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Full Length Research Paper

Rheological categorization and quality of Large-scale marketable mayonnaise using back extrusion

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When creating or redesigning food product researchers need to pay special attention to textural and rheological properties. Texture is a sensory perception derived from the structure of food and is related to viscosity and elasticity. Mayonnaise is semi-solid oil-in-water emulsion with starch in its formulations when fat-reduced. Under shear forces it exhibits different types of macroscopic flow behavior, such as shear thinning, yield stress behavior, thixotropy, and viscoelasticity. One problem with the rheological characterization of mayonnaise is that it is particularly difficult to isolate and quantify individual effects. Only sensory evaluation is capable to fully detect and describe them. Hence the ability to measure and to characterize them accurately and quickly enables the food industry to set standards for quality and to monitor deterioration during storage and distribution. Back extrusion is a method used to quantify the behavior of thixotropic fluids. The relatively short time and low cost required to conduct the test makes it a suitable technique for quality control in product development. This paper evaluates back extrusion as method to analyze mayonnaise. It is performed at 5, 25 and 40ºC in a Stable Micro Systems TA-XT2 using twelve commercial mayonnaises. The method has provided qualitative and quantitative characteristics of samples in an accurate and quick way.

Key words: Rheology, back extrusion, texture, mayonnaise.

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INTRODUCTION

Texture is a difficult term to define since it means different things to different people. Food texture is a sensory perception derived from the structure of food at molecular, microstructure, and macroscopic levels (Chen, 2009; Weenen et al., 2003; Rosenthal, 1999). Szczesniak (2002) pointed out the multidimensional nature of texture and its importance to the consumer saying that only a human being can perceive and describe it and the texture testing instruments can detect physical parameters which then must be interpreted in terms of sensory perception, the most important ones being the sense of touch and pressure.

When creating or redesigning food product researchers need to pay special attention to textural and rheological properties. The science of rheology has many applications in the field of food acceptability, food processing and handling. A number of food processing operations depend heavily upon rheological properties of the product at an intermediate stage of manufacture because this has a profound effect upon the quality of the finished product. Plasticity, pseudoplasticity, and the property of shear thinning are important quality factors in foods and the study of these properties is part of the science of rheology. Some foods, like mayonnaise, are either plastic or pseudoplastic in nature. They are required to spread and flow easily under a small force but to hold their shape when not subjected to any external force other than gravity. All of these properties fall within

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the field of rheology (Bourne, 2002).

Mayonnaise is a mixture of egg, vinegar, oil and spices, with 70 to 80% fat. It is a semi-solid oil-in-water emulsion formed by first mixing the eggs, vinegar and spices and then slowly blending in the oil resulting in closely packed 'foam' of oil droplets (Depree and Savage, 2001; Szczesniak, 2002). Mayonnaise rheology and texture can depend on the distribution of the oil, the interaction between oil droplets, and the egg yolk emulsifier.

Alteration of the mayonnaise's microstructure leads to different rheological properties. This means that the rheology is sensitive to any change in the materials microstructure (Stokes and Telford, 2004).

In emulsions, droplet size is perhaps the most important factor in determining properties like consistency, rheology, shelf life stability, color and taste. In general, emulsions with smaller droplet size result in great stability. Current equipment used for emulsion preparation includes colloid mills, sonicators or high pressure homogenizers. The advantage of high pressure homogenizers over other technologies is that more uniform droplets size distribution are obtained since the product is subjected to strong shear and cavitation forces that efficiently decrease the diameter of the original droplets (Martin-Gonzalez et al., 2009)

Rheology of mayonnaise can provide valuable information that can be used in quality control of commercial production, storage stability, sensory assessments of consistency, knowledge and design of texture, design of unit operations, and knowledge of the effects of mechanical processing on the structure of the emulsions (Gallegos and Berjano, 1992). Mayonnaise has been shown to be shear thinning, viscoelastic and thixotropic and it has a yield stress. The yield stress is the minimum stress required to enable flow or fracture due to the breakdown or alteration of a materials microstructure. One of the many difficulties encountered during the characterization of such a complex material is to isolate and quantify individual effects (Goshawk and Binding, 1998). Ingredients used in mayonnaises interact with each other either physically or chemically and determine the quality of the final products. The necessity in reduced-fat/cholesterol also in mayonnaises has made it necessary to identify appropriate ingredients for formulating these products as the removal of certain ingredients like fat may have a significant influence on the quality and taste of food emulsions (Ma and Boye, 2013).

