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Canned beans aquafaba as an egg white substitute in the technology of low-fat mayonnaise †

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Abstract: Global trends of promoting healthy lifestyle through a balanced diet with reducing the consumption of animal products and high-fat content foods contribute to the creation of new mayonnaise-like products. The aim of the study was to develop a technology for low-fat mayonnaise containing 30% sunflower oil. Canned white bean aquafaba was used as a plant-based emulsifier to create an egg-free sauce. To maintain the texture and rheological properties of the food emulsion, water soluble polymer such as carboxymethylcellulose was used as a thickener and a pectin-xanthan mixture as a gelling agent. The ratio of the main ingredients of the emulsion emulsifier/stabilizer/thickener was 3:0.7:0.3 (%). Prepared emulsion-like sauce was characterized by high sedimentation stability at the level of 98%, as well as acidity equal to 0.691 g of acetic acid equivalent per 100 g sample and pH=3.66. The volume droplet size distribution had an mean particle size of 8.4 μm and a SPAN factor of 1.7 μm, indicating typical values for these parameters of a well-homogenized mayonnaise-like emulsion. Rheological studies made it possible to classify the samples as viscoelastic systems with a pseudoplastic flow pattern and a sufficiently high value of the yield shear stress equal to 132 Pa as a quantitative parameter confirming the stability of the microstructure over time. Sensory analysis confirmed high scores for consistency, taste and smell of the end-product.

Keywords: aquafaba; mayonnaise souse; canned beans; rheology; emulsion; sensory characteristics; particle size.

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1. Introduction

All full-fat mayonnaises, as well as some low-fat mayonnaises contain egg-base components as one of the key ingredients [1]. Being a source of phospholipids and proteins, they ensure the emulsification of vegetable oils and the formation of a stable homogeneous oil-in-water emulsion. However, high levels of cholesterol and unsaturated fatty acid[2], risk of microbial contamination by Salmonella, and cost are the main disadvantages of using egg yolk in mayonnaise. An excellent alternative to egg yolk as an emulsifying ingredient in a mayonnaise formulation can be plant-based aquafaba, a liquid that is formed in the process of cooking, canning or soaking legumes or grains [3]. It is known that aquafaba beans contain high concentrations of soluble protein, starch, carbohydrates, polyphenols, insoluble fibers, saponins and other substances [4]. Bean aquafaba has a neutral taste, does not contain gluten and has the necessary physical and chemical properties to reproduce the structure and texture of classic mayonnaise. Aquafaba has pronounced emulsifying, gelling, foaming properties and acts as a thickener. The most popular in the technology of desserts, pastries and ice cream is chickpea aquafaba [5], which has also found use in the development of plant-based mayonnaises [6]. However, when replacing or adding ingredients in the formulation, one should take into account the influence of their functional and technological properties on the textural and sensory characteristics of the end-product [7]. For emulsion-based foods, in addition, this can lead to a change in the microstructure of the emulsion [8], which affects its stability. In accordance with the above comments, the purpose of this research was to develop a low-fat mayonnaise using aquafaba from commercially canned white beans, which is a by-product of canned beans. It was intended to be preliminary study and therefore did not involve consideration of the impact of different brands, types and contents of canned beans on the end-product.

2. Materials and Methods

2.1. Materials and sampling.

Low-fat (oil content 30%) egg-free mayonnaise Salad 30% Schedro™ (Schedro LLC, Lviv, Ukraine) was used as a control sample (CS) of mayonnaise sauce. Canned white beans Veres™ (Viggy Production LLC, Cherkassy, Ukraine) were chosen as a source of aquafaba. All food ingredients of the developed sample formulation were purchased at the local supermarket (Chernivtsi, Ukraine). All reagents used in the analysis were of analytical grade.

The formulation of the mayonnaise sauce (MS) contained the following ingredients: 30 g sunflower oil, 4 g aquafaba, 8 g vinegar, 1.5 g sugar, 0.5 g salt, 0.05 g baking soda, 1 g mustard powder, 1 g milk cream powder, 0.4 g pectin, 0.3 g xanthan gum, 0.3 g sodium carboxymethylcellulose, 8 g acetic and 0.3 g lactic acids, and water up to 100 g. The amount of plant protein included in the formulation was approximately 0.2% (w/w) as the minimum limit of the range (0.2-1%) of protein concentration in aquafaba for the formation of a stable oil-in-water emulsions [9].

