Effect of milk and xanthan as egg replacement on the physical properties of mayonnaise

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ABSTRACT. The milk along with xanthan at levels 0, 1.9, 3.9, 5.9, 7.9, 9.9 and 0.1 and 0.2 % (No 1 (control) to 11 respectively) as egg replacement were used for preparation of mayonnaise. Creaming index, heat stability, physical stability and rheological properties of samples over a were investigated. Also flow behavior of samples were fitted to Power law, Herschel- Bulkley and Casson models. It was found that addition milk along with xanthan to mayonnaise protected from phase separation in comparison to control sample. All the samples had stability higher than 99% except samples 1, 4, 5 and 6. The highest stability was recorded for sample No 11 (99.98%) and the lowest for 5 (74.95%) that compared with control sample had significant differences (p> 0.05). All the samples except No 1 and 5 showed heat stability higher than 99 % and the highest stability recorded for No 11 (99.72%) and the lowest for No 5 (67.42 %) and in comparison with control were significantly different (p> 0.05). Apparent viscosity decreased with increase the egg replacement from 40% to 80%, as the highest and lowest viscosity observed in samples contain 100% and 80% replacement respectively. All samples showed shear-thinning behavior and the high coefficients of determination for Power law and Herschel-Bulkley models (0.99) revealed the adequacy of these rheological models to describe flow behavior of mayonnaise.

1. INTRODUCTION

Mayonnaise is a typical oil in water emulsion prepared from vegetable oil, egg yolk, vinegar, sugar, salt, mustard and a variety of food additives (Juszczak et al. 2003). Among its ingredients, egg is most critical in term of stability of the mayonnaise. Egg is considered a high profile ingredient because of its high nutritional value and multifunctional properties, including emulsification, coagulation, foaming, and flavor product (Narsimhan and Wang 2008). Cholesterol is present in the egg yolk in quantities varying from 180 to 250 mg, depending on hen genotype (Stadelman and Cotterill, 1995). The desire to replace egg in food systems was brought about by a multitude of concerns from consumers, and processors desired to have low cholesterol and safe foods (Liu et al. 2007). So there have been done several studies on removing or decreasing egg in mayonnaise (Takeda et al. 2001; Rir et al. 1994).

The oil droplets in Mayonnaise usually stabilized by protein molecules that, either alone or together with other surface-active components (such as polysaccharides), form strong and cohesive interfacial films that may resist tensile or shearing stresses and protect the oil droplets from coalescence (Dickinson and Stainsby, 1982). Several studies have been reported on the role of proteins in the stabilization of emulsions (Joly, 1972; Srivastava, 1964). Emulsifiers act generally by one or more mechanisms, including reduction of the interfacial tension between oil and water phases, or covering fat globules with a charged layer to create a physical barrier preventing flocculation (Walstra, 1986). Stabilizers, mainly polysaccharides, usually stabilize emulsions by

increasing the viscosity of the aqueous phase. Milk whey proteins (MWP) are known to alter their adsorption behaviour at fluid interfaces responding to both different aqueous environmental conditions (Davis et al. 2004) and the presence of several food additives such as lipids and polysaccharides (Rodriguez Patino et al., 2008), sugars (Yang et al. 2009), electrolytes (Marinova et al. 2009), polypeptides (Martinez et al. 2009). Macromolecular interactions between milk whey protein and Xanthan both in solution and at the interface vicinity depended on the protein type and on the biopolymer relative concentration in aqueous subphase (Perez et al. 2009). The main interaction mechanism that would govern milk whey protein adsorption behaviour in MWP/XG mixed systems could be biopolymer interfacial segregation between the MWP and XG in the vicinity of the air–water interface (Perez et al. 2010). Polysaccharide–protein complexes are not only employed to stabilize simple oil-in-water emulsions but can be employed in more complex systems. The possible interactions between emulsion droplets and the other components of a food can be very complex. Several ingredients are generally present and give rise to final structures which are dependent on the overall composition, on the manner in which the ingredients are added and on the time/temperature variations to which they are submitted during manufacture. It is clear that the level of knowledge about such structures is still insufficient mainly because of the complexity of the interactions, reactions and products. The role of milk proteins in the unfrozen aqueous phase is recognized but is less well studied than their role at the fat interface. Proteins interact with water and polysaccharides and their hydration is responsible for a variety of functional properties, including rheological behaviour (Goff, 2002a and b).

