International Food Research Journal 20(4): 2009-2016 (2013)
Journal homepage: *http://www.ifrj.upm.edu.my*

Steady state and time dependent rheological behaviour of mayonnaise (egg and eggless)

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Article history

Received: 12 January 2012
Received in revised form:
8 March 2013
Accepted: 11 March 2013

Keywords

Mayonnaise
Egg
Rheology
Texture
Time dependent

Abstract

Time dependent and steady state flow properties of two different branded (Cremica and Funfoods) commercial mayonnaise samples of different formulation (egg and eggless) were tested using concentric cylinder rheometer. Mayonnaise samples were characterized as a shear thinning (Pseudoplastic) liquid with yield stress and demonstrated thixotropic properties also. All the samples irrespective of testing conditions (temperature and shear rates) confirmed time dependent shear thinning behaviour. Steady state rheological data of all the samples was well described by Hurshel Bulkley model ($R^2 \geq 0.967$, SE = 0.106). Hahn model was found to be the most appropriate model to describe time dependent rheology of mayonnaise. Adequacy of fitting of Hahn model was explained in terms of standards error (SE) and coefficient of determination (R^2) root mean square error values.

Introduction

Mayonnaise, one of the oldest and most used sauces worldwide and normally used as a sandwich spread is a mixture of oil, egg, vinegar and spices. Mayonnaise is a stable oil-in-water emulsion formed from the vegetable oil (not less than 65%) and egg yolks and is generally flavoured with mustard, salt, pepper, vinegar, and/or lemon juice (McClements and Demmetriades, 1998; McClements, 1999). According to Codex Alimentarius Commission (2000) specifications mayonnaise must contain at least 78.5% total fat and 6% pure egg yolk. Egg yolk is often used in mayonnaise as an emulsifier because it imparts desirable flavor, mouthfeel, and color (Baldwin, 1990; Mine, 1998). The emulsifying capacity of egg yolk is mainly due to presence of phospholipids, high density- and low density-lipoproteins (HDL and LDL). Non-associated proteins (livetin and phosvitin) along with LDL being the most important contributor to these emulsifying properties (Anton *et al*., 2000). The good emulsifying properties of egg yolk lipoproteins are attributed to their highly flexible structures, allowing great affinity and adsorption at oil–water interfaces. Vinegar, salt, sugar and mustard are added to mayonnaise as flavoring ingredients, but all of these ingredients also seem to play an important role for the physical stability of emulsions (McClements and Decker, 2000). Due to large number of vegetarian consumers in Indian market, eggless mayonnaise has become also a popular product in Indian food industry.

Understanding of rheological behaviours of food is useful to control quality, process conditions, textural properties and to design equipments such as pumps, pipelines, extruders, mixers, heat exchangers etc (Steffe, 1992). The perceived quality of food is greatly determined by product rheology and texture. For understanding rheological characteristics of foods, time dependent rheological parameters are also essential along with steady state rheological study, as foods exhibit shear thinning, viscoelastic and thixotropic character (Chan *et al*., 1994; Ravi and Bhattacharya, 2006; Basu *et al*., 2007).

The rheology of mayonnaise was investigated by several authors because of its importance for the choice of formulation, process conditions and quality control (Campanella and Peleg, 1987; Munoz and Sherman, 1990; Gallegos *et al*., 1992; Ma and Barbosa Canovas, 1995). Mayonnaise shows pseudoplastic behaviour with yield stress and time dependent characteristics (Peressini *et al*., 1998; Batista *et al*., 2006; Izidoro *et al*., 2007). For the steady shear measurement the power law, Herschel Bulkley, Carreau and Cason models have been widely used to describe the flow properties of mayonnaise (Peressini *et al*., 1998; Batista *et al*., 2006; Guilmineau and Kulozik, 2007). Transient rheological properties of

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mayonnaise were also studied by several researchers (Tiu and Boger, 1974; Figoni and Shoemaker, 1983; Chan Man Fong *et al.*, 1994; Goshhawk *et al*., 1998). Some researchers also focussed on rheological profile of low fat mayonnaise (Pons *et al*., 1994; Liu *et al.*, 2007). But no research work is reported on comparison of textural and rheological properties of egg-and eggless-mayonnaise samples.

