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REVIEW ARTICLE

Mayonnaise main ingredients influence on its structure as an emulsion

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Abstract Mayonnaise has a great potential for research and development. Today, consumers are seeking for healthier and natural food products. Generally, it is a blend of oil, egg, salt, lemon juice or vinegar and texture improvers which make its structure as oil in water emulsion. Each of mentioned ingredients has huge effects on mayonnaise emulsion quality. This paper presents information about how these components can change the mayonnaise rheological, stability and sensory attributes.

Keywords Mayonnaise · Emulsion · Stability · Rheology · Sensory

Abbreviations

HPH High pressure homogenization
LDL Low density lipoprotein
OSA Octenyl succinic acid

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Introduction

Mayonnaise is important oil in water emulsion-based food that has been produced and consumed all around the world. Today, consumers demand for healthier and natural food products resulted in introduction of new food ingredients/processing and consequently the formulation changes.

Typically, emulsions contain oil, water and emulsifier/thickening agent. In the case of mayonnaise it consists of oil, water, egg yolk, salt, sugar, sweetener, and other optional ingredients. Each of these ingredients, depending on their level and quality, determine the quality characteristics of emulsion. The perceived quality of emulsion based food products is determined by its microstructure or the interaction of its ingredients (Mirhosseini et al. 2008). Despite the thermodynamically unstable nature of oil in water emulsion based food products, they can be kinetically stable by optimizing the dispersed phase characteristics and its volume fraction, viscosity of continuous phase and also considering the processing parameters (blending ratio, processing time and temperature) (Mollakhalili Meybodi et al. 2014). Fat as one of the main ingredients of mayonnaise; is in the form of oil droplets; which the strength of interactions between them is a major determinant of mayonnaise quality. The globular proteins and phospholipids of egg yolk are known as emulsion stabilizer/textural modifier and consequently microstructural determinant factor (Ariizumi et al. 2017). The main role of emulsions texture enhancers such as thickening agents, stabilizers and emulsifiers is increasing the viscosity of continuous phase.

Formula change will influence both the quality characteristics and acceptability of the product. However, it should be noted that despite the stability of emulsion based food products like mayonnaise at the time of production, it may exhibit micro/macroscopic changes such as oxidation, syneresis during storage and distribution (McClements 2015). In other words, changing in formulation should also guarantee the appealing characteristics of food emulsion through its shelf life storage until the time of consumption.

Studying the texture of emulsions via rheological approach is a promising technique which its correlation with sensory perception can be helpful to food developers. There are a few reviews which deal with mayonnaise quality. The review published by Ma and Boye (2013) studied the properties of mayonnaise with emphasis on low fat and low cholesterol types. Sikora et al. (2008) described sauce and dressing properties including their microbial attributes and oxidative defects. The aim of this review article is to investigate the key ingredients and parameters that have fundamental effects on all types of mayonnaise as an emulsion and provide information suitable for food industry.

Formulation and structure

Mayonnaise is defined as an emulsified semisolid food prepared by vegetable oils (not less than 65% w/w). Accordingly, light and reduced fat mayonnaise means those containing at least 50% and 25% lower fat content compared to normal ones respectively.

Creaming, flocculation and coalescence are mentioned as the main destabilizing mechanisms which its occurrence should be minimized (Štern et al. 2008). Rheology, as the science of flow and deformation, is greatly important to control the quality characteristics of food emulsion dependent to changes may be done in formulation, processing and equipment.

Mayonnaise have shown the non-Newtonian pseudoplastic shear-thinning (flow behavior index < 1) behavior with yield stress and time dependent characteristics (Ma and Boye 2013). Non-linear relationship between shear stress and shear rate of mayonnaise sauce has been widely assess by Power law, Herschel Bulkley, Carreau and Cason models to determine the consistency coefficient, apparent viscosity and flow behavior index.