Aquafaba was obtained by filtering through a coarse filter a solution from commercial canned white beans. Cream and mustard powders were mixed with beans aquafaba, saturated solutions of salt, sugar and baking soda. The mixture was kept in a water bath at temperature 70°C while stirring for 30 minutes. After that, oil heated to 50°C, acetic and lactic acids, and a pre-dissolved mixture of gelling agents and thickener were added to the mixture under constant stirring. The emulsion was homogenized by a household blender MBL-10-1 (MPM, Milanówek, Poland) at power 700 W. The final sample was stored in a refrigerator at a temperature of 4°C. All measurements were performed no earlier than 24 hours after the sample was produced.

2.2. Methods

Protein concentration was quantified by the spectrometry as in [10]. The UV-absorbance was measured at 562 nm using Specord-50 spectrometer (Analytik Jena AG, Jena, Germany). A bovine serum albumin used as the reference protein.

The apparent viscosity and the yield shear stress were performed on a rotational viscometer Visco QC 300R (Anton Paar, Graz, Austria) with concentric cylinder CC12 geometry and a vane spindles, respectively. Steady shear analyses were carried out in the range of shear rate 0.1–5.0 s^{-1} over the period of 120 s at temperature 20 ˚C maintained by a thermostat Peltier PTD 175 device (Anton Paar, Graz, Austria. The experimental data on the dependence apparent viscosity on shear rate were fitted to the power-law model. The yield shear stress of samples was determined using the same rotational viscometer.

The particle and droplet size of samples was measured by laser diffraction on a PSA 1190 particle size analyzer (Anton Paar, Austria) in the range of 0.1–2500 μm. To measure the size of the drops, the emulsion was diluted in warm water (~ 30 °C) in a ratio of approximately 1/100 of their initial concentration to prevent potential multi-scattering effects and added to the measuring cell in portions to obtain the required degree of field of vision filling. All measurements were carried out at speeds of the stirrer from 150 to 450 rpm. The droplet sizes are volume mean diameter D_{43} [11]. The SPAN index was calculated as SPAN = (D_{90} – D_{10})/D_{50}, were D_{10}, D_{50}, and D_{90} are the particle diameters at 10%, 50%, and 90% in the cumulative size distribution, respectively.

The pH and total titratable acidity (TTA) of the samples were measured by 692 pH/Ion meter (Metrohm, Herisau, Switzerland) with the combined glass electrode Unitrode with Pt1000 (Metrohm, Herisau, Switzerland) using method [12].

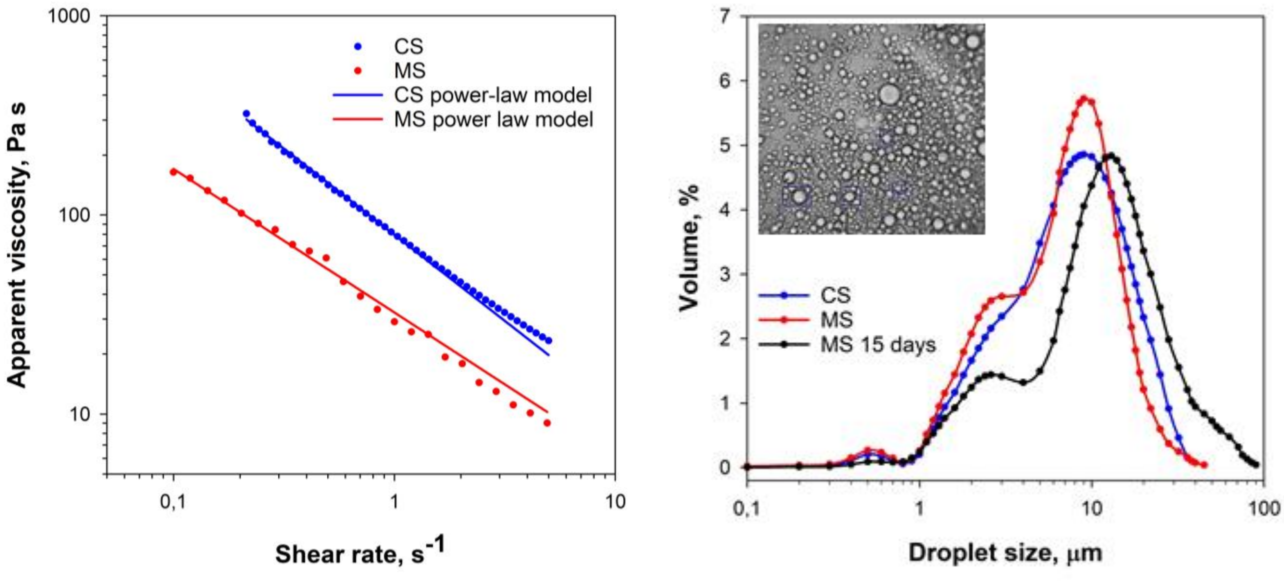
Sensory analysis was carried out in the laboratory of sensory analysis of the State Biotechnological University (Kharkov, Ukraine) similarly to [13]. Acceptance tests were used to evaluate sample characteristics such as color and appearance, consistency, taste, odor and spreadability according to the ISO 13299:2016 methodology. Ten experts from the university staff, who were trained in accordance with the ISO 8586:2012 standard, were selected to ensure the accuracy of the assessment. Participants were in a room with a temperature of 25±2°C and a relative humidity of 55±3%. During this session, panelists defined the terminology and anchor points of the scale. Samples were stored in closed containers with codes. The coded samples were presented simultaneously and rated in random order. The intensity of each sensory characteristic was recorded on a 10-point hedonic scale after the 1-hour orientation session.

