INNOVOPRO
LEADING THE CLEAN-LABEL FOOD REVOLUTION

Exploring CP-Pro 70® An Optimal Natural Emulsifier Choice

For Oil in Water Applications

Abstract

Oil-in-water (O/W) emulsions play a fundamental role in numerous food applications, including sauces, salad dressings, milk and mayonnaise. The pursuit of sustainable and clean-label products has motivated the food industry to explore natural, nutritious and sustainable emulsifiers. Considering this objective, InnovoPro has dedicated resources to investigate emulsions formulated with a chickpea protein concentrate, CP-Pro 70®, as a natural emulsifier.

This white paper demonstrates the emulsifying properties of CP-Pro 70® in oil-in-water emulsions of high and low oil content, and the stability of the emulsions under various conditions. The experiments with plant-based milk alternatives, as an example of low oil O/W emulsions, and with mayonnaise, as an example of high oil O/W emulsions, were conducted independently.

The results demonstrate that CP-Pro 70® plant-based milk alternatives (PBMA) had the highest stability compared to other assessed commercial PBMAs and cow's milk. Moreover, CP-Pro 70® PBMAs remained the most stable regardless of the applied heat treatment – high temperature short time (HTST) or ultra-high temperature (UHT). Despite no addition of stabilizers, the products exhibited greater stability by all measured parameters, when compared to similar commercially available products. The excellent stability of CP-Pro 70®-based milk alternatives is explained by particle size, particle size distribution, zeta potential, and instability index results. The shelf-life study demonstrates that the CP-Pro 70® UHT PBMA remains stable for 6 months, without the need for additional emulsifiers, thickeners or stabilizers.

In high oil concentration O/W emulsions, CP-Pro 70®-based mayonnaise, with a pH level of 5, exhibited rheological parameters similar to commercial mayonnaise. Adjustments to the pH level can control the viscosity, texture, and spoonability of CP-Pro 70®-based mayonnaise. The CP-Pro 70® emulsion, with 70% oil, remained stable for 8 months, even without any homogenization during the preparation of the mayonnaise.

Measurements of the emulsion capacity (EC) and the emulsion stability (ES) of CP-Pro 70® and other plant-based proteins demonstrated that CP-Pro 70® has the highest emulsion capacity (EC) and similar or better emulsion stability (ES) when compared to other plant-based proteins evaluated in the study.

The study affirms that InnovoPro's CP-Pro 70® serves as a natural, nutritious and sustainable emulsifier, across a spectrum of oil concentrations, from low to high. This performance enables the creation of clean-label end products.

Introduction

An emulsion is a type of colloid that consists of two immiscible liquids (usually oil and water), with one of the liquids dispersed as small droplets in the other liquid (the continuous phase). A system that consists of oil droplets dispersed in an aqueous phase is called an oil-in-water (O/W) emulsion. Examples of this type of emulsion include milk, cream, dressings, mayonnaise, sauces and frankfurters. An emulsion that consists of water droplets dispersed in an oil phase is called a water in-oil (W/O) emulsion, such as margarine and butter. The diameter of the droplets in most food emulsions varies between 0.1 and 100 μm.

Oil-in-water emulsions play a significant role within the food industry and serve as fundamental building blocks for numerous food applications. In order to form the oil-in-water emulsion, the oil must disperse as small droplets in the continuous phase. To keep the emulsion stable and prevent separation for longer periods, most food manufacturers use additives which act as emulsifiers, thickeners and stabilizers.

Emulsifiers are surface-active substances that adsorb to an oil–water interface, creating a protective membrane around droplets. Emulsifiers are used to assist the two immiscible liquids to form an emulsion by preventing aggregation, flocculation and/or coalescence.

Commonly used emulsifiers in the food industry include egg yolk, mustard, lecithin, diacetyl tartaric acid esters of mono- and diglycerides (DATEM) and sodium stearoyl lactylate. Texture modifiers (often called stabilizers) are food additives that increase the viscosity of the aqueous phase, thus reducing the mobility of the dispersed droplets. These include thickening and gelling agents, such as starch, gums (e.g., xanthan gum, guar gum), alginate, agar, pectin and other soluble dietary fibers.

Due to their amphiphilic nature (having both charged and non-charged portions) and the size of the molecules (being polymers), some food proteins act both as emulsifiers and stabilizers. Over the past decade, a notable and compelling trend has emerged within the food industry, characterized by a strong shift towards the production of products that are more sustainable and have cleaner labels. This shift has been prompted by a combination of consumer demands, regulatory changes and a heightened awareness of environmental and health-related concerns.

