Journal of Food Biosciences and Technology,
Islamic Azad University, Science and Research Branch, Vol. 11, No. 1, 89-98, 2021

The Effects of Emulsifiers Application on Characteristics of Mayonnaise

Sh. Dadkhah [a] *, P. Damanafshan [b], A. Taheri Yeganeh [c], P. Homati [d]

[a] Research and Development Food Technologist, Amadehlaziz Co., Karaj, Iran.
[b] Research and Development Supervisor, Azar Noosh Shokoofeh Co., Tehran, Iran.
[c] Research and Development Director, Food and Drug Administration Alborz University of Medical Sciences, Karaj, Iran.
[d] Quality Control and Laboratory Manager, Pak Dairy Co., Tehran, Iran.

Received: 11 November 2020 Accepted: 27 December 2020

ABSTRACT: Mayonnaise is a semisolid emulsion that is made by mixing oil with mustard, egg yolk, vinegar and is sensitive to spoilage due to its high polyunsaturated fatty acids content. The amount of oil and egg yolk added, viscosity, water quality, the volume of oil and aqueous phase, method of mixing and temperature affect the stability of mayonnaise. Phase inversion occurs when the emulsion changes from the oil-in-water (O/W) emulsion to the water-in-oil (W/O) emulsion. Egg yolk as an emulsifier has surface-active fractions such as livetin, lipovitellin, lipovitellenin that prevent coalescing and improve the texture. Phospholipid lecithin, proteins, and lipoproteins are known to be the most important to the emulsion forming properties of egg yolk. Other emulsifying agents include animal proteins, vegetables protein isolates, modified starches and gums which can be effectively used as food emulsion stabilizers because of their capacity to reduce the interfacial tension between hydrophobic and hydrophilic components. Temperature, pH and NaCl are effective on viscoelasticity of mayonnaise emulsion. Emulsifiers increase the prevalence of metabolic diseases, specially type 1 and 2 diabetes, obesity and irritable bowel disease. Currently the tendency of the consumers to purchase the food products with low fat and low energy is led to reformulation that often requires moving from one sort of emulsifier to another. In this study, different emulsifiers and their effects on the characteristics of mayonnaise were reviewed.

Keywords: *Mayonnaise, Emulsion, Emulsifiers, Egg yolk, Stability*.

Introduction

Mayonnaise is a semisolid product produced by combining the oil phase with the water phase using egg yolk as an emulsifier, with a total fat content of approximately 70–80% (Kerkhofs *et al*., 2011; McClements, 2004; Depree and Savage, 2001). The emulsion is made by slowly mixing oil with a premix that comprises of mustard, egg yolk, and vinegar. Due to the multifunctional properties of egg (such as foaming, gelling, and emulsifying characteristics), it is an important food component. Mayonnaise is composed of different lipid fractions namely phospholipids (28%), triglyceride (66%), and sterols consisted of phytosterols and cholesterol (5%). 65% of mayonnaise contains vegetable oil (Garcia, 2006). Mayonnaise can easily be auto-oxidized due to its high polyunsaturated fatty acid content, that makes it sensitive to spoilage (Wills and Cheong, 1979). In order to describe the degree of rancidity or oxidation,

* Corresponding Author: Dadkhah.sh@gmail.com

peroxide value is used (Pandey and Carney, 2008), and is one of the most commonly defined quality parameters during oil production, storage, and marketing (Saad *et al*., 2006). The peroxide value increases by 3.5 meq/kg after 15 days of storage (Wills and Cheong, 1979).

The stability of emulsification in mayonnaise depends on a variety of factors, including the amount of oil and egg yolk added, viscosity, water quality, the volume of oil and aqueous phase, method of mixing, and temperature (Harrison and Cunningham, 1985).

Phase inversion happens when the emulsion changes from the oil-in-water (o/w) emulsion to the water-in-oil emulsion (w/o), or the other way around. At the time of inversion, a more complex structure such as an oil-in-water-in-oil emulsion (o/w/o) or a water-in-oil-in-water emulsion (w/o/w) is likely to be formed as a transition state (McClements, 2016). In mayonnaise (o/w emulsion), the transition state oil-in-water-in-oil (o/w/o) can be observed during the emulsification phase inversion where small pieces of mayonnaise are floating in oil.