All experiments were performed in triplicate and results were presented as mean ± standard deviation. One-way ANOVA with Tukey's multiple comparison post-hoc test was performed to assess significant differences between groups at $p < 0.05$. Statistical data were processed using the Minitab ver. 19 (Minitab Inc., State College, PA, USA).

3. Result and Discussion

3.1. Rheological and microstructural properties

The apparent viscosity curves in double logarithmic coordinates have an approximate linear dependence for both samples, demonstrating typical non-Newtonian and shear-thinning behavior (Figure 1a).



a) b)

Figure 1. Rheological and microstructural properties of mayonnaise samples: (a) Apparent viscosity vs. shear rate in double logarithmic coordinates; (b) droplet size distribution with optical microphotograph of a diluted 1:10 emulsion.

Table 1. Comparison of properties of mayonnaise samples.

Sample	Power-law equation			Static yield stress, Pa	Droplet size distribution		Acidity	
	Consistency index, Pa·s^n	Flow behavior index	R^2		D_{43}, μm	SPAN, μm	pH	TTA, %
CS	79.6±0.8^a	0.135±0.008^b	0.9973	142±7^a	8.16	2.17	3.82±0.01^a	0.201
MS*	32.4±0.8^b	0.275±0.014^a	0.9957	132±5^b	8.40	1.74	3.66±0.01^b	0.691

*The table shows the average values for two batches of MS sample

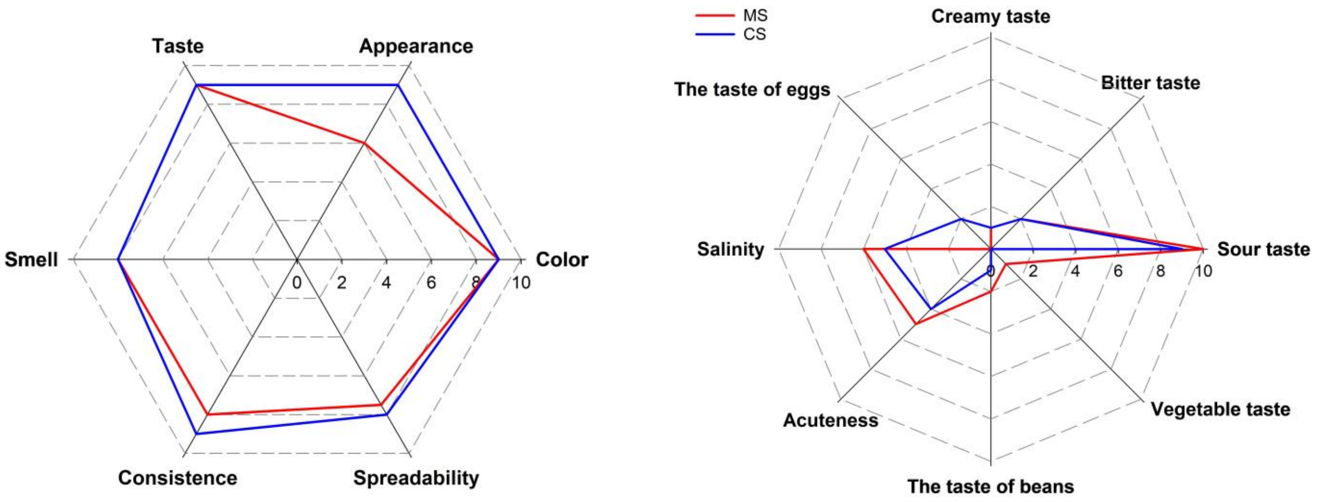
$^{a, b}$ Means within each column with different superscripts are significantly ($p < 0.05$) different

Steady shear flow or apparent viscosity η curves are usually well described by the power-law model $\eta = K\gamma^{(n-1)}$, where K is the consistency index, n is flow behavior index. The calculated K and n values are given in Table 1. For both samples, n < 1, indicating the pseudoplastic nature of the mayonnaise [14]. The K values of the CS were higher than those of the SM samples, while the opposite trend was observed for n, and these differences were statistically significant ($p < 0.05$). A lower value of K indicates a less strong and time-stable structure of the developed sample compared to the commercial one. This is confirmed by the data on the values of static shear stress 132 versus 142 ($p < 0.05$).