This study of CP-Pro 70® consists of two distinct parts, conducted independently.

Emulsifying potential of CP-Pro 70®

CP-Pro 70® is a chickpea protein concentrate that offers an impressive nutritional composition, non allergens, non-GMO and free from artificial additives. CP-Pro 70® combines strong functionality with exceptional sensory qualities. Therefore, it is an ideal choice for the booming plant-based market.

CP-Pro 70® consists of 70% protein, 10-15% fat, and 5% fibers, completed by 3-6% minerals, 1-3% other carbohydrates, and 3-4% water. The fat in the CP-Pro 70® is well dispersed and stabilized by the proteins, indicating their emulsifying potential, while the presence of soluble fibers implies possible additional thickening and water holding effect. Thus, CP-Pro 70® is not only an excellent choice of nutritious plant proteins, but also an excellent solution for the growing trend of creating clean-label products, as it reduces the need for addition of emulsifiers and texture modifiers.

This white paper presents and compares the emulsification properties of CP-Pro 70® in emulsions with low and high oil content, in various conditions, emphasizing its ability to create stable emulsions in a wide range of oil concentrations.

Plant-Based Milk Alternatives: A Prime Illustration of a Low Oil Concentration Emulsion

Milk, particularly cow's milk, has been regarded as a comprehensive source of nourishment. However, milk consumption has been on a steady decline worldwide throughout the past decade. The reasons for this include higher lactose intolerance rates, sensitivity to milk proteins, antibiotic and hormone usage in animal farming, rising vegetarian/vegan trends, and ethical and environmental concerns about the dairy industry. Plant-based milk alternatives (PBMA) are an excellent solution for consumers interested in reducing or eliminating consumption of milk. The PBMA market has been growing steadily at a forecasted CAGR of 12.3% during 2022-2030 and is estimated to reach $65.33 billion by 2030.

To efficiently replace cow's milk, a PBMA must match the nutritional and sensory characteristics, have the same or better physical stability, and the same or longer shelf-life than the original. By its physical composition, milk is an aqueous solution (of sugars and salts), an oil-in-water emulsion (milk fat droplets dispersed in a continuous aqueous phase), and colloidal dispersion of casein and whey proteins. Thus, besides microbial stability, PBMAs must stay homogeneous, with no lipid coalescence on the top and/or sedimentation of insoluble particles at the bottom. The shelf-life of UHT milk is based on its sensory characteristics (mainly flavor and color), chemical reactions (pH, enzymatic activity, Maillard reactions), and microbial growth, while physical stability is generally not a concern. Milk proteins, casein, and whey proteins have sufficient emulsifying efficiency to keep homogenized milk stable for more than 12 months.

PBMAs are produced either from fresh raw materials (legumes, nuts), flours (cereals, legumes, nuts), or from protein powders - concentrates or isolates (legumes, cereals). The shelf-life of cow's milk and PBMAs is influenced mainly by microbiological growth and physical stability. The shelf-life of refrigerated cow's milk varies from a week to a month, depending on the pasteurization conditions, while UHT processing extends the shelf-life up to 9 months, at ambient temperature. The shelf-life of pasteurized and refrigerated PBMAs varies from 2 weeks to a month, and lasts up to 6 months for UHT products that are stored at room temperature. The physical stability of PBMAs is affected by the size of the dispersed particles (including oil droplets, proteins, ungelatinized starch granules and other solids), particle size distribution, solubility of proteins and stability of the emulsion.

The homogenization step is crucial for the stability of both cow's milk and PBMA's, since smaller oil droplets and smaller particles move and aggregate more slowly and, therefore, create more stable colloidal systems. In the food industry, this process is usually carried out by homogenizers, in which the liquids are subjected to intense mechanical agitation with highspeed blenders or by being forced through high-pressure valves in one or two cycles. The steric repulsion of droplets, created by the distribution of the emulsifying proteins at the interphase, further slows down the flocculation and coalescence.

Stability of CP-Pro 70® - **Based Milk Alternative**

The stability of cow's milk and PBMAs was assessed by comparing HTST and UHT processed CP-Pro 70® - based milk alternatives, two commercial soy-based milk alternatives (soy-based milk 1 with 1.6% oil, 3.2 % protein, refrigerated) and soy-based milk 2 (with 1.9% oil, 3.6% protein, shelf-stable), and one commercial cow's milk sample (with 3% fat, 3.3% protein, refrigerated) (Figure 1).