Phase inversion may be either transitional or catastrophic. Transitional phase inversion occurs when the phase inversion is caused by a change in the formulation, such as a change in salinity or temperature (Thakur *et al*., 2008). This form of phase inversion is reversible and shows very little hysteresis. In mayonnaise changes in salinity that affect the proteins in the egg yolk are more likely to occur (McClements, 2016). Catastrophic phase inversion happens when the phase inversion is caused by a change in the oil-water ratio (Thakur *et al*., 2008). A phase inversion occurs when the distributed phase volume becomes too large. This form of inversion relies on the system hysteresis, which makes the inversion process irreversible (Kumar *et al*., 2015).

The following parameters have an impact on phase inversion of mayonnaise:

- oil content
- rotor tip speed during oil addition
- the temperature of the ingredients
- oil inlet flow rate
- amount and type of emulsifier

Egg yolk comprises 16.4% protein, 48% water, 32.9% lipid, and 2.7% carbohydrate (Privett *et al*., 1962), and the main organic components of egg yolk are lecithin, oils, solid fat, cholesterol, cephalin, protein, and pigments (Seli *et al*., 1935). The addition of acid ingredients, and the high-fat content of mayonnaise, makes it a relatively microbiologically stable product. Acid ingredients and additives contribute to the desirable flavor, are toxic to food-borne pathogens, and decrease the final pH of the product (<4.8) (Depree and Savage, 2001; Karas *et al*., 2002). *Salmonella*, *E. coli*, *Escherichia coli* O157:H7, *Staphylococcus aureus*, *Listeria monocytogenes*, and *Yersinia enterocolitica* do not survive when they are inoculated into mayonnaise (Smittle, 2000).

Emulsions and emulsifiers

Food emulsions have a vital role in food products. A two-phase system consisting of immiscible liquids that differ in stability is called emulsion (Yang and Baldwin, 1995). One of the most commonly used emulsifiers in food products is egg yolk. Surface-active fractions such as livetin, lipovitellin, lipovitellenin, etc. in egg yolk, are absorbed in the oil-in-water (o/w) interface and form a film around the oil droplets and prevent coalescing, thus egg yolk is a key ingredient in the production of many food emulsions, such as mayonnaise. (Yang and Baldwin, 1995; Breeding and Beyer, 2000). Egg yolk is in the form of liquid is an emulsion. It improves the texture of the emulsion and also gives mayonnaise flocculation properties. Phospholipid lecithin, proteins, and lipoproteins are known to be the most important to the emulsion forming properties of egg yolk (Depree and Savage, 2001; Anton, 2013).

Egg yolk

In the food industry, egg yolk is mainly used in the forms of pasteurized salted, dried yolk, and sugared frozen egg yolk. The superior emulsifying properties of egg yolk are due to the structure, thus highly processed egg yolk has lower properties compared to the fresh egg yolk. Unlike freezing or freeze-drying egg yolk, the pasteurization of egg yolk does not affect the emulsifying properties to excess. Irreversible gelation occurs, when egg yolk is frozen below -6 °C. Gelation makes the egg yolk difficult to mix and combine with other raw materials and therefore it limits the usefulness of the egg yolk. Thus, mayonnaise made with egg yolk processed this way contains larger oil droplets which means that the phases of mayonnaise separate more easily. The addition of 10% of salt or sugar, limits the gelation of egg yolk. Although freezing extended periods causes changes in quality and functionality of egg yolk, the salted egg yolk or frozen egg yolk are relatively stable (Depree and Savage, 2001).

Besides the lecithin, the pH of the emulsion has an essential effect on the stability of the emulsion. When the pH is close to the average isoelectric point of the egg yolk proteins, the viscoelasticity and stability of the mayonnaise should be highest. At a pH of 3.9, the viscoelasticity was found to be highest (Depree and Savage 2001; Kiosseoglou and Sherman, 1983).

Other emulsifying agents

The use of another emulsifier in addition to egg yolk, or a complete replacement of this important ingredient, has some benefits, such as a decrease in cholesterol content, and generally, in fat content, an increase in microbiological stability, and in some cases, lower production costs (Riscardo *et al*, 2003). For this reason, several researchers have extensively studied the emulsifying properties of animal proteins such as whey protein, casein, and meat protein (Raymundoa, Francob, Empisc, and Sousad, 2002; Riscardo *et al*., 2003). Besides, vegetable protein isolates can be effectively used as food emulsion stabilizers because of their capacity to reduce the interfacial tension between hydrophobic and hydrophilic components. Several vegetable proteins from sunflower, soy, pea, wheat, tomato seed, white lupin, and faba bean have been successfully tested to stabilize oil-in-water (o/w) emulsions (Abu Ghoush, *et al*, 2008; Raymundoa *et al*., 2002; Riscardo *et al*., 2003). Although carbohydrates such as starches and gums, do not have hydrophilic and hydrophobic sections, they are often used in food emulsions (Garti *et al*., 1997; Chouard, 2004). Modified starch/cellulose can function as emulsifiers due to the ability to absorb in the oil-water interface. Also, some types of pectin and guar gum have these properties (Dickinson, 2013).