Rheological properties of foods have an important role on the perception of taste or flavor. Smoothness, graininess, and viscosity can all influence perception. Extensive rheological studies have been carried out on mayonnaise, more so than on other salad dressings, because it is a more stable emulsion and it exhibits more complex viscoelastic rheological behavior (Rao, 1999) and also Some research was carried out on the rheological properties of emulsions stabilized with low-in-cholesterol egg products, but contradictory results were obtained (Paraskevopoulou et al. 1999; Guerrero and Ball, 1994).

In order to prepare low cholesterol mayonnaise, application of protein, such as whey protein isolate along with some thickeners has been reported. However, there is no published data on application of whole milk along with xanthan gum (XG) to replace egg yolk (EY) in mayonnaise formulation. Therefore, the present study was conducted to prepare mayonnaise by application a desirable combination of whole milk, XG, and lowering or removing (partially, totally) egg, with comparable properties those of the conventional mayonnaise, and investigating the rheological and physical properties of the product.

2. MAERIALS AND METHODS

Mayonnaise Preparation

Two egg replacers (xanthan gum and pasteurized, homogenized low fat milk mixture) were used in this study. According to the previous work, substitution of egg with milk and xanthan mixtures carried out and best formulation selected and done in this study. Substitution of egg with milk and xanthan mixtures from level of 0- 100% and 0-0.2% was selected respectively (Nikzade, 2012). Reduced egg mayonnaise samples (11 samples) were prepared according to the following procedure and by using ingredients written in Table 1. To prepare different mayonnaises, first powder ingredients (salt, sugar, xanthan, mustard, carboxymethyl cellulose, sorbate, benzoate) were mixed, vegetable oil was added slowly and for 5 min mixed. Vinegar gently was poured and mixed and the rest of oil was added slowly into the aqueous phase (Nikzade, 2012). Then this pre emulsion was homogenized with the stirrer operating. To compare different properties, 1 control samples (one industrial sample) were also prepared with the formulations shown in Table 1. Each formulation was prepared one time and each experiment was performed in 2 replicates. After preparation, the samples kept in refrigerator (4-5 ºC) until the analysis (Liu et al., 2007).

Table 1. Formulation of Mayonnaise prepared in this study

Ingredients (%)	Control (No 1)	No 2	No 3	No 4	No 5	No 6	No 7	No 8	No 9	No 10	No 11
Oil	66	66	66	66	66	66	66	66	66	66	66
Water	13.225	13.225	13.225	13.225	13.225	13.225	13.225	13.225	13.225	13.225	13.225
Vinegar	6	6	6	6	6	6	6	6	6	6	6
Egg	10	8	6	4	2	0	8	6	4	2	0
Milk	0	1.9	3.9	5.9	7.9	9.9	1.8	3.8	5.8	7.8	9.8
Xanthan	0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Sugar	3	3	3	3	3	3	3	3	3	3	3
Salt	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Mustard	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
CMC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Potassium sorbate and sodium benzoate	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75

3. PHYSICAL PROPERTIES OF MAYONNAISE SAMPLES

Creaming index

Immediately after preparation, 50 mL of each emulsion was poured into a cylindrical glass tube, sealed with a plastic cap and stored at 4 °C for 30 days. The emulsion index was measured by the change in height of the bottom serum phase (H) along storage time. The creaming index (CI) was determined according to Eq. (1) (Nikzade, 2012).

$$CL = (H/ H_0) \times 100$$

where H_0 represents the initial height of the emulsion.