Back extrusion is a method used to quantify the behavior of thixotropic fluids. The relatively short time and low cost required to conduct the test makes it a suitable technique for quality control in product development.

Yield stresses can be easily determined (Brusewitz and Yu, 1996). It involves two physical movements: (a) a cylindrical plunger is forced down into the fluid and (b) the fluid flows upward through a concentric annular space. Usually, the cylindrical plunger is a solid rod and the fluid is contained in a cylindrical cup. The force required to extrude the fluid in the direction opposite to that of the rod is measured (Gujral and Sodhi, 2002; Paoletti et al., 1995; Kaneda and Takahashi, 2011).

Since mayonnaise rheological properties are related to the formulation, process parameters, the storage temperature and commercial mayonnaises present differentiated formulations analysis performed in distinct temperatures demonstrates such differences in its rheology. Moreover, as the complexity of texture can only be fully detected and described by sensory evaluation, the ability to measure it accurately and quickly enables the food industry to set standards for quality and to monitor deterioration that occurs during storage and distribution.

This paper evaluates back extrusion as a method to analyze mayonnaise rheologically and texturally, discussing the results in different formulations.

MATERIALS AND METHODS

Twelve commercial mayonnaises were analyzed. Eight of them were traditional type (codes I, II, III, IV, V, VI, VII and VIII) and four of them were light type (codes III Light, IV Light, V Light and VII Light) as shown in Table 1. The exact composition of these commercial mayonnaises is not known. All of them were bought in local supermarket.

Tests were carried out in a TA-XT2 texturometer (Stable Micro Systems, UK) using Back Extrusion Cell (A/BE) using 5 kg load cell. Dimensions of the back extrusion probe are: Inner cup diameter 55 mm; cup height 70 mm and compression plate diameter 45 mm (Figure 1). The data were captured by the program "Texture Expert

Exceed" (Stable Micro Systems, UK). The parameters used were tested in advance and are shown in Table 2. Back extrusion was performed at 5, 25 and 40ºC. Mayonnaises were stored at each one of these temperatures in a controlled temperature refrigerator for 24 h prior to analysis. By the time of the analysis the samples were removed from the refrigerator, filled in the cup and tested immediately. At least two independent tests were made in each mayonnaise.

RESULTS AND DISCUSSION

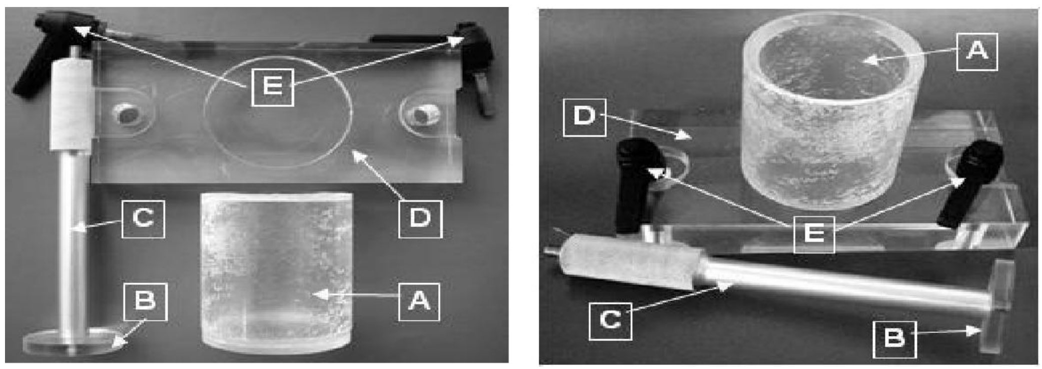
Force as a function of time curves (also Force-Time curve) obtained using probe back extrusion for commercial mayonnaises at 25°C are in Figure 2. Since similar overall behavior was seen in all samples only a few curves are shown in order to make the understanding easier.