Tiu and Boger (1974) found pseudoplastic behavior, and time-dependent characteristics of mayonnaise with a certain proximate value of yield stress. They used a modified Hercshel Bulkley model containing a structural parameter to account for time dependent effects under constant shear rate. Figoni and Shoemaker (1983) investigated the time dependent flow properties of a commercial mayonnaise at constant shear rates and proposed a thixotropic model for description of the rheological data. According to their model, the rate and amount of structural breakdown incurred by the shearing process at faster shear rates appeared large relative to the breakdown incurred by shear history and pretreatment. Chan Mon Fong *et al.* (1994) also developed a rheological model for structured fluids like mayonnaise based on kinetic description of structural density which can describe shear thinning, shear thickening, thixotropic and rheopectic behavior with one set of parameters.

The objective of this present study was to determine and compare the textural and rheological properties of egg and eggless mayonnaise of two commercial brands (Funfoods and Cremica). Both steady state and time dependent rheological studies were carried out for mayonnaise samples and experimental data were fitted with different rheological models. In mayonnaise egg acts as an emulsifier and some thickeners (starch/xanthan gum) are added in low concentration to stabilize the emulsion. But in cases of eggless mayonnaise, instead of using eggyolk concentration of xanthan gum and modified starch are added in high concentration to give the desired viscosity of the product. This paper aims to identify the differences in textural and rheological characteristics of egg and eggless mayonnaise in commercial products due to this compositional differences. Steady state (Herschel Bulkley) and time dependent (Weltman, Hahn, Figoni and Shoemaker, Structural Breakdown) models were tested for validation of rheological data.

Material and Methods

Mayonnaise samples

Four different commercially available and popular mayonnaise samples (Brand: Funfoods and Cremica, Variety: egg and eggless) of two manufacturers were procured from the local market. Fun Foods mayonnaise bottles had a net weight of 300 gm while Cremica mayonnaise bottles net weight was 220 gm. All the sample bottles were kept in refrigerator during the study. Before doing the rheological and textural experiments the samples were taken out from the refrigerator 3 h prior to the experiments for attainment of room temperature and subsequently experiments were carried out.

Chemicals

Sodium carbonate, Folin and Ciocateu's phenol reagent and petroleum ether were procured from Loba Chemie, Mumbai. Sodium hydroxide pellets was purchased from Central Drug House (CDH), New Delhi. Sodium potassium tartarate and copper sulphate were purchased from Qualigens Fine Chemicals, Mumbai. Bovine serum albumin (pH = 6-7) was supplied by Sisco Research Lab, Mumbai.

Moisture content

Moisture content of each sample was determined gravimetrically in triplicate by drying in a hot air oven at 105^{o}C for 24 h and expressed on a dry matter basis (AOAC 1990).

Fat estimation

Fat extraction was carried out using petroleum ether as solvent in a soxhlet extraction apparatus. After extraction ether was evaporated and the residue was weighed. Residual weight indicated crude fat content present in food.

Protein estimation

Estimation of protein content of the mayonnaise samples was done according to Lowry method (1951). Three solutions (A, B and C) were prepared initially for carrying out the protein estimation. Solution A (2% sodium carbonate solution dissolved in 0.1N NaOH (w/v)); solution B (1% hydrated copper sulphate in distilled water (w/v)); solution C (Rochelle's salt: 2% sodium potassium tartarate in distilled water (w/v)). Working solution was prepared by mixing of 1 ml of solution B, 1 ml of solution C and 98 ml of solution A. Freshly prepared Folin's reagent was diluted with equal volumes of distilled water. Protein solution (0.5 ml) was mixed with 5 ml of working solution. The mixed solution was incubated at 37^{o}C for 10 mins. Then 0.5 ml of Folin reagent was added and mixed. The solution was incubated again at 37^{o}C for 30 mins. Bovine serum albumin (1 mg/ml) was dissolved in distilled water and was used as standard solution at selected concentration. The absorbance (at 680 nm) of bovine serum albumin at selected concentration levels were used to make the standard curve with water as a blank sample. Then absorbance of samples at 680 nm was measured and their concentration was found from the standard curve. For measurement of absorbance of samples UV-Vis spectrophotometer (UVPC 2401, Shimadzu, Singapore) was used.