From left to right: commercial cow's milk,

CP-Pro 70®-based milk alternative, commercial soy-based milk alternative 1, and commercial soy-based milk alternative 2.

CP-Pro 70® PBMA has the lightest color compared to other PBMAs and its sensory characteristics are similar to cow's milk.

Figure 1: PBMA and Cow's Milk Samples Used in the Experiment.

The production of CP-Pro 70®-based milk alternative starts with mixing protein powder with water and oil, and is followed by pasteurization or UHT, homogenization and ends with the filling stage (Figure 2).

Mixing all ingredients Recommended at 60°C → *Pasteurization/ UHT* → *Homogenization 2 stages 200 and 50 Bar* → *Cool down* → *Filling*

Figure 2: CP-Pro 70®- Based Milk Alternative Beverage Production Process Flow Chart

Three PBMA's were prepared, from three different commercial CP-Pro 70® lots. The HTST samples were produced with 6% CP-Pro 70® (4.2% protein) and 3% canola oil and 91% tap water, thermally treated at 90®C for 3 min, and kept refrigerated. The UHT samples were produced with 4.2% protein, 1.6% oil, thermally treated at 145®C for 4-6 seconds, and kept at room temperature (~25®C). All samples were tested by a leading academic research institute. The tests include particle (droplet) size, particle (droplet) size distribution, particle charge, and stability/instability index determination. The results presented below are the average of the 3 batches.

Particle size and **particle size distribution** were determined by laser diffraction method using Malvern Mastersizer 3000. All samples had similar particle size, with averages ranging between 0.21 and 0.46 µm (Figure 3). The sample of the 3% fat cow's milk, had the highest average droplet size, while both commercial soy-based milk alternatives had an additional peak at 1.65 µm. Although HTST CP-Pro 70®-based milk alternative had 10% particles/droplets with over 1 µm, the UHT- processed CP-Pro 70®-based milk alternative had a narrow distribution, with no additional peaks or tailing of the curve, with 90% of particles below 0.74 µm.

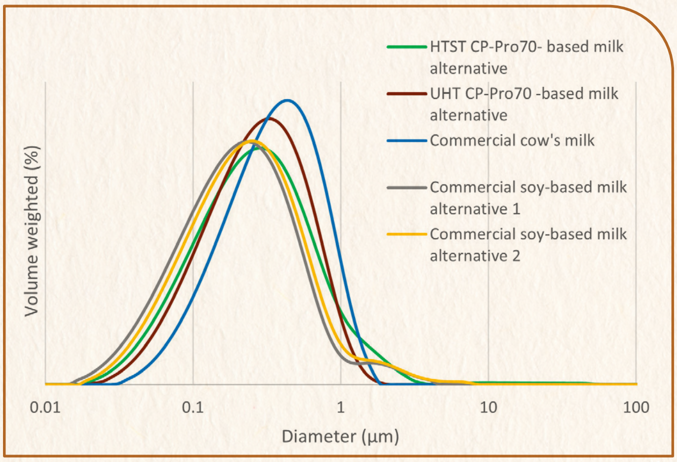


Figure 3: Particle Size Distribution Comparison of PBMA and Cow's Milk

Zeta potential (droplets charge) was determined by Malvern Zetasizer Ultra. The droplets dispersed through the continuous phase have an inner electrical potential, called the Stern layer, and an outer layer, called the slipping plane. Zeta potential is the electrical potential in the slipping plane. The Zetasizer combines dynamic light scattering for determining particle size and the electrophoretic light scattering technique to measure the charge on the surface of dispersed droplets and particles.

Generally, higher zeta potential value (negative or positive) gives an indication of higher stability of colloidal systems, as particles (droplets) repel each other and consequently inhibit aggregation, flocculation, coalescence or sedimentation.

All tested samples had a negative zeta potential (Figure 4). Both CP-Pro 70®-based milk alternatives (HTST and UHT processed) registered the highest negative zeta potential at ~30 mV, while the negative zeta potential of the commercial soy milk alternatives was in the mid-20's mV, and the negative zeta potential of cow's milk value was in the lower 20's mV.

CP-Pro 70®-based milk alternatives exhibit great potential to create stable milk-like emulsions, regardless of the applied thermal treatment (HTST or UHT).