The elastic modulus (G') is dominant to loss modulus (G'') in oscillatory investigation of mayonnaise sauce confirming the formation of weak gel (Maruyama et al. 2007). The yield stress (Y_c) as an important factor in determining the acceptability of final product by the consumer is known as the stress at which the mayonnaise starts to flow (Huang et al. 2016). The yield stress, zero shear viscosity and elastic moduli are well established to be related with bulk perception at early stages of oral consumption. The relation between mayonnaise main ingredients on its structural characteristics (rheological and textural characteristics) and sensory perception are considered thoroughly in the next.

Influence of mayonnaise ingredients on structure

Oil

Oils are mainly blend of triacylglycerols (usually $> 95\%$), diacylglycerols, monoacylglycerols and free fatty acids. Its physicochemical characteristics including its degree of crystallization, melting point, molecular structure, droplet size, volume fraction, degree of oxidation and/or lipolysis are critical in determining the emulsions properties (Dickinson 1987; McClements 2015).

Concerns existed about the negative health impacts of overconsumption of fatty foods have led to a trend within the food industry towards the production of healthier mayonnaises. Optimizing the formulation of low-fat mayonnaises with different oil content have been assessed regarding rheological characteristics (Mozafari et al. 2017). Results show that, reduction in oil content from 56 to 37% led to significant decrease in apparent viscosity, consistency coefficient (k), firmness, stability and increase in flow index (n). Generally, the rheological properties of the structured emulsions switch from a plain viscous fluid with a Newtonian character at lower oil phase volume (< 0.4) to a thick cream-like material with a yield stress and gel-like attributes as the oil phase volume increases (> 0.4) (Anvari and Joyner 2017).

There is a unanimous that with decreasing disperse-phase volume fraction, the viscosity and thus the stability of emulsions like mayonnaise will have been decreased (McClements 2015; Mozafari et al. 2017). This behavior can be explained by two processes of flocculation-deflocculation of oil droplets and macromolecules orientation. As the shear rate increases, droplets deflocculation surpasses and thus the apparent viscosity will be decreased. According to the second process, orientation in the position of unorganized long chain molecules (e.g. stabilizers or thickening agents) will reduce the resistance against flow and consequently decrease the viscosity (McClements 2015).

Despite the importance of apparent viscosity, consistency coefficient (k) and flow index (n) in determining the flow behavior of mayonnaise, no direct connection has been observed between these parameters and sensory attributes. Although, higher consistency coefficient (k) means mayonnaise is more viscous. Changes in consistency could be connected to the balance of interparticle colloidal attractive and repulsive chemical forces (Golchoobi et al. 2016).

In a recent study published by Ross et al. (2019), they observed correlation between apparent viscosities at shear rates of 10 s^{-1} and 100 s^{-1} with oral cohesiveness and stickiness perception respectively. Albeit, they utilized dispersions and thus the oil effect was not considered in their results.

Full-fat mayonnaise homogenized with fast or slow speed mixer was studied for textural characteristics. Decrease in oil droplets size due to high emulsification intensity led to an increase in firmness and adhesiveness of mayonnaise but neither appearance nor taste or flavor attributes were affected (Olsson et al. 2018). The authors reported that the decrease in oil droplet size caused an increase in both surface area and contacting points between droplets which these interactions could led to an increase in storage modulus (G′), the elastic parameters of dynamic viscoelasticity.

Another studies proposed that increase in apparent viscosity in emulsions with lower oil fractions could be due to smaller disperse phase diameters which caused to more open network organized (Primacella et al. 2019; Su et al. 2010).

Moreover, a report has mentioned that there is a critical average droplet size below which the rheological properties of mayonnaise depends on the total surface area made by droplets at any adjusted disperse phase volume (Guilmineau and Kulozik 2007). Upper the critical average droplet size, other factors such as molecular interaction between oil droplets will be dominant.

In addition, oil droplet directly affects sensory attributes like perceived texture, lubrication, coating and flavor release. On the other hand, increasing in oil droplets diameter can lead to some storage time defects like creaming and sedimentation that both are described as gravitational separation (McClements 2015).