Raw materials affecting the stability

Salt as a raw material in mayonnaise can improve the stability, and the quality in three diverse ways. Firstly, it neutralizes the charges on proteins, which allows the lipovitellin to absorb water, and that strengthens the layer on the surface of the oil droplets, thus the egg yolk granules swell. Secondly, salt helps to disperse the egg yolk granules and make more surface-active material available, and thirdly, the neutralization of charges allow adjacent oil droplets to interact more strongly (Depree and Savage, 2001; Kiosseoglou and Sherman, 1983).

The most significant effect on the emulsifying properties is the salting of egg yolk with the unionized NaCl. In comparison to ionized NaCl or KCl salted egg yolk, mayonnaise made with unionized NaCl salted egg yolk shows higher stability, viscosity, and firmer emulsion when assessed by measuring the tendency to spread under its weight, which is due to the effect of ions in water interactions. Small Na^+-ions have had a strong electrical field that tends to facilitate interactions between water molecules to form structures. Also, polyvalent ions have a similar effect. Unlike large monovalent ions (K^+, I^-, Cl^-) that tend to disrupt these water interactions, polyvalent ions increase the viscosity of the emulsions (Harrison and Cunningham, 1986; Depree and Savage, 2001).

The interactions in an emulsion can be weakened by sucrose, due to the shielding of reactive groups. This prevents the charged carbohydrates (such as carboxymethyl cellulose) from interacting with egg white proteins and effectively forming cross-links between oil droplets. Strong protein-sugar interactions change the structure of the emulsion by reducing the size of the droplet, which then enhances the stability of the emulsion. (Depree and Savage, 2001; Huck-Iriart *et al.*, 2011).

Mustard increases the stability of an emulsion. The flavor is formed by volatile sulfur compounds, which are soluble in oil and slightly soluble in water. As a consequence, mustard can serve as an emulsifier. Mustard has also an antioxidant effect in mayonnaise. Studies show that mustard containing mayonnaise has a longer shelf-life than mustard-free mayonnaise (Depree and Savage, 2001; Lagunes Galvez *et al*., 2002; Ghorbani Gorji *et al*., 2016).

In home-made and early commercial mayonnaise, due to a combination of creaming and coalescence of the oil droplets, the most likely form of spoilage was the breakdown of the emulsion. As the understanding of the physical-chemical processes in the formation and breakdown of emulsions has improved, thus the production of emulsions that can remain stable for months rather than weeks has become possible. This increase and improvement in stability mean that slower chemical processes, especially auto-oxidation have become more important.

There is a trend towards the production of lower fat content mayonnaise as well as a shift in the type of oils used. As new formulations of mayonnaise are developed to meet new consumer’s requirements, the chemical interactions inside mayonnaise will change and this will affect the physical, oxidative, and flavor stability of the product.

Rheology

Rheological measurements are tools for the physical characterization of emulsions. It can analyze the viscoelastic properties, structural differences, and stability of the emulsions by measuring shear behavior. It analyzes and compares the differences in physical properties and behavior of similar products such as traditional mayonnaise and light mayonnaise. According to the results of analyzing and comparing traditional and light mayonnaise by Tabilo-Munizaga and Barbosa Cánovas, under stress/ strain sweep test, light mayonnaise slightly has longer viscoelastic regions. It also indicates that although traditional mayonnaise can show phase separation during storage, it has a more stable structure than light mayonnaise. The results show that in yield stress analysis, the traditional mayonnaise can be pumped easier than the light mayonnaise, however, the flow behavior in both mayonnaises indicates a uniformity of the microstructure (Tabilo-Munizaga and Barbosa-Cánovas, 2005).

The viscoelasticity of o/w emulsions stabilized with egg yolk is affected by the temperature, pH, and NaCl. The effect of salt is greater at pH below or above the isoelectric point and can be due to the concentration of protein adsorbed on the oil drop surfaces rising and contributing to a more pronounced cross-linking of the segments projected from the drop surfaces. Viscoelasticity increases at elevated temperatures, due to the increased degradation of the micelle, which provides more protein segments for interaction and cross-linking. The addition of carboxymethyl cellulose to the o/w emulsions increases the viscoelasticity, possibly due to carboxymethyl cellulose egg yolk interactions (Kiosseoglou and Sherman, 1983).