Rheological measurements

Rheological properties of egg and eggless mayonnaise were measured using a rheometer (Model MC1, Paar Physica, Germany). Yield stress of the mayonnaise samples was measured in duplicate by the direct yield measurement program of the MC1 Paar Physica rheometer. Ramp logarithmic profile was used with the shear stress as the set variable, which was chosen between 1 to 100 Pa for mayonnaise samples respectively. The measurement duration was 263 s, where the initial interval of data recording was 30 s, which logarithmically decreased to 1 s. These experiments permitted the measurement of yield stress as the point when the shear stress-shear rate curve started showing departure of shear rate from zero. This condition indicated initiation of flow and the corresponding shear stress was considered as the yield stress.

The mayonnaise sample (approximately 3 mL) was placed in a concentric cylinder arrangement (Z4 probe with cup radius = 7.59 mm, bob radius = 7.0 mm, angle of measuring bob cone, α =120°). Temperature control system (TEZ-180/MC1) was used to maintain constant temperature of the sample during the measurement. A controlled temperature bath (±0.1°C) fitted with the circulation pump circulated water through the jacket surrounding the rotor and cup assembly to maintain the desired temperature. Sample was allowed to rest for 5 min for temperature equilibration after it was loaded in the sample cell. This time was found to be sufficient to achieve a maximum temperature variation of ± 0.5°C between the specified- and sample- temperature in each run. All the tests were replicated thrice and average values were used in analysis.

Steady state rheological behavior of mayonnaise was studied at 20, 30, and 40°C. Shear rate was increased linearly from 0.1 to 200 s^{-1}. Steady state relationship between shear stress-shear rate of food materials is expressed in terms of Herschel Bulkey model (equation 1).

$$\tau = \tau_o + K\dot{\gamma}^n \qquad (1)$$

where, τ is shear stress (Pa), τ_o is yield stress (Pa), $\dot{\gamma}$ is shear rate (s^{-1}), K is consistency index ($Pa.s^n$), and n is flow behavior index (dimensionless) signifying the extent of deviation from Newtonian behavior.

Time dependent rheology

Time dependent rheology was studied by subjecting the samples to constant shear rates (10, 30, and 50 s^{-1}). All the experiments were done 5 min after loading of the sample for temperature equilibration. Time dependent rheological properties (shear stress and apparent viscosity) of the samples were measured in triplicate at selected temperatures (20, 30, and 40°C). Equilibrium shear stress values were experimentally determined and then used in time dependent rheological modeling and computation of model parameters. Samples were sheared at a particular shear rate and temperature for 3 h and the corresponding shear stress and apparent viscosity values were considered as the equilibrium shear stress (τ_e) and viscosity values at a given shear rate and temperature.

Time dependent shear stress decay characteristics have been mathematically described by several researchers (Weltman, 1943; Hahn *et al.*, 1959; Figoni and Shoemaker, 1983; Nguyen *et al.*, 1998). To quantify time dependency of mayonnaise at selected shear rates and temperatures, shear stress and time of shearing data were fitted to the Weltman, Hahn, Figoni and Shoemaker, and structural kinetic models.

Weltman model

Weltman model (1943) is expressed as given in Equation 2:

$$\tau = A - B\ln t \qquad (2)$$

where, τ is shear stress (Pa) at any given time of shearing (*t*). The parameter *A* represents the initial stress while *B* is time coefficient of structure breakdown.