Physical Stability

Physical Stability of Emulsion was determined in terms of amount of oil separated from an emulsion during centrifugation. 15 gr Samples of mayonnaise (F1) were centrifuged in 15-mL tubes at 5000 rpm for 30 min at room temperature to remove the top oil layer (Mun et al. 2009). The weight of precipitated fraction (F2) was measured, and the emulsion stability of mayonnaise was expressed as:

$$Physical\ stability\ \% \ (F2/F1) \times 100$$

Heat stability

For measurement heat stability, 15 gr of each sample transferred to test tubes and stored at 50 °C for 48 h. They were, then, centrifuged for 10 min at 3,000 rpm. Finally, heat stability was characterized according the below equation (Mun et al. 2009). F2 equal to the weight of precipitated fraction and F1, initial weight of sample.

$$Heat\ stability\ \% \ (F2/F1) \times 100$$

Rheological properties

The Apparent viscosity of the Mayonnaise samples determined at room temperature at Shear rate (60 s^{-1}) (Mohammadzadeh et al. 2013) with the aid of a Brookfield RDVD-II, viscometer (Brookfield Engineering Laboratories, USA) using spindle No 7 at different rpms (5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90, 100, 105,120,140, 150, 160, 180, 200). For each sample two readings were taken and their means were reported. 500 ml sample was placed in a 600 mL low form Griffin

beaker and a disc was inserted into the sample. To eliminate any time-dependent behavior, sample was subjected to pre-shearing until a constant torque was observed. Formal data collection of torque at various rotational speeds followed immediately (Steffe, 2006). Mitschka method (1982) tested with spindle No 7. Values of a_i (on the torque dial from units 0 -100) are converted to the (average) Shear stresses τ_i (in pa) on spindle used by

$$\tau_i = k_{at} \, a_i$$

Pairs of τ_i - Ni (rotational speed in rpm) valid for spindle are plotted in the log – log form. When this dependence is sufficiently close to a linear one, the fluid under test is of the power –law type. The slope of the log τ_i - log N dependence in this case is equal to the flow index of the fluid or n.

Using values of k_{ny} (n) for this flow index and spindle number, the corresponding values of the Shear rates y_i (in s^{-1}) are then calculated as

$$y_i = k_{ny}(n) \, N_i$$

The relevant pairs τ_i - y_i are assumed to be the points of the viscosity function of the fluid sample tested. Conversion factor for the method described by mitschka (1982) were used in this study.

To determine flow parameters, flow behavior of all samples were fitted to Power law (eq. 1), Herschel- Bulkley (eq. 2), Casson (eq. 3) models, respectively (Rezaei et al. 2011).

(eq. 1) $\tau = k \, k_y^{(n)}$

Where τ (Pa) is shear stress, k (Pa.s^n) is consistency coefficient, γ (1/s) is shear rate and n (−) is flow behavior index.

(eq. 2) $\tau = \tau_0 + k\gamma$

Where τ (Pa) is shear stress, τ_0 (Pa) is yield stress, k (Pa.s^n) is consistency coefficient, γ (1/s) is shear rate and n (−) is flow behavior index.

(eq. 3) $\tau^{0.5} = \tau_0^{0.5} + k\gamma^{0.5}$

Where τ (Pa) is shear stress, τ_0 (Pa) is yield stress, k (Pa$^{0.5}$.S$^{0.5}$) is consistency coefficient and γ (1/s) is shear rate.

Statistical analysis
The results in this study were evaluated by the completely randomised design using the software SPSS 16. The significant differences (P< 0.05) between the treatments were evaluated by the Duncan multiple range test procedure. All experimental determinations were assayed in triplicate.

4. RESULTS AND DISCUSSIONS

Physical properties
Creaming index
The compositional analysis of milk and Mayonnaise, pH and acidity of samples reported in previous study (Ghajari shamooshaki et al, 20015). In this study, addition of milk along with xanthan (as egg replacement) to mayonnaise protected from phase separation of the emulsions compared with control sample during storage period of 30 days. This is due to the sharp increase in viscosity which prevented the fluid from moving there by decreased creaming rate (McClements, 2004). But the creaming phenomenon was observed in sample contains 80% replacer after 30 d

period storage due to large particle size and low viscosity (Mangino,1994). Similar creaming behaviours of different concentrations of XG in mayonnaise were explained by Sun et al. (2007). Also Hennoc et al. (1984) reported that in emulsions contain 60% oil, the presence of xanthan for preventing the phase separation is essential.