Anvary and Joyner (2017) in their paper proposed that concentrated emulsions like mayonnaise with oil phase volume fraction higher than 0.6, do not exhibit any creaming regardless of protein-based emulsifier concentration and consequently the oil phase volume fraction play a key role in emulsion creaming. The authors observed that creaming defect occurred again, when the oil phase volume fraction has been increased to 0.85. They explained that insufficient amount of protein (gelatin) for prefect covering of oil droplets caused coalescence of oil droplets and creaming.

There is another phenomenon which proposed that the competitive adsorption between stabilizers and/or emulsifiers is the driving force for creaming. Accordingly, the more greatly adsorbing molecule already linked to one interface will competitively relocate a more weakly adsorbing molecule from other interface, causing a bridge between the two droplets (McClements 2015).

It is believed that there is a significant correlation between storage modulus (G′) and sensory attributes such as hardness, adhesiveness and fracturability (Maruyama et al. 2007). In a study conducted by Ariizumi et al. (2017), it was found that the complex viscosity and droplet size of prepared mayonnaise were significantly affected by the oil temperature and the mixer rotor speed. These findings reveal that some adjustment to processing conditions could be more economically efficient than other solutions such as adding texture modifiers to enhance mayonnaise quality.

Di Mattia et al. (2015) and Chetana et al. (2019) studied the textural properties of mayonnaise formulated with different kind of vegetable oils. Their results showed that oil droplet size distribution, firmness, consistency, storage modulus (G′) and yield stress were influenced by the type of oil used. In this regard, the differences in physicochemical characteristics have been expected. Accordingly, using more saturated and shorter fatty acids in mayonnaise led to a decrease in firmness, storage modulus and apparent viscosity.

Moreover, in study conducted by Chetana et al. (2019), it has been revealed that increasing the sesame oil portion in a blend of rice bran/sesame oil, will change its fundamental quality parameters significantly such as oil phase separation, unpleasant smell/flavor development. Also, according to sensory analysis, the brightness had a considerable impact on the perceived appearance of the studied mayonnaises. It has been revealed that decreasing the droplet size will increase the light scattering and consequently change the gray color of the mayonnaises to white. It can be concluded that considering the respective sensory limitations and defects parallel to texture analysis is essential when formulation is modifying.

The yield stress is one of the most important quality parameters of mayonnaise; determining its stability at low stress situations, like storage and transportation. The consumer related expectations such as good pourability and spreadability of mayonnaise at the time of utilization and perceived thickness or creaminess during mastication, are also dependent to the level of yield stress. Moreover, manufactures concerned attributes in processes like mixing, stirring and pumping through pipes are affected by this parameter (Dickinson 1987; McClements 2015).

Some investigations emphasized the effect of disperse-phase volume fraction on yield stress (Golchoobi et al. 2016; Ghazaei et al. 2015). Generally, low fat mayonnaise exhibits higher yield stress; so it can be concluded that it would be pumped harder than full fat ones. On the other hand, usually the light mayonnaise stability is lower than the regular-fat containing ones. The disperse phase volume fraction and droplets particle size affect the density of inter-particle relationships and microstructure of emulsions which both of them determine the level of yield stress

(McClements 2015). In another study conducted by Ross et al. (2019), relation between rheological and sensory parameters of hydrocolloid-thickened fluids were investigated. Accordingly, it was found that yield stress was not a direct indicator of the studied sensory properties.

Some authors suggested studying static yield stress instead of yield stress which is equal to stress where a 10% reduction in the average storage modulus (G′) is obtained. Accordingly, this parameter is more applicable than yield stress when studying processing condition, such as pumping (Primacella et al. 2019).

Generally, mayonnaise shows a time dependent characteristic (thixotropy) and there's a direct correlation between fat level of mayonnaise and its thixotropic loop area. This property corresponds to a growing destruction of the product structure as the time of shear forwards. Štern et al. (2008) found reverse relationship between thixotropy level and palatability of studied low fat mayonnaise.