Hahn model

Hahn *et al.* (1959) argued on theoretical basis that stress decay of thixotropic substances should follow the first-order type relationship which could be mathematically expressed as Equation 3:

$$\log(\tau - \tau_e) = P - at \qquad (3)$$

where, τ_e is the equilibrium shear stress value which is reached after a long shearing time; *P* represents initial shear stress (Pa), and α indicates rate of structural breakdown for the sample (s^{-1}).

Figoni and Shoemaker model

Figoni and Shoemaker (1983) suggested the thixotropic model based on their work on transient rheology of mayonnaise as given by Equation 4:

$$\tau = \tau_e + (\tau_{\max} - \tau_e)\exp(-kt) \qquad (4)$$

where, τ_{max} is initial shear stress; (τ_{max}-τ_e) represents the quantity of breakdown structure for shearing, and k is a kinetic constant of structural breakdown (s^{-1}).

Structural kinetic model

This model postulates that the change in the rheological properties is associated with shear-induced breakdown of the internal fluid structure in the food (Abu Jdayil, 2003). When a system undergoes structural changes it is responding to the applied force instantaneously; nevertheless, time dependent behaviour is observed because the structural changes are continuously occurring. With this continous change in structure comes a continuous change in the amount of stress the structure can withstand and in its resistance to flow. Hence time dependent characteristics of the material are observed. The model can be expressed mathematically as given in Equation 5:

$$\left(\frac{\tau_o - \tau_\infty}{\tau - \tau_\infty}\right) - 1 = kt \qquad (5)$$

where, τ_o is initial apparent shear stress at $t = 0$ (structured state), τ_∞ is the final or equilibrium apparent viscosity at $t \rightarrow \infty$ (equilibrium structured state); and k is structural breakdown parameter. Both τ_o and τ_∞ are functions of the applied shear rate only. Equation 6 allows a simple way for testing the validity of the model and determination of the model parameter k (Abu-Jdayil 2003).

Both steady state and time dependent rheological studies were carried out at selected temperatures and experimental data was fitted with different rheological models. Investigation of the temperature dependence of these model parameters was conducted and validation of the rheological model was presented. The values of statistical parameters coefficient of determination (R^2), standard error (SE), and root mean square error (RMSE) were obtained to evaluate the accuracy of fit to the experimental results in different mathematical models, steady state (Herschel-Bulkley) and time dependent (Weltman, Hahn, Figoni and Shoemaker, Structural Breakdown).

Textural measurement

The textural properties of mayonnaise samples were measured using Texture Analyzer, TA.XT. Plus (Stable Microsystems, U.K.) with respect to spreadability parameters only, because mayonnaise is spread on bread. Spreadability parameters included hardness, stickiness, work of shear, and work of adhesion values, according to following definitions:

Spreadability is the ease with which a product can be spread. It is a desired characteristic of margarine, mayonnaise, butter, jam, chocolate spreads, etc. Hardness (N) is defined as the maximum force on a product that displays substantial resistance to deformation. Stickiness (N) is defined as the maximum force necessary to overcome the attractive forces between the surface of the food and the surface of the probe with which the food comes in contact. It is a textural property possessed by confectionery or gelled products like cheese, jam, and adhesives. Work of shear (g.s) is the total amount of force required to carry out the shearing process. It is a measure of ease of spreadability. Work of adhesion (g.s) is the total amount of the force involved in the withdrawal of probe from the sample.