The form of these curves is consistent with a typical force-distance curve obtained from back extrusion test described by Bourne (2002), who also divided the curve in sections explaining what is happening in each one of them. The sections displayed in Figure 2 are described in Table 3 using Bourne's as a base.

The reader should be warned that the use of Force-Time graphic instead of Force-Distance is due to the fact that time and distance parameters are numerically equal (25 s and 25 mm, respectively) and the velocity parameter is 1 mm/s (Table 2), therefore, the two

Table 1. Sample codes for commercial mayonnaises used.

Commercial mayonnaise	Sample code
Traditional	I, II, III, IV, V, VI, VII and VIII
Light (same brand as III)	III Light
Light (same brand as IV)	IV Light
Light (same brand as V)	V Light
Light (same brand as VII)	VII Light



(a) (b)

Figure 1. Back extrusion probe set (a) cup and base disassembled and (b) cup and base assembled. Letters A to E mean: (A) inner cup, (B) compression plate, (C) extension bar, (D) base and (E) screw-nut.

Table 2. Parameters settings used in the stable micro systems TA-XT2.

Parameter	Setting
Test mode and option	Measure force in compression/return to start
Pre-test speed	1.0 mm/s
Test speed	1.0 mm/s
Post-test speed	1.0 mm/s
Distance	25 mm
Time	25 s
Trigger type	Auto
Trigger force	10 g
Data acquisition rate	200 pps

graphics produce curves with exactly same shape.

From section A to B the mayonnaise is immediate compressed with an instantaneous elastic deformation, which means its original form can be recovered instantaneously and completely if the force is removed, theoretically speaking, because few foods are perfectly elastic possessing flow properties in addiction to elasticity, most frequently 'plastic' and 'viscoelastic' (Bourne, 2002).

In section B the yield value is reached. When expressed in terms of shear stress this represents the 'yield stress' the minimum force that must be exceeded before flow begins. This type of flow is often found in foods and mayonnaise is a typical example of them.

Permanent deformation starts in section B going through section C because now original form cannot be recovered neither instantaneously nor completely if the force is removed because the flow has started through the annular concentric space and the behavior starts to changes from solid to liquid.

In section C maximum force is reached and a viscous deformation with a constant force from section C to D starts showing the viscoelatic property of mayonnaise. This section is a Newtonian region since force is independent of distance or time (or shear stress), leading to a constant viscosity.