Physical stability

Results of physical stability shown in Fig 1. During 90 d storage period, all the samples had stability higher than 99% except samples 1, 4, 5 and 6. The highest stability was recorded for sample No 11 (99.98%) and the lowest for 5 (74.95%) that compared with control sample had significant differences (p> 0.05). during 30, 60 and 90 d storage, stability of samples No 1, 4, 5 and 6 gradualy decreased and in comparison to control sample had significant differences (p> 0.05), but samples No 2, 3, 7, 8 ,9, 10 and 11 during 90 days storage showed stability higher than 99% and had not significant difference each other (p< 0.05) but compared with control sample significantly different (p>0.05). It might be due to the increased viscosity and lower particle size of these samples in comparison to others that led to slow down the droplet movement (Sathivel et al. 2005). The results of this study is agree with those reported by Abu Ghoush et al. (2008), Nikzade et al. (2010) and Mun et al (2009).
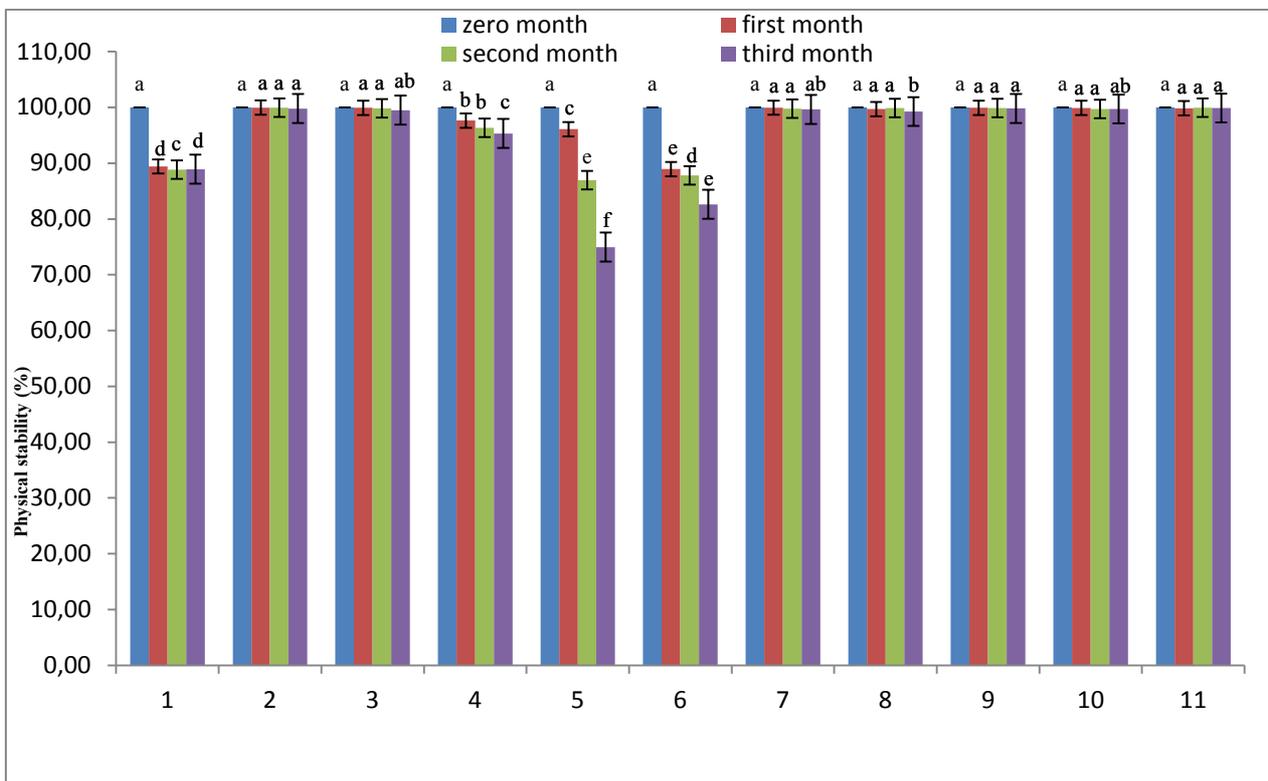

Fig 1. Changes in Physical stability, means in the same column indicated by similar letters were not significantly different (P>0.05). 1 = control sample.