Spreadability was measured using spreadability probe (perspex conical) with 45° angle at room temperature (25 ± 2°C). The spreadability fixture was a set of precisely matched male and female perspex 90° cones. The sample holder (female cone) was fixed on a heavy-duty platform on the baseholder of the instrument. Force calibration of the instrument was done prior to start of the experiment to minimize measurement error. The height calibration was then done with return distance of 30 mm, return force of 20 g and return speed of 20 mm/s. The male cone probe moved down so that it fitted into the female cone sample holder. The instrument was operated at test speed = 3 mm/s, post test speed = 10 mm/s, distance = 30 mm, trigger type button with a 5 kg load cell. The spreadability fixture had female cone sample holder that was filled before testing and locked into the base holder, precisely centered under the matching upper male cone probe. The mayonnaise sample was filled into the lower female cone with a spatula. The material was pressed to eliminate air pockets that were visible through the transparent perspex cones, and the surface was leveled with a flat knife. The textural data (force vs. time) was analyzed by the instrument software (TEE 32) and parameters (hardness, stickiness, work of shear, and work of adhesion) were recorded. The tests were performed in triplicate and the average values were used.

Statistical analysis

A statistical program (STATISTICA version 5.0, StatSoft, Inc. Tulsa, USA) was used to perform non-linear regression on the rheological data (shear stress-time or apparent viscosity-time data).

Results and Discussion

Proximate composition

The proximate analysis of the mayonnaise samples is summarised in Table 1. It has been found that fat content is higher in egg mayonnaise samples of both brands (Funfoods and Cremica) whereas protein content was approximately same for both egg and eggless sample for a particular brand. Moisture content of egg samples of both brands were lower compared to eggless samples.

Texture analysis

Spreadability parameters of the egg and eggless mayonnaise samples are reported in Table 2. The stickiness and work of adhesion values of eggless samples (both Funfoods and Cremica) were greater than those of the egg sample. Also, the firmness and work of shear values of egg mayonnaise samples were more than that of eggless mayonnaise samples of both the brands. The increased textural firmness and stickiness is due to higher oil or fat content in the egg mayonnaise samples. Higher fat content in the egg mayonnaise samples promote the flocculation of adjacent oil droplets to form a weak gel network. The strength of the interactions between oil droplets depends on the van der Waals attractions, which are balanced to some extent by electrostatic and steric repulsion (Depree and Savage, 2001). But the egg yolk components combines to form a membrane around the lipid droplets in which egg yolk proteins enter into hydrophobic interactions with long chain saturated triglycerides derived from the oil phase (Kiosseoglou and Sherman, 1983). Thus a gel network was formed which increased the firmeness and stickiness values of the egg mayonnaise samples. But in case of eggless mayonnaise samples stronger gel network results from the prominent hydrogen bonding network of starch/xanthan gum present as thickening agent in the samples. Presence of high amount of thickening agents leads to increased firmness and stickiness values in eggless mayonnaise compared to egg mayonnaise. Both Cremica and Funfoods eggless mayonnaise samples showed higher firmness and stickiness characteristics compared to egg mayonnaise samples of the same brand.

Steady rate rheology

Shear stress vs. Shear rate curves depicted the non-Newtonian pseudoplastic character of commercial mayonnaise samples and showed higher shear stress with increasing shear rates for all mayonnaise samples (Figure 1). The shear stress values of eggless samples of both the brands were greater than the egg samples at a particular shear rate. It was found that rheological data of all mayonnaise samples was well described by the Herschel-Bulkley model ($R^2 \geq 0.967$, $SE \leq 0.106$). Figure 2 depicts the fitting of Herschel Bulkley model for Funfoods egg mayonnaise samples at selected temperatures.

Table 1. Proximate composition of mayonnaise samples

Samples	Moisture Content (%)	Proteins (%)	Fat (%)	Ash (%)
Eggless I	49.587	1.533	47.1	1.780
Egg I	9.194	1.519	88.8	0.487
Eggless II	45.934	1.099	51.8	1.167
Egg II	20.315	1.102	77.8	0.783