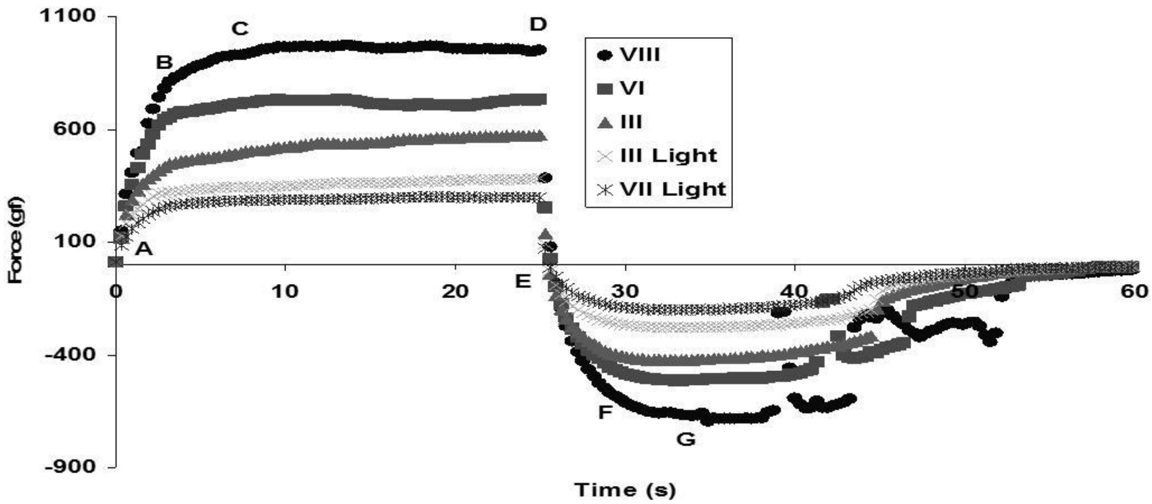


Figure 2. Force-Time curve obtained using back extrusion method for commercial mayonnaises at 25°C. Symbols represent samples (●)VIII, (■)VI, (▲)III, (×)III Light and (*)VII Light (Table 1). Sections A to G are explained in Table 3.

Table 3. Steps that can be indentified in a typical force-distance/time curve obtained from back extrusion test.

S/N	Step	Section in Figure 2
1	Compression plate begins to plunge into the sample;	A
2	Force rises steeply over a short time of movement compressing the	A to B
3	sample; Yield value is reached and elastic deformation begins;	B
4	Extrusion starts through the annular concentric space - behavior change region “from solid to liquid”	B to C
5	Maximum force is reached and constant stress region begins with viscous deformation;	C
6	Newtonian region, the shear stress is independent of shear rate, leading to constant viscosity (in point D, the compression plate starts to go up);	C to D
7	Compression plate reverses direction and starts to move upward and force falls to zero	D
8	Force falls steeply over a short time of movement decompressing the sample	E
9	Yield value is reached and elastic deformation begins	F
10	Extrusion starts through the annular concentric space – behavior change region “from solid to liquid”;	G

Szczesniak (2002) defined ‘Hardness’ as the force necessary to attain a given deformation, a resistance of the food to the applied compressive forces and Bourne (2002) defined it as the peak force in a force-time curve resulting from a test that compresses a bite-size of food that imitates the action of the jaw, therefore, section C can be termed as ‘hardness’.

After section D same sequence of phenomena is observed in a mirror form between sections E and G with negative values of force. These forces in module are smaller than the ones observed in respective A-D sections, which means mayonnaise exhibits shear-thinning and thixotropy characteristics.

By backing extrusion twice the same sample, one following immediately the other, mayonnaise thixotropy and dependency of shear stress and of shear historical became clear as can be seeing in Figure 3. Here two different samples from brand V, V1 and V2, are back extruded twice: V11 and V21 by the first time and V12 and V22 by the second time. Force and viscosity

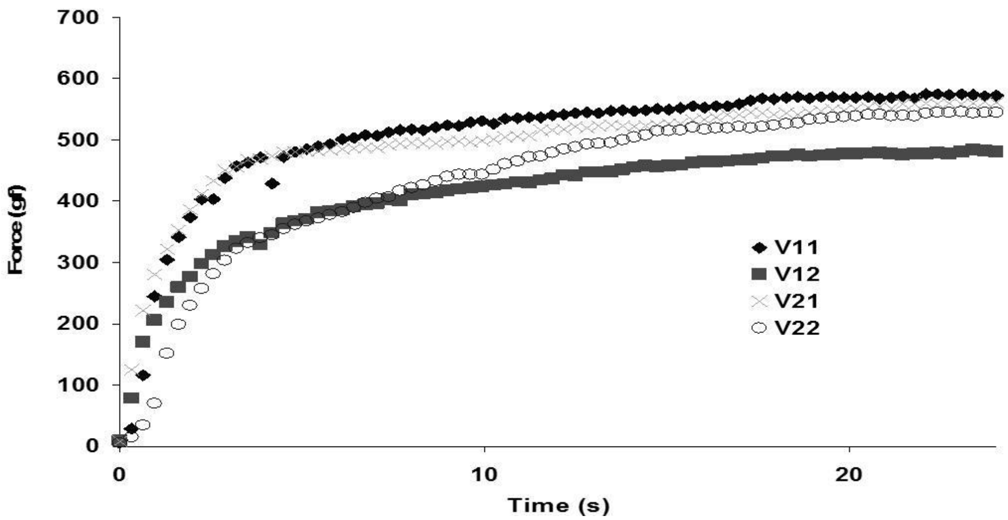


Figure 3. Force-time curve obtained using back extrusion method for brand V at 25ºC in a repeated extrusion. (◆)V11: First sample, first extrusion; (■) V12: First sample, second extrusion; (×)V21: Second sample, first extrusion; (○)V22: Second sample, second extrusion.