Increasing the salt concentration of mayonnaise above a certain amount does not result in a continuous increase of viscoelasticity, as with o/w emulsions. Aggregation of egg yolk components in the aqueous phase can reduce the adsorption of proteins. Shielding of reactive groups in sugar can reduce the viscoelasticity of mayonnaise. Partial replacement of egg yolk by egg white in mayonnaise increases the viscoelasticity, possibly because of the interaction of the egg white molecules with the adsorbed egg yolk components and strengthening the interlinkages between adjacent oil drops (Kiosseoglou and Sherman, 1983).

Emulsifying and thickening agents such as sodium caseinate, xanthan gum, and lecithin-whey protein concentrate can affect the stability of the emulsions. Sodium caseinate was found to be the most effective emulsifying and thickening agent, which in its presence is the viscosity, and stability of the double-emulsified mayonnaise are increased while its particle size decreased. This reduction in particle size is known to improve the rheological properties of double mayonnaise (Peressini et al., 1998; Wendin and Hall, 2001; Tabilo-Munizaga and Barbosa-Cánovas, 2005; Yildirim *et al*., 2016; Mezger, 2011).

Dietary emulsifiers and their impacts on human body

Over the last few decades there has been a tendency towards increased consumption of processed foods and beverages, and, in turn, food additives and processing aids used in the production of such foods and beverages. Emulsifiers are a class of food additives that are widely used in food processing to modify the flavor, or improve the texture, stability and, shelf-life of food products (Glade and Meguid, 2016; Roca-Saavedra *et al*., 2018). Due to the hydrophobic and hydrophilic moieties of the emulsifiers, they are used to create mixtures of two immiscible liquids (lipids and water) to produce a homogeneous, stable food product like mayonnaise (Shah *et al*., 2017; U.S. FDA, 2010).

Emulsifiers constitute approximately 75% of all approved food ingredients on the global market (Shah *et al*., 2017). Therefore, they have been postulated to be contributors to the increasing prevalence of metabolic diseases, specifically type 1 and 2 diabetes, obesity, and irritable bowel disease (Chassaing *et al*., 2015; Chassaing *et al*., 2017; Glade and Meguid, 2016; Roca-Saavedra *et al*., 2018). Recent studies have indicated that the use of sodium carboxymethyl cellulose and/or polysorbate 80 can damage the mucosal layer and allow bacteria to cross the epithelial surface, eventually leading to metabolic diseases (Chassaing *et al*., 2015, 2017). Over the past few years, the prevalence of metabolic disease and health conditions that comprise metabolic disease has risen (Ford *et al*., 2004).

Roca-Saavedra *et al*. (2018) has discussed the effects of various dietary components, including food additives (food emulsifiers, non-nutritive sweeteners, essential oils) and micronutrients (minerals and vitamins), on the gut microbiota, and stated that these dietary factors have significant impacts on the human gut microbiota, and equilibrium changes in gut microbiota may lead to adverse physiological conditions (metabolic diseases) by affecting fatty acid oxidation, food intake, and vitamin/nutrient absorption. In-vitro and animal evidence suggests that food additives such as emulsifiers may contribute to gut and metabolic diseases through alterations to the gut microbiota, intestinal mucus layer, increased bacterial translocation, and associated inflammatory response.

The most commonly used emulsifier is phospholipid lecithin, a natural zwitterionic surfactant found in both plant and animal cell walls (Kinyanjui *et al*., 2003). It is usually commercially sourced from sunflowers, and soybeans, but perhaps best known as a key component of egg yolks, accounting for their emulsifier properties used to produce food products such as mayonnaise. Single egg yolk contains 1.8 gr of lecithin. In the Western diet, the average daily intake of lecithin from food sources is 3.6 gr/day and can be up to 7 gr/day (Canty and Zeisel, 1994; Palacios and Wang, 2005). Lecithin contains varying amounts of phospholipids: phosphatidylethanolamine (egg lecithin 12%; soy lecithin 20-30%); phosphatidylcholine (egg lecithin 80% w/w; soy lecithin 20-30%); and phosphatidylinositol (egg lecithin 5%; soy lecithin 20%) (Palacios and Wang, 2005; American Lecithin Company, 2009).