I is Cremica ; II is Funfoods

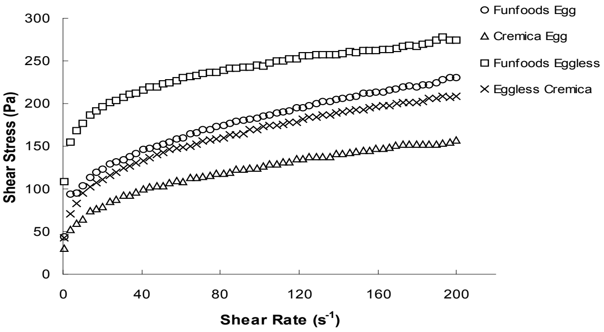

Figure 1. Steady state rheogram for four different mayonnaise samples at 30°C

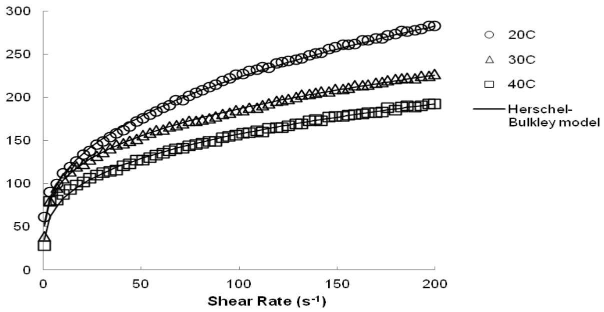

Figure 2. Herschel Bulkley model fitting of Funfoods egg mayonnaise at selected temperatures

Herschel-Bulkley model parameters (τ_o, K, n) and statistical parameters (coefficient of determination and standard error) of mayonnaise samples of two commercial brands are summarized in Table 3. The consistency index values for mayonnaise samples decreased with increasing temperatures, while variation of flow behaviour index with temperature was not systematic (Table 3). The flow behavior index of all mayonnaise samples was less than 1 which indicated they were shear-thinning and pseudo plastic.

Time dependent rheology

Typical time dependent rheograms of mayonnaise samples revealed thixotropic behavior indicating continuous breakdown or rearrangement of structure with time of shearing (Figure 3). It can be seen from Figure 3 that shear stress values for eggless

Table 3. Herschel-Bulkley model parameters for egg and eggless mayonnaise samples (Funfoods and Cremica) at selected temperatures

Temperature (°C)	Parameters	Eggless I	Egg I	Eggless II	Egg II
20	τ_o	12.85	12.8	24.25	14.9
	K	52.11	35.165	113.28	46.26
	n	0.29	0.324	0.167	0.314
	R^2	0.999	0.998	0.995	0.989
	SE	0.009	0.106	0.013	0.037
30	τ_o	14.9	14.9	24.25	20.4
	K	37.59	25.97	102.56	38.99
	n	0.310	0.252	0.168	0.315
	R^2	0.999	0.993	0.997	0.985
	SE	0.011	0.032	0.0109	0.044
40	τ_o	10.8	14.9	28.1	10.8
	K	30.86	25.27	76.58	33.42
	n	0.328	0.317	0.2	0.321
	R^2	0.999	0.997	0.988	0.967
	SE	0.106	0.017	0.025	0.067

I is Cremica and II is Funfoods

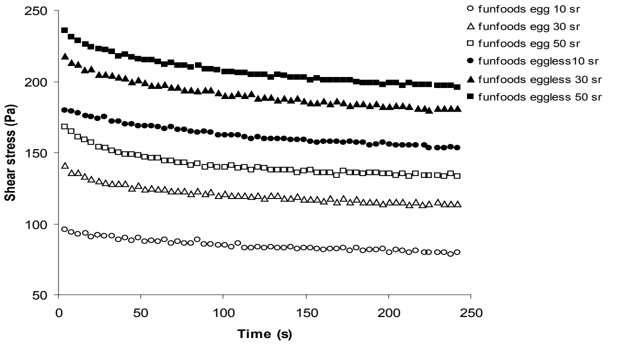

Figure 3. Rheograms of mayonnaise samples (Egg Funfoods & Eggless Funfoods) at 30°C at selected shear rates