Heat stability

In this study, all the samples except samples No 1 and 5 showed heat stability higher than 99 % during 30 d storage period. The highest stability recorded for sample No 11 (99.72%) and the lowest for No 5 (67.42 %) and in comparison with control were significantly different (p> 0.05), but after 60 and 6 d storage, decrease the heat stability observed in samples No 1, 5, 4 and 6, that significantly different (p> 0.05) compared with control sample. Rest of sample during 90 d storage had heat stability higher than 99% and had not significant differences compared with each other (p< 0.05). Our results were agree with those reported by Thompson and Reniers (1981) about application of whey protein as egg replacement in salad dressing. Results shown in Fig 2 and Table 2.
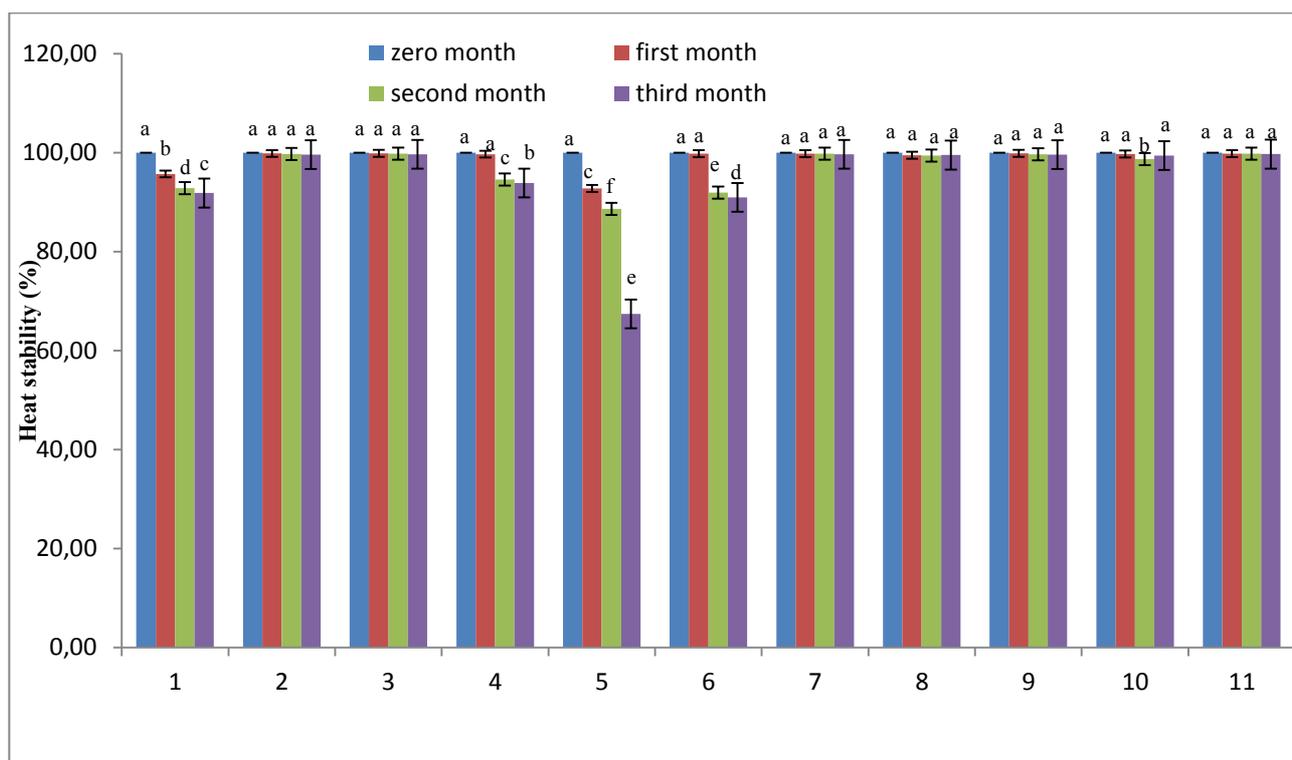
Fig 2. Changes in heat stability, means in the same column indicated by similar letters were not significantly different (P>0.05). 1 = control sample.