The Bohlen's theory of flow is a useful concept which explains some of the rheological properties of mayonnaise (Di Mattia et al. 2015; Laca et al. 2010). The complex modulus (G^*) in Bohlin's theory is connected to proportional coefficient (A), oscillation frequency (**ω**) and the reciprocal of the coordination number (z). Accordingly, the proportional coefficient reveals the strength of the mayonnaise emulsion interactions and the coordination number represents their level in the three-dimensional structure. Decrease in level of z and A is due to tendency of oil droplets to coalesce when the mechanical stress is applied (Ghazaei et al. 2015).

Using ultra-high pressure homogenization is supposed to help product developers to produce low fat mayonnaise without adding thickeners or artificial emulsifiers. Alvarez et al. (2018) studied the influence of optimum pressure level, designed internal flow pattern, apparatus valve geometries and ingredients on rheological and sensory attributes of mayonnaise. Their results showed that, the employment of high pressure homogenization (HPH) usually leads to an increase in mayonnaise temperature. As the specific heat (C_p) of oils and water is different, products with more oil content are more vulnerable to be increased in temperature. Moreover, the gelling point of low density lipoprotein (LDL) (egg yolk's key emulsifier) is 75 °C and this temperature is achievable at intense HPH processing. Thus, it should be emphasized that, when a special technology like HPH is used in a product development, side effects existed that should be considered carefully.

Egg yolk

Hen egg has a complex structure which is divided into two main fractions: egg yolk and egg white with distinguished applications in food industry. Egg yolk is usually used as an emulsifier, whereas egg white is more commonly used for stabilizing foams. Egg yolk can be separated into plasma and granules by centrifugation, which account for (78%) and (22%) of yolk dry matter, respectively. Plasma is rich in low-density lipoproteins (85%) and livetins (15%), while granules are mainly composed of high-density lipoproteins (70%), phosvitin (16%) and low-density lipoproteins (12%). Another important egg component is lecithin; a surface-active molecules with HLB number of 2–8 (Wu 2014).

These components have the ability to be adsorbed at oil/water interface and stabilize the mayonnaise emulsion (McClements 2015). Accordingly, emulsifying properties of egg yolk is due to the granular micro-particles organized from coalesced low-density lipoprotein, the phosphor proteins, and hydrophobic interactions of these particles with the long chain triglycerides which all of them leads to oil droplets coating (Guilmineau and Kulozik 2007; Kiosseoglou and Sherman 1983a).

Mayonnaise prepared with different egg yolk concentration but with fixed egg white content has been studied for its quality parameters. Results indicated stability during long-term storage; complex viscosity and mean oil droplet diameter were affected by egg yolk level. Moreover, the long-term stability was affected not only by egg protein load but also by protein composition in the adsorbed layer at the emulsion interface. Accordingly, decrease in concentration of more surface active egg yolk proteins led to increased adsorption of egg white proteins at the interface layer (Ariizumi et al. 2017).

Bengoechea et al. (2009) studied the effect of the egg yolk concentration on the dynamic rheological parameters of mayonnaise processed in semi-continuous device. Their results showed that, the critical strain (γ_c), an index of mayonnaise extensibility, decreased with increasing the egg yolk content up to 4% w/w; whereas the plateau modulus G_N^0, an indicator of the intensity of the entangled network that develops between the adsorbed and non-adsorbed protein molecules, was directly influenced by the level of egg yolk. Moreover, these authors found that critical strain and plateau modulus were highly related to the mayonnaise sensory and organoleptic attributes.

In another study, decreasing in egg yolk granules content has been reported to decrease the mayonnaise stability resulting decrease in its phospholipids. However, from sensorial point of view, when egg yolk granules level in formulation surpassed its optimum concentration, decrease in flavor and odor acceptance was inevitable (Laca et al. 2010). As phospholipids are the major emulsifying agents in egg yolk, their modification would possibly enhance its properties by improving its interfacial characteristics of oil phase (Kim et al., 2009). One of the methods for egg yolk modifying could be using phospholipase A_2 enzyme which can hydrolyzes the ester bond at the sn-2 position of phospholipids. According to the study conducted by Kim et al. (2009), mayonnaise prepared with phospholipase A_2 hyrolysed egg yolk (6% w/w) has better stability and sensory quality than untreated ones. The authors explained that structural changes in LDL to increase its molecular flexibility will lead to its increased absorption ratio at interface and consequently the final products stability.