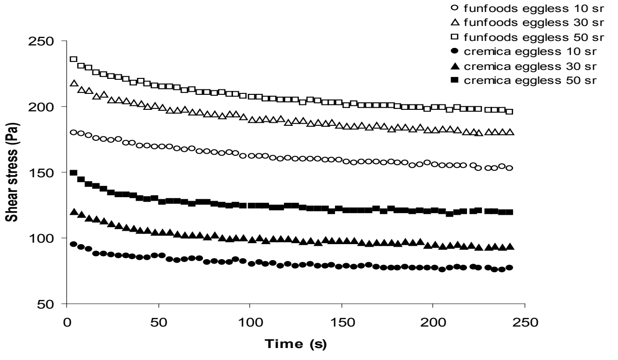

Figure 4. Rheograms for eggless mayonnaise samples (Funfoods and Cremica) at 30°C at selected shear rates

mayonnaise (Funfoods) samples exceeded the corresponding shear stress values of egg mayonnaise (Funfoods) samples at a selected shear rate. Similar feature was observed for Cremica mayonnaise samples also (Figure not shown). It may be due to presence of good amount of thickening agents like xanthan gum/starch used for manufacturing eggless mayonnaise.

Figure 4 represents shear stress-time data for eggless mayonnaise (Cremica and Funfoods) samples at 30°C. It was observed that shear stress values for Funfoods eggless mayonnaise samples were higher than Cremica eggless mayonnaise samples at a particular shear rate. Shear stress decreased rapidly with time of shearing in the beginning (up to 50 s) followed by slower rate of decrease later on, and finally approaching a constant value corresponding to the equilibrium state. In the initial phase of shearing (up to about 50 s), shear-stress was sensitive to the time of shearing, and decreased rapidly. Later, this stress decay became slower, until a fairly constant shear-stress value was approached. Equilibrium shear stress (τ_e) values for mayonnaise samples were found to be dependent on the shear rate employed for measurements, but independent of composition (egg or eggless) and temperature. Since τ_e values were found to be very close (within ±5%) for all samples at a specific shear rate, the average value was therefore considered for calculation.

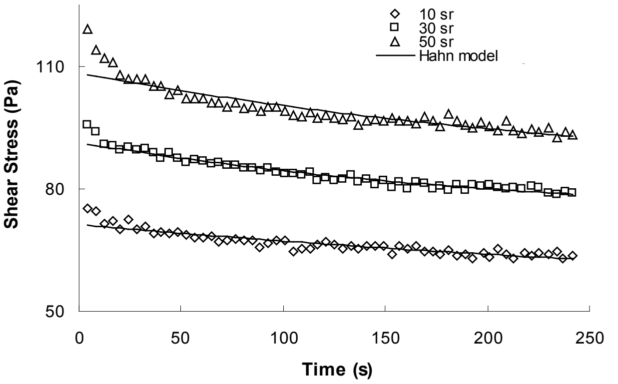

Figure 5. Hahn model fitting for Cremica egg mayonnaise at 30°C at selected shear rates

Linear regression of Equations 2, 3, 4, and 5 was carried out to evaluate time dependent rheological behavior. The model coefficients and statistical parameters are reported in Table 4 for mayonnaise samples at selected temperatures. The coefficients of Weltman, Hahn, Figoni and Shoemaker, and Structural Kinetic models varied with both shear rate and temperature. Parameters α (Weltman model), *P* (Hahn model), and (τ_{max} - τ_e) (Figoni and Shoemaker model) represent the shear stress needed to initiate the structure breakdown during shearing process. Obviously, shear stress needed to initiate deformation should increase with the rate of shearing but variation of parameters with temperature was not systematic. It was found that coefficient of determination (R^2) was closer in all the models tested. The coefficient of determination for Hahn model varied between (0.81-0.98) for both egg and eggless mayonnaise samples (Cremica and Funfoods). But Hahn model (Equation 4) was found to give a better fit of the experimental data for mayonnaise samples on the basis of lower Standard Error (S.E., range 0.0012-0.05) and Root Mean Square Error (R.M.S.E., ≤ 0.014) values.