Table 2. Physical stability, heat stability and particle diameter size of different mayonnaise samples

Sample No	physical stability (after 90 d storage)	heat stability (after 90 d storage)	particle diameter size (µm)
(1) Control	88.91 ± 0.101^d	91.86 ± 0.162^c	3.268 ± 0.386^d
2	99.79 ± 0.015^a	99.62 ± 0.140^a	4.300 ± 0.658^c
3	99.51 ± 0.01^{ab}	99.70 ± 0.05^a	4.557 ± 0.930^{bc}
4	95.33 ± 493^c	93.90 ± 0.1^b	5.529 ± 0.085^b
5	74.95 ± 0.150^f	67.43 ± 0.404^e	7.983 ± 1.090^a
6	82.61 ± 506^e	90.99 ± 1.09^d	4.296 ± 0.639^c
7	99.62 ± 0.055^{ab}	99.70 ± 3.040^a	2.963 ± 0.097^d
8	99.26 ± 0.450^b	99.53 ± 0.222^a	3.049 ± 0.271^d
9	99.81 ± 0.01^a	99.63 ± 0.50^a	4.297 ± 0.178^c
10	99.70 ± 0.011^{ab}	99.44 ± 0.150^a	5.473 ± 0.433^b
11	99.88 ± 0.015^a	99.72 ± 3.047^a	2.697 ± 0.122^d

Means in the same column indicated by similar letters were not significantly different (P>0.05)

Rheological properties

After calculating the Shear rate, Shear stress and Apparent viscosity, established the related curves. The Apparent viscosity of mayonaise samples decreased with increase shear rate, indicating a non-Newtonian fluid and showed shear-thinning behavior that characterized by flow behavior index values of less than 1 (Table 3). In the other study, all investigated mayonnaise samples containing lupin protein and xanthan gum, showed a shear thinning behavior (Raymundoa et al. 2002).

In this study, Apparent viscosity of mayonnaise samples decreased with increasing the egg replacement from 40% to 80%, as the highest and lowest viscosity observed in samples contain 100% and 80% replacement respevtively. (Fig 3). Increase the shear rate and replacers percentage caused to decrease the apparent viscosity, but apparent viscosity of samples contain 20%, 40% and 100% egg replacement in compared with control were higher, also with increase the xanthan,