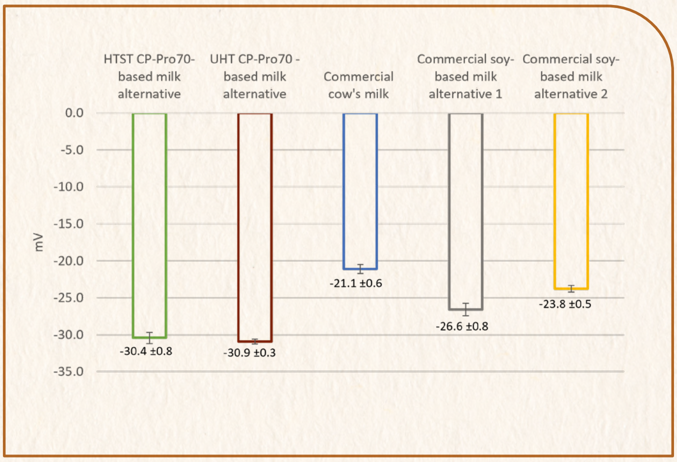


Figure 4: Zeta Potential Comparison of PBMA and Cow's Milk

Stability of PBMAs and cow's milk was further assessed using Lumisizer **instability index.** The Lumisizer detects the intensity of light transmission through a sample over time, while applying centrifugal force on the sample. The Lumisizer algorithm calculates the instability index. The higher the value of the index, the less stable the product. In this experiment samples were tested over a period of time, and the final instability index reflects the reading after 10 hours.

Both the HTST and UHT processed CP-Pro 70®-based milk alternatives, had the lowest instability index values, indicating that the stability of the CP-Pro 70®-based emulsions is similar or superior compared to other samples (Figure 5). The low instability index of CP-Pro 70®-based emulsions is, at least partially, the result of the small particle size, the narrow size distribution, and the highly charged droplets, compared to commercial soy-based milk alternatives and cow's milk.

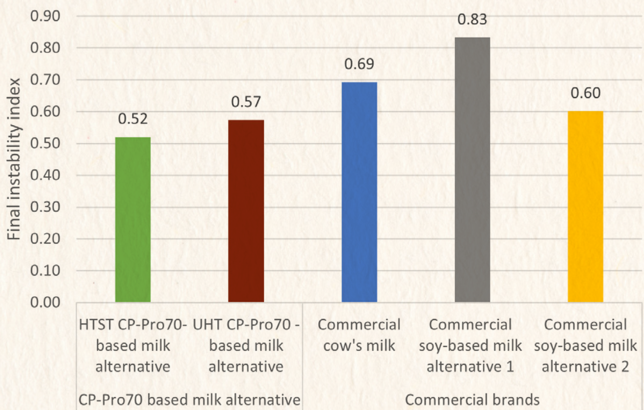


Figure 5: Final Instability Index Comparison of PBMA and Cow's Milk

The shelf-life study of UHT-processed CP-Pro 70®-based milk alternative was carried out over 12 months, at ambient temperature, with visual inspection of the samples at intervals of three months. Samples were inspected for any signs of sedimentation on the bottom of the bottle, creaming (oil layer at the top) or flocculation (within the matrix of the beverage). The results indicate a 6-month shelf-life stability for CP-Pro 70®-based UHT-processed milk alternatives.

Emulsions with larger droplet size and particle size distribution or lower zeta potential and higher instability index are likely to be stabilized by the addition of emulsifiers, stabilizers and thickening agents (E322, E410, E407, E410, E432, E471, etc.), while those with smaller droplet sizes, particle size distribution and higher zeta potential remain stable longer. This is especially important for clean-label products, where the list of ingredients should be short, and free form stabilizers and thickening agents.

Key Takeaways:

- The measurements and results of particle size, particle size distribution, zeta potential, instability index and a shelf-life study, indicate that the stability of CP-Pro 70®- based milk alternatives is superior to the stability of commercial soy-based milk alternatives and cow's milk.
- The type of thermal processing, HTST or UHT, created minimal differences in the physical stability of CP-Pro 70®- based milk alternatives.
- UHT-processed CP-Pro 70®-based milk alternatives had 6 months stability at room temperature, without the addition of emulsifiers, stabilizers or thickeners.
- UHT-processed CP-Pro 70® - based milk alternatives were considerably lighter than soy-milk alternatives already on the market.