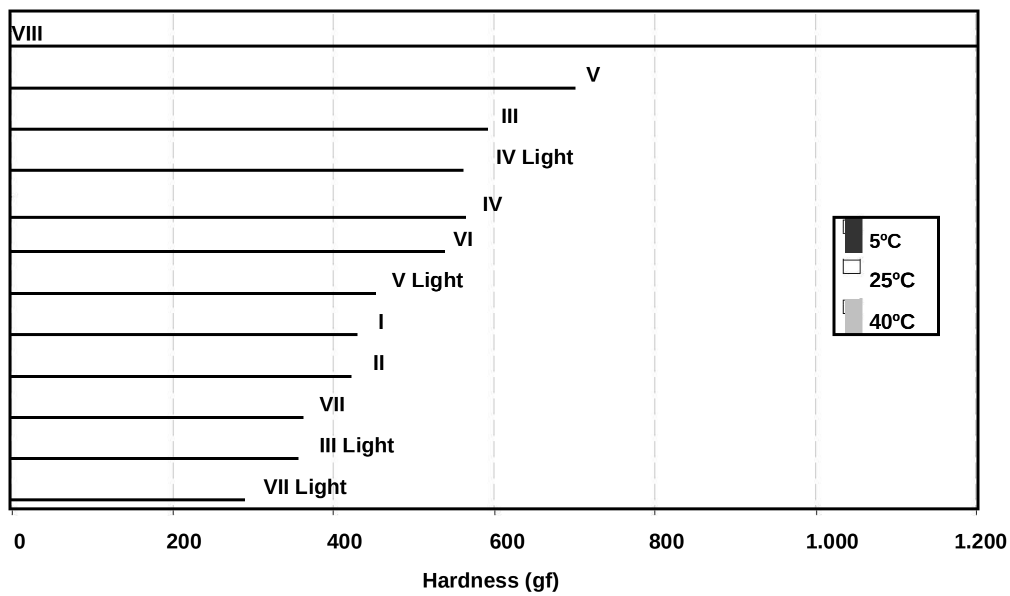


Figure 4. Hardness obtained from back extrusion test of mayonnaise samples at 5, 25 and 40°C.

reduction presented in second extrusion also indicates that compression force affect mayonnaise structure irreversibly by breaking it down.

The non-linear rheological properties of commercial mayonnaise were studied by Kaneda and Takahashi (2011). The stress growth behavior under constant shear flow was observed using a strain control-type rheometer. As the stress-strain curves of commercial mayonnaise showed non-linear behavior, the curves were analyzed with a polynomial model that is a power series of strain. Two types of commercial mayonnaise were investigated - traditional and low-fat mayonnaise. The second order coefficient of the polynomial model revealed that the structure fracture behavior of these types of mayonnaise was very different. Because the fracture behavior of semisolid foodstuffs is considered to be an important mechanical property, the approach may be useful for quantitative estimation of the texture of such foods.

Mayonnaise rheological properties are related with formulation, process parameters and storage temperature. By performing rheological analysis in distinct temperatures it is possible to demonstrate such differences. Figure 4 and Table 4 present hardness values (medium) obtained at 5, 25 e 40°C using back

Table 4. Hardness obtained from back extrusion test of mayonnaise samples at 5, 25 and 40°C.