viscosity of all samples increased in comparison to control, but increase the replacers caused to decrease the viscosity of all samples except 100% replacement as the highest viscosity recorded for sample No (100% milk and 0.2 % xanthan gum). Flow rheogram of mayonnaise samples formulated by various amounts of milk, xanthan, and egg is presented in Fig 4. For all mayonnaise samples, relationship of shear stress and shear rate was nonlinear and they showed a shear thinning behavior (pseudoplastic fluids). In concentrated emulsions, the droplets are close enough together to interact with each other which may lead to the formation of a three-dimensional network of aggregated droplets and consequently to a higher viscosity. As the shear rate is increased, the hydrodynamic forces cause aggregates to become deformed and eventually disrupted which results in a reduction in the viscosity (McClements, 1999; Su et al, 2010).
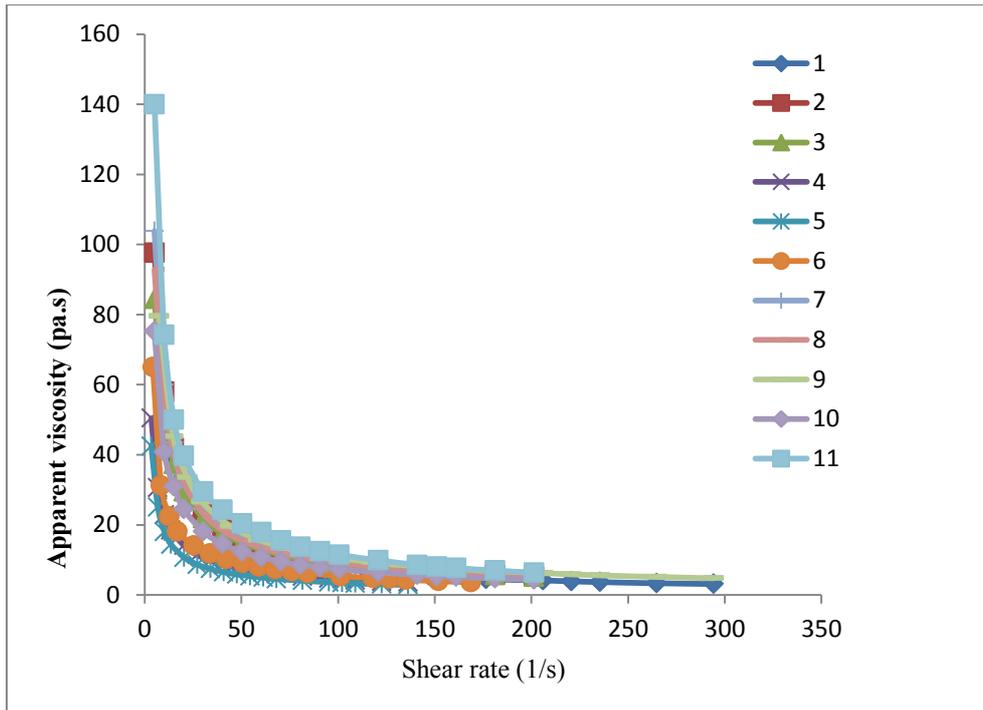
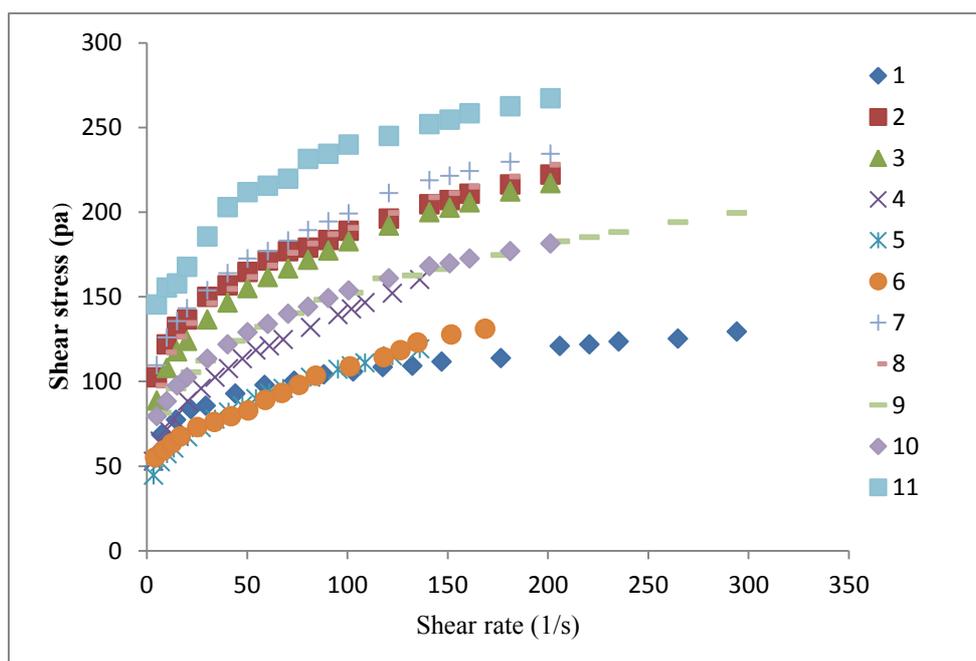Fig 3. Apparent viscosity versus Shrear rate for different mayonnaise samples.

Fig 4. Shear stress versus Shear rate for different mayonnaise samples

Due to the commercial importance of mayonnaise, the rheological characteristics of mayonnaise have been extensively studied. The flow properties (consistency index, *K; flow* behavior index, *n;* and yield stress, to) of mayonnaise have been studied by Paredes et al. (1998), Yilmazer et al. (1991), and Several rheological equations, such as the power law, the Casson model, and the Herschel-Bulkley model, have been used to describe the stress response to deformation in mayonnaise (Paredes et al. 1998). However, the reported flow parameters (K, n, and yield stress) are different from reference to reference due to differences in selected measuring ranges, corrections considered, and types of products.

In this study, the flow parameters obtained by fitting the data to Power law, Herschel-Bulkley and Casson models. High coefficients of determination for Power law and Herschel-Bulkley models (0.99) revealed the adequacy of these rheological models to describe flow behavior of mayonnaise samples. This is agree with those reported by Maruyama et al. 2007; Liu et al. (2007); Mun et al (2009) and Su et al (2010) about mayonnaise.