Mayonnaise
A Key Illustration of Emulsions with High Oil Concentration

Mayonnaise is a creamy oil-in-water (O/W) emulsion, with oil droplets in a continuous phase of water. The basic components of the traditional egg-based mayonnaise are 70-80% oil, 10-20% water, 5-9% egg yolk, and vinegar/lemon juice to achieve a pH level of 3.6–4.1. Commercially-available vegan mayonnaise is based on the same basic formula as traditional mayonnaise, with adjustments of component quantities. Vegan mayonnaise pH levels range between 4-5.5.

Rheology Properties

Rheological measurements are often used to describe physical and functional properties of food products and may help producers anticipate ingredient behavior during the production process and in the final product.

Rheological tests were conducted on CP-Pro 70® high oil O/W emulsions. The formulation of CP-Pro 70® emulsions is based on only three ingredients: 69% canola oil, 29% water, and 2% CP-Pro 70®.

The emulsions were prepared by adding CP-Pro 70® to water and mixing with a mixer at a constant speed. Canola oil was gradually added to the dispersion while mixing continuously. Once the complete oil quantity was added, the mixing speed was elevated and sustained until mayonnaise was fully formed. The effect of the pH level was tested at pH=3 (below the isoelectric point of chickpea proteins), at pH=5 (close to the isoelectric point) and at pH=7. The pH adjustment was performed after the emulsion was created, since adding acids prior to the creation of the emulsion could result in a larger droplet size, in reduced elastic modulus and in lower viscosity of the mayonnaise. The presented results of the CP-Pro 70®-based mayonnaise are the average of three lots.

Emulsion viscosity was determined using a research rheometer (AR2000, TA Instruments) fitted with a 40mm crosshatched plate measuring system, test gap set to 500 µm.

Mayonnaise samples at all tested pH levels exhibited shear thinning behavior, becoming less viscous with increased shear (Figure 6). The zero shear viscosity of CP-Pro 70®-based emulsions was highest at pH=5 (955 Pa.s), followed by the viscosity at pH=7 (156 Pa.s), and lowest at pH=3 (55 Pa.s). This trend corresponds with the reduction of the net electrical charge of chickpea proteins, which is lowest at a pH level of 4.7. However, the effect of the pH levels becomes negligible at the shear rate of 10 s-1 and beyond.

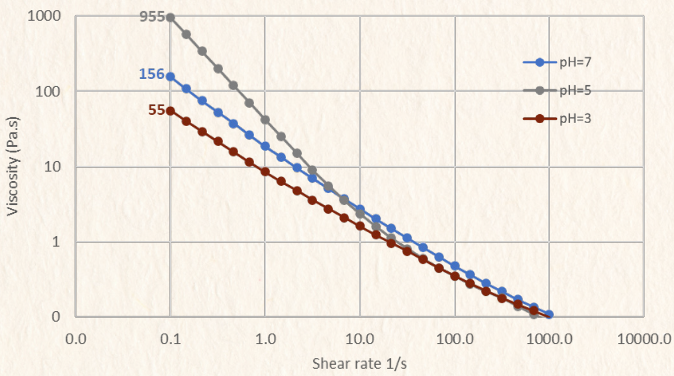


*Figure 6: CP-Pro 70® Mayonnaise Shear Rate Sweeps All results presented are the average of three different CP-Pro 70® lots. * Scale is logarithmic*

Complex modulus is a measure of resistance to deformation, and refers to the stress that is applied to a sample without deforming it. Complex modulus was measured on CP-Pro 70®-based mayonnaise samples at different pH levels. Comparison was also made to commercially available mayonnaise data, with higher and lower concentrations of oil. These samples were named: Commercial mayonnaise A, Commercial mayonnaise A light, Commercial mayonnaise B and Commercial mayonnaise B light.

Low oil commercial mayonnaise contains added starch or gums, in order to maintain the texture of traditional mayonnaise.

The resistance to deformation of the CP-Pro 70®-based mayonnaise, which indicates how the product behaves at rest (on the supermarket shelf, for example) and when used in the kitchen (e.g., squeezed from the bottle, mixed, or spread) is depicted in Figure 7. At pH=5, the mayonnaise is most resistant to deformation, forming a stiffer emulsion than at pH=7 or pH=3. The stiffer emulsion at pH 5 may indicate the proteins' rigid gelling formation, which breaks as the stress exceeds 100 Pa. For samples with pH=7 and pH=3, the slope is more gradual, indicating a more spread-like behavior of the mayonnaise, once enough stress is applied to deform its original structure.