There are studies which investigate formulating mayonnaise with frozen or pasteurized egg yolk (Huang et al. 2016; Yang and Cotterill 1989). The point is that freezing or heating treatments are used to reduce the microbial spoilage and prolong the shelf-life of the egg yolks and mayonnaise. Freezing egg yolk in the presence of 10% w/w NaCl or sucrose solutions are the most common methods used. However, one of the defects may occur is its gelation which negatively influences the functional properties of the yolk including its emulsifying capacity. This problem is due to disruption of lipoproteins and protein aggregations initiated by ice crystal development as a result of high salt concentrations (Kim et al. 2009).

Huang et al. (2016) characterized the differences between mayonnaises containing fresh and frozen egg yolks. They reported that the frozen egg yolk decreased the products thermal stability. Also, the gelation transition temperature, an indicator of change from elastic to viscose structure, decreased due to denaturation and transformation of hydrophobic sites inside the egg yolk proteins. Moreover, consistency index (k), hardness and overall acceptability had been reported to be higher compared with control samples and the yield stress was not significantly affected in the presence of frozen egg yolk.

Primacella et al. (2019) studied the effects of freezing and partial enzymatic hydrolysis practices of egg yolk on mayonnaise quality. Accordingly, thixotropy level, yield stress, apparent viscosity, consistency coefficient (k) and flow index (n) were affected by type of frozen/hydrolyzed egg yolk. These authors found that peptides produced from the enzymatic hydrolysis of egg yolk or egg white proteins could be effective gelation preventers. They explained that, the interaction of peptides with the egg yolk proteins during freezing will provide a complex which increases the stability through thawing. Moreover, mayonnaise formulated with frozen-thawed yolk containing 5% hydrolyzed egg yolk protein was very similar in texture, particle size and stability to mayonnaise prepared with normal fresh yolk.

In an industrial scale, egg yolk salted solutions are pasteurized at temperatures between 60 to 68 °C for a few seconds to about 10 min. However, this treatment like previous mentioned matter (egg yolk freezing) has its positive and negative consequences on mayonnaise attributes (Wu 2014).

Guilmineau and Kulozik (2007) studied the effect of the egg yolk pasteurization condition on the mayonnaise rheological properties. According to their report, oil droplets size of mayonnaise are decreased continuously with increasing the pasteurization time up to 4 min; which led to a three-fold increase in consistency coefficient of mayonnaise. These authors explained another mechanism that probably was important. Accordingly, pasteurization treatment resulted in denaturation via thermal unfolding of egg yolk proteins especially LDL lipoproteins. The critical role of this protein in decreasing the interfacial tension of oil/water interfaces has been emphasized by some researchers (Kim et al. 2009; Motta-Romero et al. 2017). Using pasteurized egg yolk in formulation increased the thixotropy level which could be related to structural modification of denatured proteins.

Generally, complete or partial substitution of egg yolk with protein alternatives could have negative effects on some sensorial properties such as spreadability, mouth firmness, mouth coating and mayonnaise surface shine. The decreased shelf life in formulations provided by other protein sources is attributed to their increased pH (Herald et al. 2009). If the mayonnaise pH is near to the optimum isoelectric point of the egg yolk, their electric charge will be minimized and therewith resulted in strong texture formation with maximum stability. Typically, the maximum viscoelastic attributes is obtained at pH range of (3.5–3.9) (Kiosseoglou and Sherman 1983b).