Figure 5 shows Hahn model fitting of the

Table 4. Time dependent rheological models parameters for mayonnaise (eggless funfoods) samples at selected temperatures at shear rate = 10s^{-1}

Model	Temperature (°C)	Model parameters			
Weltman		**A**	**B**	**R^2**	**S.E.**
	20	5.166	0.0005	0.82	0.131
	30	5.165	0.0006	0.92	0.413
	40	5.051	0.0007	0.88	0.191
Hahn		**P**	***a***	**R^2**	**S.E.**
	20	1.704	0.0008	0.86	0.024
	30	1.688	0.0012	0.95	0.020
	40	1.52	0.0023	0.94	0.05
Figoni & Shoemaker		τ_{max}-τ_e	*K*	**R^2**	**S.E.**
	20	50.54	0.0019	0.89	0.461
	30	50.85	0.0026	0.95	0.245
	40	33.15	0.0052	0.94	0.116
Structural Kinetic		**K**		**R^2**	**S.E.**
	20	0.003		0.83	0.178
	30	0.004		0.98	0.544
	40	0.014		0.94	0.235

Table 5. Hahn models parameters for mayonnaise (Cremica and Funfoods Eggless / Egg) samples at selected temperatures at 30°C

Sample	Shear Rate (s^{-1})	Model parameters			
Eggless I		**P**	***a***	**R^2**	**S.E.**
	10	1.420	0.0013	0.89	0.032
	30	1.584	0.0013	0.89	0.031
	50	1.641	0.0009	0.87	0.024
Eggless II		**P**	***a***	**R^2**	**S.E.**
	10	1.688	0.0012	0.95	0.020
	30	1.779	0.0012	0.95	0.021
	50	1.784	0.0013	0.94	0.022
Egg I		**P**	***a***	**R^2**	**S.E.**
	10	1.303	0.0009	0.85	0.029
	30	1.356	0.0011	0.92	0.031
	50	1.438	0.0014	0.87	0.041
Egg II		**P**	***a***	**R^2**	**S.E.**
	10	1.548	0.0008	0.92	0.017
	30	1.705	0.008	0.90	0.204
	50	1.809	0.008	0.84	0.025

rheological data for the Cremica egg mayonnaise samples. The figure revealed a good agreement between the predicted and experimental shear stress values. Table 5 summarises the Hahn model parameters for Funfoods and Cremica (Eggless and Egg) mayonnaise samples. It can be inferred from the table that Hahn model parameter P increased with increasing shear rate, but α did not show any systematic trend. With rise in temperature P decreased, but variation of α was not systematic (Table 4 and 5). Parameters P was higher in case of eggless samples compared to egg mayonnaise samples in both Cremica and Funfoods samples. It reflects that more amount of initial stress is needed for initiating structural breakdown. Also parameter P was higher in case of Funfood samples compared to Cremica samples (both egg and eggless) (Table 5).

Mayonnaise samples exhibited both yield stress as well as time dependent characteristics. For this type of soft solids, rheological properties change not only with shear rate but also with time of shearing and shear history (Tiu and Boger, 1974; Basu *et al.*, 2007; Basu and Shivhare, 2010). It is interesting to note that there was no systematic trend of steady state model (Herschel Bulkley) parameters with composition. But time dependent parameters were related to the composition (egg/eggless and brand) of mayonnaise samples.

Conclusions

Mayonnaise samples of both the brands (Cremica and Funfoods) under steady state conditions followed Herschel Bulkley model. It was further observed that mayonnaise samples (Cremica and Funfoods) also exhibit a time-dependent non-Newtonian behaviour. Characterisation of the stress–time behaviour of mayonnaise samples helps us to understand the consistency and stability of mayonnaise samples (egg and eggless). We can conclude that although eggless samples tried to mimic the egg mayonnaise samples but there is a subtle difference in it's physical character which is evident from the textural and rheological findings.

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