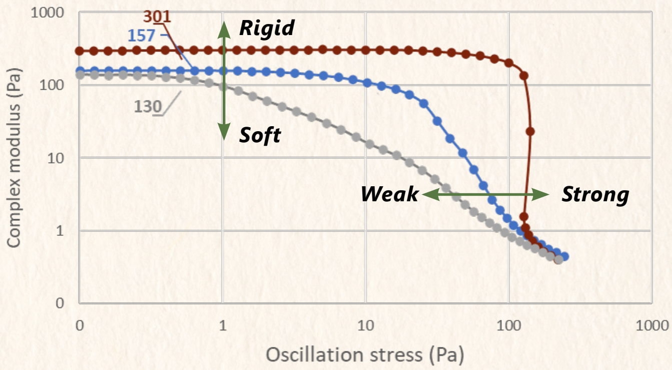


*Figure 7: Complex Modulus in Increasing Oscillation Stress of CP-Pro 70®-Based Mayonnaise at pH=7, 5, and 3. * Scale is logarithmic*

In comparison, the slopes of commercial mayonnaises, both regular and light, indicate ease of spreadability (Figure 8) and are similar to the slope of CP-Pro 70®-based high oil emulsion at pH=7. The gradual decline in the complex modulus signals that softer gelling occurred in these products. This difference can be related to the additional ingredients in commercial formulae, such as stabilizers, thickeners, salt, etc.

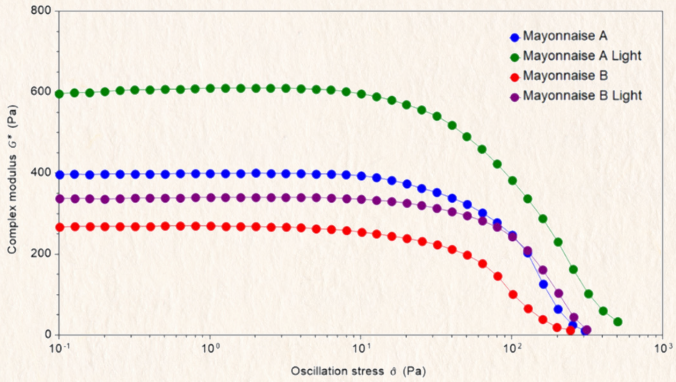


Figure 8: Complex Modulus in Increasing Oscillation Stress of Commercial Mayonnaise (Light and Regular Mayonnaise). Figure provided by Centre for Industrial Rheology

The value of the complex modulus plateau in CP-Pro 70®-based emulsions at pH=5 is higher than at pH=7 and pH=3, indicating its more rigid structure (Figure 7). The stiffer structure at pH=5 is related to the proximity to the isoelectric point of chickpea proteins, which decrease the repulsive force between the droplets and allows them to stay more tightly packed.

The CP-Pro 70®-based emulsion at pH=5 had a complex modulus plateau value similar to Commercial mayonnaise B (Figure 9), although slightly more resistant to deformation. Commercial egg-based mayonnaise must be at pH range of 3.6-4.1 unlike vegan mayonnaise, due to microbial regulation.

The difference in the complex modulus plateau between Commercial mayonnaises A&B to CP-Pro 70® - based mayonnaise can be related to the production process or to additives used in commercial products, but not used in the model formula of the CP-Pro 70®-based emulsion, as well as to the different amount of proteins in the products.

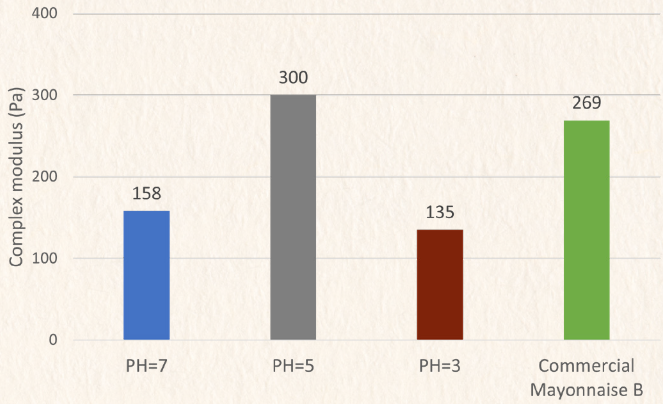
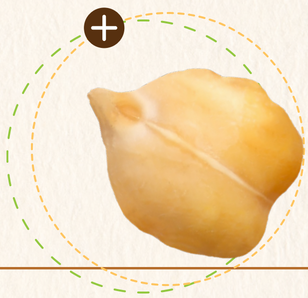


*Figure 9: Complex Modulus Plateau Comparison and CP-Pro 70®- Based Mayonnaise at pH=7, 5, and 3, and Commercial Mayonnaise. * Scale is logarithmic*



Emulsion
Capacity and Stability

The emulsion capacity and stability of CP-Pro 70®, unless otherwise noted, were prepared with only three ingredients: 69% canola oil, 29% water, and 2% CP-Pro 70® using the same process described in the “Rheology Properties” chapter above. For the other plant-based proteins tested, the formula was adjusted according to their protein content, in order to match the protein percentage.