Since egg yolk granules have lower cholesterol content compared to whole egg yolk, they could be used as a functional ingredient in the food industry. Low-cholesterol mayonnaises were produced by separating egg yolk granules from egg yolk plasma through subjecting whole egg to centrifugation at different NaCl diluted solutions (Laca et al. 2010; Motta-Romero et al. 2017). Their results showed that formulations with higher viscosity and emulsion stability have been achieved compared with those prepared with whole egg yolk. These authors explained that, one reason could be the disruption of the electrostatic repulsion forces between proteins due to higher ionic strength generated by salt; which led to better protein aggregation at the oil/water interface layer and so increased emulsion stability. According to Motta-Romero et al. (2017) report, in contrast to liquid egg yolk granules, the spray dried ones are better acted to improve the rheological properties of mayonnaise emulsions.

Texture modifiers

Generally, imitation of the sensory and texture of normal mayonnaise is hard in formulation of reduced fat or egg-free ones. There are some non-fat ingredients such as polysaccharides and proteins with various functionalities that have been utilized in preparing low fat or egg-free mayonnaise. Hydrocolloids can stabilize emulsions by two main mechanisms; first by coating the oil droplets as a thin film to prevent them from coalescence and second by increasing the viscosity of emulsion which decrease the motion of dispersed phase droplets (Dickinson 1987). However, the stabilizing mechanism of some charged hydrocolloids such as carboxy methyl cellulose can be more due to stearic charge-related stabilization than consolidation of continuous phase (Golchoobi et al. 2016). Polysaccharides thickeners could change the viscosity of mayonnaise like emulsions, at defined level of pH, concentration, ionic strength and temperature (Sikora et al. 2008).

Usually, replacing oil with a single polysaccharide or gum gives neither same rheological nor sensory quality as full fat type mayonnaise. In this regard, an optimization of two or three ingredient is recommended due to their potential synergistic interaction (Juszczak et al. 2003). The food industry employs these synergistic interactions with the aim of replacing the expensive ingredients by cheaper ones and/or improving the rheological or functional properties. In a study conducted by Nikzade et al. (2012), a significant drop in taste and flavor has been observed in formulation of low fat mayonnaise using single guar gum, despite its acceptable rheological properties.

Su et al. (2010) found that formulation of low fat mayonnaise (40% w/w oil) with combination of xanthan gum and guar gum or citrus fiber and guar gum at the optimum level, gives satisfactory results. They explained that changes observed in apparent viscosity are due to the generation of tridimensional structure between xanthan/guar gum and citrus fiber/guar gum. Their results showed that, most of the rheological and sensory attributes of developed product was as same as commercial control ones. Nevertheless, they observed differences in some other parameters like a_w and pH. Increase in a_w of low fat mayonnaise due to increase in water percentage of product is inevitable; so its effect on shelf life and other quality factors of mayonnaise should be evaluated (Keerthirathne et al. 2016). Usually the pH of formulations containing fat replacers would be higher than that of full fat ones due to the dilution of acetic or citric acid in the continuous phase. However, the effect of primary raw ingredients pH should also be considered. Also, hydrocolloid based texture modifiers should be stable at acidic pH of mayonnaise during storage time.

Anvari and joyner (2017) studied the effect of protein–polysaccharide interaction on structural and rheological characteristics of concentrate emulsions. According to their report when pH increased from 3.6 to 9.0, creaming defect occurred. The differences in creaming degree have been reported to be induced by variation in zeta potential of protein and polysaccharide at each pH. Accordingly, these differences will lead to different attractive or repulsive electrostatic interactions which finally determine stability of mayonnaise like emulsions.

Paredes et al. (1989) studied the effects of storage time on steady flow behavior of low fat mayonnaise (52% w/w oil) stabilized with xanthan gum. In their report they mentioned that the level of consistency coefficient (k) had been decrease after 24 h storage at 3 °C. As keeping at 20 °C is the minimum temperature required to dissolve this hydrocolloid, they suggested that mayonnaise storage between 18 and 30 °C is reasonable for proper solubilization of xanthan gum to provide a desired viscosity. Accordingly, from an industrial point of view, it seems that in formulation of low fat mayonnaise using hydrocolloids, considering an aging time before distribution of product is recommended.