No studies have yet been conducted on the effect of lecithin on either bacterial translocation or microbiota. A quantity of 1.4- 8.1 gr/Lit of lecithin enters the human intestine in bile, which, with bile secretion around 0.75 Lit/day, amounts to 1- 6 gr/day of phosphatidylcholine entering the human intestine daily (Boyer, 2013). The presence of phosphatidylcholine in bile prevents cholesterol gallstone formation and reduces the toxicity of bile acid micelles (Tompkins *et al*., 1970). Ingestion of high dosage of lecithin (22-83 gr/day for 2-4 months) in healthy individuals has shown no obvious ill effects, however, a lowering of plasma triglyceride levels has been reported (Cobb *et al*., 1980). Although the European Food Safety Authority recommends an adequate intake of dietary choline (a quaternary amine, mainly present in lecithin as phosphatidylcholine and released during intestinal lipase digestion) as 400 mg/day for adults, it may have been considered unnecessary to define a safe limit (JECFA, 1974a; EFSA NDA Panel, 2016).

Egg yolk, soy lecithin and lecithin components such as phosphatidylinositol in short-term dietary supplementation studies have shown elevations in high-density lipoprotein (HDL)-cholesterol (Burgess *et al*., 2005; Blesso *et al*., 2013), and a reduction in serum low-density lipoprotein (LDL)-cholesterol (Mourad *et al*., 2010). Also encapsulated phosphatidylcholine designed for colonic delivery has shown promise in the treatment of ulcerative colitis (Karner *et al*., 2014). However, dietary lecithin, or more specifically phosphatidylcholine, has been indicated as a risk factor for coronary artery disease (a consequence of the conversion of choline by the intestinal microbiota to the proatherogenic metabolite trimethylamine-N-oxide) (Tang *et al*., 2013).

Over the last few decades, numerous reports have proved the relationship between excessive fat intake and a variety of health problems, such as obesity, cancer, and cardiovascular heart diseases. The World Health Organization has advised consumers to moderate the intake of fatty substances. Most of the consumers of low-calorie or fat products are not on diet, but they try to stabilize or even decrease their weight. Therefore manufacturing and marketing of low-fat and low-calorie foods have increased. In order to achieve weight loss, the daily calorie intake from fat should not exceed 30% of the total daily calorie intake. The common dietary recommendations consist of, reduction of fat content in the daily diet, preference of products contributing to a healthier diet, such as low calorie or fat products, replacement of animal fat with vegetative, such as lard with corn/soybean oil, which are rich in essential fatty acids and fat removal from foods. In order to limit the coronary artery disease, it is recommended to decrease the dietary intake of saturated fatty acids, cholesterol, and to replace them with carbohydrates and fats rich in essential fatty acids. Unsaturated fatty acids are capable of decreasing the level of cholesterol, while trans-fatty acids are related to high levels of total and LDL cholesterol and with several heart diseases.

Conclusion

The most important components for the production of the mayonnaise and salad dressings are oil and emulsifier. The high oil content in these products which are o/w emulsions causes stability problems that must be solved with the aid of an emulsifier (Dalgleish, 1997; Raymundo, *et al*., 1998). The most commonly used oils in the production of commercial mayonnaise and salad dressings are vegetable oils, namely sunflowers, and soybeans. Egg yolk is the most commonly used emulsifier in the food industry, but other low or no cholesterol emulsifiers such as milk and soy protein have been also used. Currently, the tendency and the growing interest of the consumers is to purchase food products and ingredients with low oil content, low fat, and low energy. Lowering the oil content and moving from egg yolk as a key emulsifier to another, requires to use an effective thickening agent to help stabilize the oil droplets against coalescence and to achieve an emulsion with the physical properties similar to those of traditional mayonnaise. The thickening agents that can be used for this purpose are xanthan gum, galactomannans, pectin, intact or modified starches, and propylene glycol alginate. Due to the tendency to develop new mayonnaise and salad dressing products with low-fat content, and low cholesterol, it is important to characterize these products to optimize the composition and processing conditions of the non-traditional food emulsions. The knowledge of the physical behavior of these products is also important for the design of the unit operations, quality control, storage stability, and control of the processing variables (Davis, 1973; Raymundo *et al*., 2000).

Choosing an emulsifier for a specific food emulsion is often governed by the local food laws combined with consumer preferences for texture, appearance, and mouthfeel. Quality standards for food products vary in different countries, thus manufacturers create a need to meet these requirements by different formulations, including the type of emulsifiers. Different types of emulsifiers available to the food industry can be used for a given application with equally good performance. However, some reformulation is often required when moving from one sort of emulsifier to another.