Emulsion capacity was determined by placing a fixed amount of the emulsion into a vial and recording the height. The vial was then centrifuged, and the height of the separated layer and remaining emulsion was measured again. The emulsion capacity was measured as follows:

$$\textbf{Emulsion capacity} = \frac{\text{Height of emulsion in vial after centrifuge}}{\text{Innitial height of emulsion added to vial}} \times 100$$

Emulsion capacity was determined by putting the same vial at accelerated conditions with a heat bath for a period of time and centrifuging the vial again. The stability was calculated as follows:

$$\textbf{Emulsion stability} = \frac{\text{Height of emulsion in vial after heat treatment and centrifugeInnitial}}{\text{Innitial height of emulsion added to vial}} \times 100$$

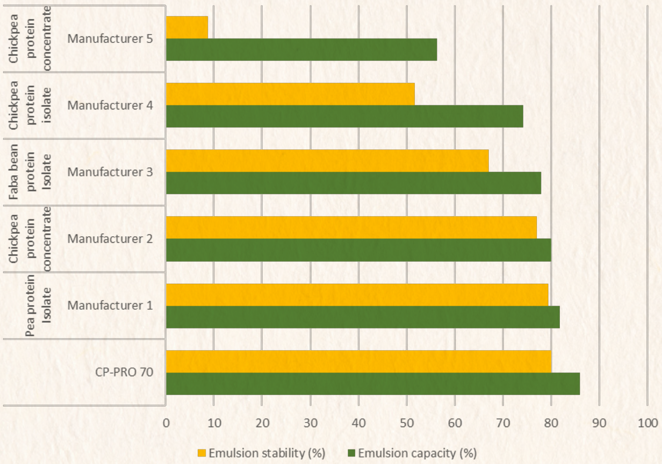


Figure 10: Emulsion Capacity and Stability of CP-Pro 70® and of Commercially Available Plant proteins in High Oil O/W Emulsions.

** CP-Pro 70® typical results presented*

Emulsion capacity ≥ 85% is considered excellent, 70 – 84.9% acceptable, <70% is unacceptable. Emulsion stability of ≥85% is excellent, 80 – 84.9% very good, 75-79.9% good, 70-74.9% acceptable and <70% is unacceptable.

CP-Pro 70®-based high oil O/W emulsions had superior emulsion capacity compared to other tested commercially available proteins. CP-Pro 70®-based mayonnaise had high stability after accelerated testing conditions, and was able to resist sustained high temperature and centrifugal forces (Figure 10).

CP-Pro 70®'s extraordinary emulsifying functionality is the result of InnovoPro's unique extraction process. The gentle extraction procedure selectively concentrates desired components and preserves the native structure of proteins. Furthermore, soluble dietary fibers in CP-Pro 70® may increase viscosity of the aqueous continuous phase, contributing to the emulsion's stability.

Shelf-life stability study was performed on CP-Pro 70®-based mayonnaise with a complete recipe, similar to standard recipes of commercial mayonnaise, containing, oil, water, CP-Pro 70®, sugar, vinegar, mustard paste and salt. The mayonnaise was produced by mixing dry ingredients into water and, with continuous shear, gradually adding the oil into the mixer (Thermomix TM-5/6). The product was kept at ambient temperature (approx. 25°C) and visually inspected monthly. The results demonstrated that no separation occurred during 8 months of storage. The emulsion was stable for 8 months, even when no homogenization was applied during the preparation of the mayonnaise.