Developing a low fat mayonnaise formulation with improved functional and nutritional properties will be a valuable plan. Some studies examined the addition of dietary fibers, natural antioxidants and food hydrocolloids to emulsions (Liu et al. 2019; Yang et al. 2019).

In the study conducted by Yang et al. (2019) they formulate a low fat mayonnaise (30% w/w oil) with sodium alginate and konjac glucomannan. Accordingly, glucomannan, a health promoting dietary fiber, due to its acetyl groups has good emulsifying properties. Also, Alginate is a hydrocolloid polymer of (1 → 4)-linked β-D-mannuronic acid and α-L-guluronic acid residues in multiple orders and forms firm gels when the Ca^{2+} is added. Their results showed that apparent viscosity, storage modulus, yield stress, thixotropy and stackability of formulated low fat mayonnaise was very similar to commercial full fat sample. The authors explained that both alginate and glucomannan solutions have good intermolecular associations when they existed alone. However, when these hydrocolloids were mixed together, due to critical overlap concentration (C*) concept, there were no intermolecular connections between them which indicated that self-association mechanism determined mentioned rheological results. However, in their report the sensory attributes of developed mayonnaise were not evaluated.

Generally, some polysaccharides (e.g., starch) in their native form have some impotence such as weak acidic condition tolerance, temperature intolerance and high shear sensitivity and so using chemically or physically modified forms of them is inevitable (Sikora et al. 2008). High fat mayonnaise (70% w/w oil) formulated with modified starch as stabilizer possessed the highest coordination number (**z**), means existence of high level of interaction, compared with additive-free mayonnaise samples. The authors mentioned that addition of starch in formulation was the determining factor (Laca et al. 2010).

Starch modified with octenyl succinic acid (OSA) has an amphiphilic attributes due to inherent hydrophilic property of native starch and hydrophobic feature of OSA. Actually, starch-OSA chain enters to oil in water interface and long amylopectin chains prevent the oil droplets coalescence. Consequently, (OSA)-modified starch can act as a bifunctional ingredient (Chivero et al. 2016).

In the Ghazaei et al. (2015) study, they formulated a low cholesterol and low fat (30% w/w oil) mayonnaise with set amount of xanthan gum and guar gum and by replacing egg yolk (from 25 to 100% w/w) with (OSA)-modified potato starch. Results indicated samples containing 100% w/w OSA-modified potato starch are poor in rheological and overall acceptability compared with control, despite their acceptable stability. The authors proposed that combination of 25% egg yolk and 75% (OSA)-modified potato starch give the best results.

Abdulmola et al. (1996) explained interactions between starch and other hydrocolloids in the terms of flocculation phenomenon. They proposed a bridging flocculation between swollen starch granules and xanthan gum polymer chains which possibly governed their improved rheological results.

An emerging strategy for designing more healthy, sustainable and lower cost food products is using egg or meat alternatives such as plant- based or dairy based protein ingredients (Herald et al. 2009; Liu et al. 2018). Rheological, microstructure and sensory properties of egg-free mayonnaise formulated containing 1% w/w modified gluten was compared with a full-fat type product. Small-amplitude test showed that oscillatory yield stress (storage and loss modulus cross over point) and storage modulus (G′) gradually increased with increasing the gluten concentration. Moreover, the droplets size and their distribution, thermal stability and sensory attributes of developed mayonnaise were similar to control sample (Liu et al. 2018). Based on the results of another report, gluten particles are highly surface active which enhance the strength of the links between the oil droplets by surrounding mechanism (Takeda et al. 2001).

Another reliable substitute for egg yolk could be milk whey proteins. Their suitability is due to their interfacial functions such as the ability to be simultaneously absorbed at water and oil phases, and delay coalescence of droplets. Accordingly, the emulsifying properties of whey proteins depend on their structure, temperature history, concentration, mayonnaise pH and ionic strength (McClements 2015).