References

Abu Ghoush, M., Samhouri, M., Al-Holy, M. and Herald, T. (2008). Formulation and fuzzy modeling of emulsion stability and viscosity of a gumeprotein emulsifier in a model mayonnaise system. Journal of Food Engineering, 84, 348e357.

American Lecithin Company, Lecithins and phospholipids, http://www.americanlecithin.com/lecithin_2009 (accessed 3 April 2019).

Anton, M. (2013). Egg Yolk: Structures. Functionalities and Processes: Egg Yolk: Structures, functionalities and processes. Journal of the Science of Food and Agriculture, 93(12), 2871–2880.

Aryana, K. J., Haque, Z. Z. and Gerard, P. D. (2002). Influence of whey protein concentrate on the functionality of egg white and bovine serum albumin. International Journal of Food Science and Technology, 37, 643–652.

Blesso, C. N., Andersen, C.J., Barona, J. and Volek, J. S. (2012). Whole egg consumption improves lipoprotein profiles and insulin sensitivity to a greater extent than yolk-free egg substitute in individuals with metabolic syndrome. Metabolism: clinical and experimental, 62(3), 400–410.

Boyer, J. L. (2013). Bile formation and secretion. Comprehensive Physiology. Comprehensive Physiology, 3, 1035–1078.

Breeding, C. J. and Beyer, R. S. (2000). Eggs, In Food Chemistry: Principles and Applications, edited by Christen G. L., and Smith, J.S. Science Technology Systems, West Sacramento CA.

Burgess, J. W., Neville, T. A., Rouillard, P., Harder, Z., Beanlands, D. S. and Sparks. D. L. (2005). Phosphatidylinositol increases HDL-C levels in humans. Journal of Lipid Research, 46, 350-355.

Canty, D. J. and Zeisel, S. H. (1994). Lecithin and choline in human health and disease. Nutrition Reviews, 52, 327–339.

Chassaing, B., Koren, O., Goodrich, J. K., Poole, A. C., Srinivasan, S., Ley, R. E. and Gewirtz, A. T. (2015). Dietary emulsifiers impact the mouse gut microbiota promoting colitis and metabolic syndrome. Nature, 519(7541), 92–96.

Chouard, G. (2004). More than gelling. Colloidal systems for permanent stabilization. Food Marketing and Technology, 18, 15–18.

Chassaing, B., Van de Wiele, T., De Bodt, J., Marzorati, M. and Gewirtz, A. T. (2017). Dietary emulsifiers directly alter human microbiota composition and gene expression ex vivo potentiating intestinal inflammation. Gut, 66, 1414–1427.

Cobb, M., Turkki, P., Linscheer, W. and Raheja, K. (1980). Lecithin Supplementation in Healthy Volunteers Effect on Cholesterol Esterification and Plasma, and Bile lipids. Annals of Nutrition and Metabolism, 24, 228–237.

Dalgleish, D. G. (1997). Adsorption of protein and the stability of emulsions, Trends in Food Science and Technology, 8, 1-6.

Davis, S. S. (1973). Rheological properties of semi-solid foodstuffs, Journal of Texture Studies, 4, 15-40.

Daugaard, L. (1993a). Protein based emulsifiers for production of mayonnaise. Scandinavian Dairy Information, 7, 52–54.

Depree, J. A. and Savage, G. P. (2001). Physical and flavour stability of mayonnaise. ***Trends*** in ***Food Science*** and ***Technology,*** 12(5/6), 157–163.

Dickinson, E. (2013). Stabilising Emulsion-Based Colloidal Structures with Mixed Food Ingredients. Journal of the Science of Food and Agriculture, 93 (4), 710–721.

EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA). (2016). Dietary reference values for choline. EFSA Journal, 14(8), 4484.

Ford, E. S., Giles, W. H. and Mokdad, A. H. (2004). Increasing prevalence of the metabolic syndrome among U.S. Adults. Diabetes Care, 27(10), 2444-2449.

Garcia, K. M. (2006). Quality Characterization of Cholesterol-Free Mayonnaise Type Spreads Containing Rice Bran Oil. Master thesis, Louisiana State University, Baton Rouge.

Garti, N., Aserin, A., Sternhein, B. and Madar, Z. (1997). Fenugreek galactomannans as food emulsions. LWT-Food Science and Technology, 30, 305–311.