Key Takeaways:

- CP-Pro 70®- based high oil O/W emulsions had superior emulsion capacity compared to other tested chickpea protein concentrates and isolates, and compared to pea and faba bean protein isolates, while maintaining high emulsion stability, after accelerated conditions.
- CP-Pro 70®- based emulsions with 70% oil were stable for 8 months, even though no homogenization was applied during the preparation of the mayonnaise.
- CP-Pro 70®- based mayonnaise demonstrated shear-thinning behavior.
- Control over viscosity and texture is achievable by adjusting the pH levels of the CP-Pro 70®- based mayonnaise. For higher viscosity and stiffer CP-Pro 70®-based mayonnaise, the pH level should be adjusted closer to the isoelectric point (pH=4.7). For more spreadability and a less viscous product, the pH level needs to be either higher or lower than the isoelectric point.
- At pH=5, the CP-Pro 70®- based mayonnaise has rheological properties that are similar to those of commercial egg-based mayonnaise.

Conclusions

CP-Pro 70® is an excellent emulsifier both in low and high oil concentration in O/W emulsions.

Using CP-Pro 70® can decrease or eliminate the number of ingredients (E-numbers) in the final product, due to its superior emulsion performance.

CP-Pro 70® - based high oil concentration emulsions remain stable without homogenization.

CP-Pro 70®- based emulsions are visually lighter compared to other tested plant-based emulsions and achieve texture that is comparable to commercial products, without using additives and texture modifiers.

CP-Pro 70®- based products presented similar or superior stability compared to commercial products, despite not having additives.

CP-Pro 70® - based low oil concentration emulsions remain stable when using HTST or UHT heat processes.

References

[1] Abdel-Haleem, A. M., Omran, A. A., & Hassan, H. E. (2022). Value addition of broken pulse proteins as emulsifying agents. Journal of Food Measurement and Characterization, 16(2), 1367-1382.

[2] Braun, K., Hanewald, A., & Vilgis, T. A. (2019). Milk emulsions: Structure and stability. Foods, 8(10), 483.

[3] Centre for Industrial Rheology website https://www.rheologylab.com/articles/food/fat-replacement/. Last accessed 23 July 2023.

[4] Depree, J. A., & Savage, G. P. (2001). Physical and flavour stability of mayonnaise. Trends in Food Science & Technology, 12(5-6), 157-163.

[5] Isendahl, H. (2022). Rheological characterization of typical food products. Division of system processing, Department of Food Technology, LTH faculty of Engineering. Lund, Sweden.

[6] Li, M., Doyle, L., Velazquez, R., Pangloli, P., & Wu, T. (2023). The amount of vinegar added before and after emulsification affects the physical property and stability of mayonnaise. LWT, 182, 114899.

[7] McClements, D. J. (2004). Food emulsions: principles, practices, and techniques. CRC press.

[8] Ozturk, B., & McClements, D. J. (2016). Progress in natural emulsifiers for utilization in food emulsions. Current Opinion in Food Science, 7, 1-6.

[9] Reyes-Jurado, F., Soto-Reyes, N., Dávila-Rodríguez, M., Lorenzo-Leal, A. C., Jiménez-Munguía, M. T., Mani-López, E., & López-Malo, A. (2023). Plant-based milk alternatives: Types, processes, benefits, and characteristics. Food Reviews International, 39(4), 2320-2351.

[10] Straits research website https://straitsresearch.com/report/dairy-alternatives-market. Last accessed 06 August 2023

[11] Tahmaz J, Sejfić A., Karahmet E., Operta S., Isaković S. (2023). Sensory properties of homemade and industrial mayonnaise. Proceedings. 1st International symposium on biotechnology. 17–18 March 2023. Cacak, Serbia.

[12] United States Department of Agriculture Economic Research Center website https://www.ers.usda.gov/amber-waves/2022/june/fluid-milk-consumption-continues-downward-trend-proving-difficult-to-reverse/. Last accessed 15 August 2023

[13] Wang, J. C., & Kinsella, J. E. (1976). Functional properties of novel proteins: Alfalfa leaf protein. Journal of food science, 41(2), 286-292.

[14] Widerström, E., & Öhman, R. (2017). Mayonnaise: quality and catastrophic phase inversion. Lund University, Sweden

[15] Worldwide, M. I. (2015). Zeta potential-An introduction in 30 minutes. Technical note.

[16] Zhang, S., Holmes, M., Ettelaie, R., & Sarkar, A. (2020). Pea protein microgel particles as Pickering stabilisers of oil-in-water emulsions: Responsiveness to pH and ionic strength. Food Hydrocolloids, 102, 105583.

Contact Our Team Today

for further information or questions

INNOVOPRO

LEADING THE CLEAN-LABEL FOOD REVOLUTION

4 Hashizaf Street,
10th floor, Ra'anana
4366411, Israel

(T) +972.76.5406.457

Office@innovopro.com

www.innovopro.com