The smaller n value of the CS sample indicates the strongest shear thinning behavior and the best spreading effect in practical use. Usually, a lower value of K also determines a lower emulsion viscosity, which is observed in Figure 1a and confirms other studies available on this fact, for example [15][16]. Differences in the K value of the control samples of mayonnaise and mayonnaise without yolk were associated with the strength of the interaction of the emulsion droplets with various emulsifiers and the strength of the network matrix. This factor turned out to be predominant in the value of viscosity, despite the fact that the factor values n have the opposite trend.

Particle size is an important characteristic for mayonnaise-like emulsions because it affects stability, shelf life and sensory indicators. It is known [15], that the higher the degree of dispersion of the oil phase, the better the stability of the emulsion-base of the final product. Diluted emulsion contains a mixture of various sizes aggregates of spherical oil droplets, their associates in the form of flocs, as well as particles of biopolymers of various sizes not adsorbed on the surface of the droplet [11]. This is cohering with a similar bimodal volume droplet size distribution obtained for both mayonnaise samples with the visualized small peak for the individual particles (Figure 1b). The first peak at about 2.5 μm apparently corresponds to individual droplets, and the second one near 8 μm characterizes flocculated drops. The presence of individual drops and floccules is clearly visible in the optical micrograph embedded in Figure 1b. The volume droplet size distribution of MS had a mean particle size of 8.40 μm and a SPAN factor of 1.74 μm, which indicates typical values for the parameters of a well-homogenized mayonnaise-like emulsion (Table 1). Similar values were obtained for sample CS with a wider distribution of droplet sizes. It should be noted that the drop size values obtained for the SM sample are lower than those described for other egg-free mayonnaises at the level of 32-38 μm for mayonnaise-like emulsions based on pea pod powder [17], 22-31 μm and 34-37 with rocket seed and chia seed gum nanoparticle, respectively [2].

The stability of freshly prepared mayonnaise was 98%. With further storage of the SM sample in a refrigerator at a temperature of 4°C for 15 days, visual signs of separation were not observed. However, the study of the size distribution of droplets indicates an increase in droplet flocculation, which is accompanied by a decrease in the number of individual droplets and an increase in the number of large floccules (Figure 1b). The process of flocculation of drop emulsions is a destabilizing factor for the emulsion and is important for obtaining the final product of high quality. But the influence of this factor can only be confirmed by experimental studies of the stability of the emulsion over a longer storage time. The stabilization factor of mayonnaise-base emulsions is associated with the efficient formation of adsorption layers of protein on the surface of oil droplets. For the possibility of the adsorption process, the protein must be neutral, in the form of dense globules, or have a small positive charge. The latter is characteristic of proteins in the CM sample, which has a pH of 3.82 (Table 1), while red and green beans have an isoelectric point at pH 4.4 [16]. For those non-absorbable anionic polysaccharides that do not form complexes with proteins, mechanistic stability control occurs due to thickening and gel-forming effects in the continuous aqueous phase, as well as the formation of aggregated emulsion structures by bridge-flocculation, in which individual biopolymer particles are involved in the matrix. Therefore, their concentration also decreases, as evidenced by a decrease in the peak value attributed to biopolymer molecules (Figure 1b).



(**a**) (**b**)

Figure 2. Spider plots of sensory descriptive analysis: (**a**) appearance and texture attributes; (**b**) basic tastes.

3.4. Sensory analysis

Canned beans aquafaba mayonnaise did not have any extraneous or specific tastes and smells (Figure 2a). The grayish-white color, which is unusual for consumers, was rated 6 points. In perspective, this shortcoming can be easily eliminated by adding natural organic dyes. From the results of the sensory analysis, it can be concluded that aquafaba does not add any additional flavor to the taste of mayonnaise (Figure 2b). This is expressed in the absence of plant and bean flavors, while at the same time one feels the sharpness, saltiness and acidity. These flavors reinforce each other and are caused by the presence of acids, mustard and sodium chloride.

4. Conclusion

Low-fat mayonnaise was made from canned aquafaba beans as an egg white substitute. The results showed that the appearance of the mayonnaise samples did not change significantly, except color. The droplet size of the developed and control mayonnaise samples were similar. Mayonnaise emulsions showed pseudoplastic behavior, but the viscosity of the developed mayonnaise was slightly lower than the control. The emulsion stability of the aquafaba-based mayonnaise was maintained for 15 days. Therefore, these results show that canned aquafaba beans can be successfully used as an emulsifier in the formulation of regular mayonnaise.

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