Ghorbani Gorji, S., Smyth, H. E., Sharma, M. and Fitzgerald, M. (2016). Lipid Oxidation in Mayonnaise and the Role of Natural Antioxidants: A Review. Trends in Food Science and Technology, 56, 88–102.

Glade, M. J. and Meguid, M. M. (2016). Dietary emulsifiers, the human intestinal mucus and microbiome, and dietary fiber. Nutrition, 32, 609–614.

Harrison, L. J. and Cunningham, F. E. (1985). Factors influencing the quality of mayonnaise. Journal of Food Quality. 8, 1–20.

Harrison, L. J. and Cunningham, F. E. (1986). Influence of Salt on Properties of Liquid Yolk and Functionality in Mayonnaise. Poultry Science, 65(5), 915–921.

Huck-Iriart, C., Roberto Jorge, C. and Herrera, M. L. (2011). Effect of Processing Conditions and Composition on Sodium Caseinate Emulsions Stability. Procedia Food Science, 1, 116-122.

JECFA (Joint FAO/WHO Expert Committee on Food Additives). (1974a). Lecithin. In Toxicological evaluation of some food additives including anticaking agents, antimicrobials, antioxidants, emulsifiers and thickening agents (pp. 10-11). Geneva, Switzerland.

Karas, R., Skvarca, M. and Zlender, B. (2002). Sensory quality of standard and light mayonnaise during storage. Food Technology and Biotechnology, 40, 119-127.

Karner, M., Kocjan, A., Stein, J., Schreiber, S., Boyen, G. V., Uebel, P., Schmidt, C., Kupcinskas, L., Dina, I., Zuelch, F., Keihauer, G. and Stremmel, W. (2014). First multicenter study of modified release phosphatidylcholine “LT-02” in ulcerative colitis: a randomized, placebo-controlled trial in mesalazine-refractory courses. The American Journal of Gastroenterology, 109, 1041– 1051.

Kerkhofs, S., Lipkens, H., Velghe, F., Verlooy, P. and Martens, J. A. (2011). Mayonnaise production in batch and continuous process exploiting magnetohydrodynamic force. Journal of Food Engineering, 106, 35–39.

Kinyanjui, T., Artz, W. and Mahungu, S. (2003). Emulsifiers: Organic Emulsifiers. In Encyclopedia of Food Sciences and Nutrition (pp. 2070–2077). Elsevier Science Ltd: Amsterdam.

Kiosseoglou, V. D. and Sherman, P. (1983). Influence of Egg Yolk Lipoproteins on the Rheology and Stability of O/W Emulsions and Mayonnaise. 1. Viscoelasticity of 45 Groudnut Oil in Water Emulsions and Mayonnaise. Journal of Texture Studies, 14 (4),397-417.

Kumar, A., Li, S., Cheng, C. M. and Lee, D. (2015). Recent Developments in Phase Inversion Emulsification. Industrial and Engineering Chemistry Research, 54(34), pp.8375-8396.

Lagunes-Galvez, L., Cuvelier, M. E., Ordonnaud, C. and Berset, C. (2002). Oxidative Stability of Some Mayonnaise Formulations During Storage and Daylight Irradiation. Journal of Food Lipids, 9(3), 211–224.

McClements, D. J. (2004). Food Emulsions: Principles, Practice, and Techniques. Second Ed. Boca Raton : CRC Press, pp. 3-4.

McClements, D. J. (2016) Food emulsions: Principles, Practices and Techniques. Third Ed. Boca Raton: CRC press, pp. 564-570.

Mourad, A. M., Pincinato E. C., Mazzola, P. G., Sabha, M. and Moriel, P. (2010). Influence of soy lecithin administration on hypercholesterolemia. Cholesterol, 2010, 1-4.

Palacios, L. E. and Wang, T. (2005). Extraction of egg-yolk lecithin. Journal of the American Oil Chemists’ Society, 82, 565–569.

Pandey, G.N., and Carney, G.C. (2008). Environmental Engineering. McGraw-Hill, New Delhi.

Peressini, D., Sensidoni, A., and Cindio, B. (1998). Rheological Characterization of Traditional and Light Mayonnaises. Journal of Food Engineering, 35(4), 409-417.

Privett, O. S., Blanl, M. L. and Schmit, J. A. (1962). Studies on composition of egg lipid. Journal of Food Science, 27, 463–470.

Raymundo, A., Empis, J. and Sousa, I. (2000). Effect of pH and NaCl on rheological and textural properties of lupin protein emulsions, in Gums and Stabilizer for the Food Industry 10, edited by Williams, P.A., and Phillips, G.O. Royal Society of Chemistry, U.K., pp. 350-365.