Table 3. The parameters for Power law and Herschel-Bulkley and Casson models in this study

parameters	Power law			Herschel-Bulkley				Casson		
Sample No	n	K (pa.s)	R^2	n	K (pa.s)	τ_{0} (pa)	R^2	K (pa.s)	τ_{0c}	R^2
1	0.168	48.83	0.9948	0.220	29.88	23.109	0.9955	0.189	68	0.9698
2	0.203	74.33	0.9972	0.253	49.42	31.152	0.9978	0.352	102.36	0.974
3	0.240	60.35	0.9991	0.271	47.54	16.88	0.9993	0.399	87.70	0.975
4	0.301	35.41	0.9980	0.367	22.94	17.91	0.9989	0.491	49.53	0.9844
5	0.285	28.99	0.9958	0.412	12.63	23.83	0.9995	0.409	39.94	0.9893
6	0.282	29.74	0.9631	0.692	24.19	48.91	0.9968	0.381	43.09	0.9962
7	0.213	75.15	0.9961	0.316	33.80	54.68	0.9987	0.377	104.48	0.9820
8	0.227	67.18	0.9979	0.293	40.45	35.35	0.9989	0.390	95.74	0.9791
9	0.246	48.97	0.9992	0.275	38.54	14.62	0.9994	0.322	78.79	0.9751
10	0.240	50.53	0.9976	0.319	27.89	31.04	0.9992	0.365	73.38	0.9804
11	0.185	100.82	0.9984	0.227	69.30	38.03	0.9889	0.357	135.42	0.9578

Power law parameters for samples: Consistency index, *K, of* samples with increase the replacing percentage upto 40% increased, but for upper contents except 100% replacing, decreased, as the highest Consistency index, *K* (100.82 pa.s) observed in sample contains 100% milk along with 0.2% xanthan, and the lowest (28.99 pa.s) recorded for sample contains 80% replacement along with 0.1% xanthan. These results were not similar with those reported by Rahmati et al. (2012) about soya milk as egg replacement in mayonnaise. Also the highest shear thickening property observed for control and 100% milk replacement along with 0.2% xanthan. Also for all samples, *flow* behavior index, *n*, recorded less than 1, and showed shear-thinning behavior.

Herschel-Bulkley parameters for samples: The lighest yield stress observed in samples contain 20% replacement (54.68 and 31.15 pa) and then 100% replacement (48.91 and 38.03 pa). Consistency index, *K,* of samples with increase the replacing percentage upto 40% increased, but for upper contents except 100% replacement, decreased, as the highest Consistency index, *K* (69.30 pa.s) observed in sample contains 100% milk along with 0.2% xanthan, and the lowest (12.63 pa.s) recorded for sample contains 80% replacement along with 0.1% xanthan. Results of this study were not similar with those reported by Rahmati et al. (2012) about soya milk as egg replacement in mayonnaise (icrease the soya milk in mayonnaise caused decrease the *K*)

Casson parameters for samples: This model had low Cooridnation for charactirize the rheological behavior of mayonnaise in comparison to two previous model. As a result, in spite of high R2 (0.95–0.98), Casson model was found to be an inappropriate rheological model

In the other study, all investigated mayonnaise samples containing lupin protein and xanthan gum, showed a shear thinning behavior (Raymundoa et al. 2002). The Power law model and Herschel-Bulkley were able to properly explain flow characteristics of mayonnaise samples. From this point of view, it can be concluded that milk with xanthan gum, not only maintained the structure of mayonnaise, but had a greater effect on the viscosity and flow parameters of mayonnaise samples compared to egg.

5. CONCLUSION

It was found that Flow behavior index values of different mayonnaise samples were determined less than 1, which indicates the samples are shear thining. Rheological characteristics of all samples were shear thinning and the apparent viscosity of them decreased with increasing shear rate. The flow parameters fitted to Power law, Herschel-Bulkley and Casson models showed that High coefficients of determination recieved for Power law and Herschel-Bulkley models (0.99), and revealed the adequacy of these rheological models to describe flow behavior of mayonnaise samples.

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