{a}	43.07 ± 1.72^{a}
Chewiness (mJ)	0.93± 0.16^{a}	1.48 ± 0.13^{b}	1.22 ± 0.16^{ab}

^{a,b,c} Different letters in each row indicate significant differences among different treatments ($p < 0.05$)

3.5 Microstructure and textural properties of EW and CCW whipped cream

As shown in Figure 1a, EW foam particles had a thick membrane, the boundaries between foam particles were easier to observe than those from CCW foam particles (Figure 1b). On the other hand, foam particles of CCW whipped cream has a clear membrane and the foam surface has been solidified (Figure 1c).

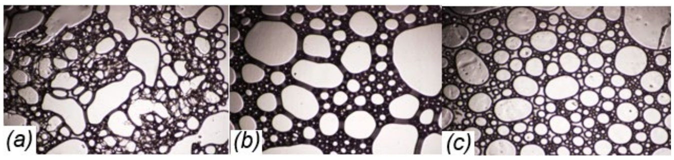

Figure 1: Foam images from fluorescence microscopy: (a) EW foam; (b) CCW foam, (c) CCW whipped cream

The diameter of foam particles of EW whipped cream (177.16 ± 78.54 µm) (Figure 1a) was significantly smaller than that from CCW whipped cream (277.96 ± 132.72 µm) (Figure 2c). The foam particles of EW whipped cream had small size and thick membrane so that EW foam was more stable and had better structure properties as compared to CCW whipped cream. EW whipped cream also has significantly higher hardness and gumminess index than CCW whipped cream due to special structure properties of EW. On the contrary, chewiness index and springiness index of CCW were significantly higher than those of EW because of the double interaction of sucrose-protein-xanthan gum. The differences between structure characteristics of EW whipped cream and CCW whipped cream were presented in Table 7.

Table 7: Structure characteristics of whipped creams

Structure characteristics	EW whipped cream	CCW whipped cream
Hardness (g)	69.12 ± 6.29^{b}	39.67 ± 0.58^{a}
Adhesiveness (mJ)	0.93 ± 0.26^{b}	0.94 ± 0.03^{b}
Cohesiveness	1.11 ± 0.11^{a}	1.42 ± 0.04^{b}
Springiness (mm)	1.46 ± 0.05^{a}	3.09 ± 0.18^{b}
Gumminess (g)	70.53 ± 4.05^{b}	48.87 ± 3.17^{a}
Chewiness (mJ)	1.02 ± 0.02^{a}	1.48 ± 0.13^{b}
Foam particle average diameter (μm)	177.16 ± 78.54^{a}	277.96 ± 132.72^{b}

4. Conclusion

By using CCW combined with food additive, a new recipe of whipping cream has been successfully developed. Comparing physical characteristics of foam made by whipping CCW with those made from EW has proved that CCW is a good alternative for replacing EW in making vegan desserts or cakes. The results of this study may be significant to innovate new technologies utilizing legume proteins to produce eggless, non-dairy cold desserts, and contribute to reduce the burden of livestock industry also aiming to protect the environment.

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