Raymundo, A., Empis, J. and Sousa, I. (1998). Optimization of lupin protein emulsion composition, Polish Journal of Nutrition of Science, 48, 127-134.

Raymundo, A., Franco, J. M., Empis, J. and Sousa, I. (2002). Optimization of the composition of low-fat oil-in-water emulsions stabilized by white lupin protein. Journal of the American Oil Chemists' Society, 79(8), 783-790.

Riscardo, M. A., Franco, J. M. and Gallegos, C. (2003). Influence of composition of emulsifier blends on the rheological properties of salad dressing-type emulsion. Food Science and Technology International, 9, 53-63.

Rir, L., Feldman, L., Aserin, A. and Garti, N. (1994). Surface properties and emulsification behavior of denatured soy protein. Journal of Food Science, 59, 606–607.

Roca-Saavedra, P., Mendez-Vilabrille, V., Miranda, J. M., Nebot, C., Cardelle-Cobas, A., Franco C. M., and Cepeda, A. (2018). Food additives, contaminants and other minor components: Effects on human gut microbiota-a review. Journal of Physiology and Biochemistry, 74, 69-83.

Saad, B., Wai, W. T., Lim, B. P. and Saleh, M. I. (2006). Flow injection determination of peroxide value in edible oils using triiodide detector. ***Analytica Chimica Acta***, 565, 261–270.

Seli, H. M., Olsen, A. G. and Kremers, R. E. (1935). Lecithin-protein: the emulsifying ingredient in egg yolk. ***Industrial*** and ***Engineering Chemistry***, 27, 1222–1223.

Shah, R., Kolanos, R., DiNovi, M. J., Mattia, A. and Kaneko, K. J. (2017). Dietary exposures for the safety assessment of seven emulsifiers commonly added to foods in the United States and implications for safety. Food Additives and Contaminants. Part A, Chemistry, Analysis, Control, Exposure and Risk Assessment, 34, 905–917.

Smittle, R. B. (2000). Microbiological safety of mayonnaise, salad dressings, and sauces produced in the United States: a review. Journal of Food Protectection, 63, 1144–1153.

Tabilo-Munizaga, G. and Barbosa-Cánovas, G. V. (2005). Rheology for the Food Industry. Journal of Food Engineering, 67, 147-156.

Takeda, K., Matsumura, Y. and Shimizu, M. (2001). Emulsifying and surface properties of wheat gluten under acidic conditions. Journal of Food Science, 66, 393-399.

Tang, W. H. W., Wang, Z., Levison, B. S., Koeth, R. A., Britt, E. B., Fu, X., Wu, Y. and Hazen, S. N. (2013). Intestinal microbial metabolism of phosphatidylcholine and cardiovascular risk. New England Journal of Medicine, 368, 1575-1584.

Thakur, R. K., Villette, C., Aubry, J. M. and Delaplace, G. (2008). Dynamic Emulsification and Catastrophic Phase Inversion of Lecithin-based Emulsions. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 315(1-3), pp. 285-293.

Tompkins, R. K., Burke, L. G., Zollinger, R. M. and Cornwell, D. G. (1970). Relationship of biliary phospholipid and cholesterol concentrations to the occurrence and dissolution of human gallstones. Annals of Surgery, 172, 936-945.

International Food Information Council (IFIC) Foundation, Overview of Food Ingredients, Additives and Colors, November 2004; revised April 2010. https://www.fda.gov/food/ingredientspackaginglabeling/foodadditivesingredients/ucm094211.htm

Wendin, K. and Hall, G. (2001). Influences of Fat. Thickener and Emulsifier Contents on Salad Dressing: Static and Dynamic Sensory and Rheological Analyses. LWT - Food Science and Technology, 34(4), 222-233.

Wills, R. B. H. and Cheong, C. L. (1979). Use of peroxide value and carbonyl to determine the onset of rancidity in mayonnaise. Food Chemistry, 4, 259-261.

Yang, S. C. and Baldwin, R. E. (1995). Functional Properties of eggs in Food. In Eggs Science and Technology, Edited by Stadelman, W.J., and Cotterill, O.J. 4th Ed. The Haworth Press, New York, pp. 405-465.

Yildirim, M., Sumnu, G. and Sahin, S. (2016). Rheology. Particle-Size Distribution. and Stability of Low-Fat Mayonnaise Produced via Double Emulsions. Food Science and Biotechnology, 25(6), 1613-1618.