Vingerhoeds et al. (2009) proposed that whey proteins surrounded oil droplets give a creamy, fatty, and thick mouth feel. In this way, microparticulated whey proteins (Simplesse™) have been introduced to market as they are similar in dimensions to oil droplets and can imitate most of their textural and sensory attributes. Moreover, depending on the experienced temperature, whey proteins could get influenced by partial or complete denaturation and extensive aggregation occurs through hydrophobic attraction and disulfide bond formation (Biller et al. 2018).

Emulsification capacity of a protein relies on extent of its diffusibility into droplets interface, adsorbability and degree of un-folding due to the influence of interfacial tension. Magnitude of hydrophilic and hydrophobic groups which are determined by amino acid sequences, pH, ionic strength and temperature, regulate the diffusibility (Sikora et al. 2008).

Finally, it is worthy to be considered that when food industry intends to choose an emulsifier both the processing condition and properties of raw ingredients should be considered. Thus, parameters like the minimum oil droplet size that can be achieved by a definite level of emulsifier, the minimum dose of emulsifier needed to obtain a desired droplet size and the storage stability produced by an emulsifier are measured (McClements 2015).

Salt and acidulant

Salt exclusive of its function as flavor improver, play four primary roles in mayonnaise structure (Martínez et al. 2007). Firstly, salt assists to the egg yolk granules dispersion. Secondly, salt helps to deactivate electric charge of proteins, which this effect results in increase in adsorption of these proteins at the surface of oil droplets. Thirdly, the neutralization of any charge allows adjacent oil droplets to interact more strongly. Finally, salt modifies the hydrophobic interactions between non polar amino acids with changing the structural arrangement of water molecules at interface layer. However, adding salt more than optimum level resulted in aggregation of egg yolk proteins in continuous phase of the emulsion instead of coating the oil droplets (Kiosseoglou and Sherman 1983b). Martínez et al. (2007) studied the effect of salt concentration on the quality of salad dressing-type emulsions. They found that increasing the salt content resulted in an increase in storage (G′) and loss modulus (G″) and gradually decrease in tan delta (G″/G′) which shows generation of more elastic structure in mayonnaise. However, salt addition has not significant effect on oil droplet size distribution. Another defect that may occur during storage time is water evaporation which can leads to an increased creaming. Increase in ionic strength of the water phase increased the electrostatic repulsion between oil droplets and thus the creaming is inevitable (Miyagawa et al. 2019).

Xiong et al. (2000) confirmed that the ratio of egg yolk to acidifying agent (e.g. acetic acid or citric acid) is the key factor which determines the pH of mayonnaise. Accordingly, the pH of fresh egg yolk is usually near 6.0, but progressively increases to 6.4–6.9 during storage, depending on the storage temperature and time. The pH of acetic acid (vinegar) is about 2.8. From a safety point of view, if acetic acid is in dissociated form it dissolves in oil phase and so it has no antimicrobial activity. Also, they found that with increasing oil content, the pH of mayonnaise increased especially when the oil phase volume fraction is (> 0.5). In the study conducted by Wang et al. (2020), authors found that by decreasing the pH of mayonnaise, its stability improved and creaming was not accrued. They mentioned that, one reason could be through increasing the oil droplets size with the pH enhancement.

Conclusion

Mayonnaise is a popular food dressing with high potential for research and development. Its ingredients have great effects on its emulsion structure. Oil related variables like droplets size and dispersed phase fraction are the most important factors which affects mayonnaise quality. Formulating mayonnaise with different types of hen's egg like whole egg, normal egg yolk, frozen egg yolk and pasteurized egg yolk could have vast distinct results on its quality. When we are aiming to choose one or more texture modifier for mayonnaise formulation development it would depends on our expectation and available resources. Each of hydrocolloids or proteins can affects mayonnaise emulsion with particular mechanism. Salt is an important factor because it affects the electric charge of mayonnaise particles. The pH of mayonnaise depends on its formulation and besides of safety concerns it has a significant role in mayonnaise emulsion stability. Finally, investigating the effects of other ingredients like mustard, vegetables and sugar on mayonnaise emulsion, can be suggested for later studies.

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