Sample/brand	5ºC	25ºC	40ºC
I	407.22^{a,b}	430.03^{a,b}	229.99^{a}
II	396.48^{a,b}	419.20^{a,b}	314.88^{a,b}
III	544.04^{b,c}	590.25^{b,c}	427.06^{b,c}
III Light	355.25^{a,b}	349.65^{a,b}	320.28^{a,b}
IV	563.70^{b,c}	556.25^{b,c}	452.32^{c}
IV Light	447.59^{a,b,c}	561.35^{b,c}	479.80^{c}
V	640.37^{c}	698.26^{c}	510.02^{c}
V Light	361.95^{a,b}	450.27^{a,b}	312.22^{a,b}
VI	536.07^{b,c}	515.78^{a,b,c}	447.51^{c}
VII	272.89^{a}	362.96^{a,b}	287.20^{a}
VII Light	243.91^{a}	287.67^{a}	209.32^{a}
VIII	894.75^{d}	1054.83^{d}	823.20^{d}

^{a,b,c} Same letter shows no significative difference at 5% level at Tukey-HSD Test.

extrusion method for all samples. It is possible to see the variation due to temperature and brand.

Laverse et al. (2012) studied the microstructure and quantification of fat in four types of mayonnaise. The dynamic-mechanical properties of the mayonnaise samples were also studied using a controlled-strain rotational rheometer. Four types of commercially produced mayonnaises, chosen to exhibit variability in terms of visible structure of fat, were used for the experiments. Appropriate quantitative three-dimensional parameters describing the fat structure were calculated. With regards to the microstructural and rheological relationship, results from the correlation carried out show that a correlation exists among some microstructural and rheological parameters of the mayonnaise samples. The results showed that X-ray microtomography technique was used by is a suitable technique for the microstructural analysis of fat as it does not only provide an accurate percentage volume of the fat present but can also determines its spatial distribution.

Marinescu et al. (2011) studied the application of beta-glucan prepared from spent brewer's yeast as a fat replacer in mayonnaise. Fat was partially substituted by P-glucan at levels of 25, 50 and 75%. The results indicated that all mayonnaises exhibited thixotropic shear thinning behavior under steady shear tests and were rheologically classified as more solid like gels. The mayonnaise with 50% beta-glucan showed higher storage stability than the other samples. It has been demonstrated that spent brewer's yeast beta-glucan can be used as a fat replacer in mayonnaise as well as an emulsion stabilizer.

Brand VIII presents the highest hardness values in the three temperatures. Brand VII Light presents the smallest hardness in the three temperatures. Brand VIII is the harder and brand VII Light is the softer in terms of texture.

A large number of ingredients called "texturizing agents" (also described as texturizers, thickeners, viscosity modifiers, bodying agents, gelling agents and stiffening agents) are available to help bring the texture of foods in to the range preferred by consumers (Bourne, 2002). A thickener is a chemical component or mixture of components that can impart long-term emulsion stability by thickening a food system, reducing the movement of the system and by forming viscous, ordered networks in the continuous phase to prevent oil separation (Ma and Boye, 2013). Brand VIII has higher hardness due to the starch (texturizing agents) in its formulation, possibly starch or modified starch that can be used combined with non-starch hydrocolloids to obtain products such as reduced-fat mayonnaise with desirable textural properties. Textural change can be obtained due to specific interactions between starch and emulsifiers and non-starch hydrocolloids in these products, and the starch and hydrocolloids combination can reduce the long and slimy texture of reduced-fat products compared to when hydrocolloids are used alone (Ma and Boye, 2013).

Nikzade et al. (2012) optimized mixture proportions of low cholesterol-low fat mayonnaise contained soy milk as an egg yolk substitute (10%) with different composition of xanthan gum, guar gum and mono- and diglycerides emulsifier (0 to 0.36% of each component) were determined by applying the simplex-centroid mixture design textural and rheological properties and sensory characteristics for effective formulation process. Results revealed that the best mixture was the formulation contained 6.7% mono- diglycerides, 36.7% guar gum and 56.7% xanthan gum. The xanthan gum was the component showing the highest effect on all the properties of mayonnaise samples. In addition, an increase of xanthan gum followed by guar gum caused greater values for the stability, heat stability, consistency coefficient, viscosity, firmness, adhesiveness, adhesive force and overall acceptance and lower value for flow behavior index.

Except for brands III Light, IV and VI all other brands exhibit a reduction in their hardness from 25 to 5°C. This can be justified by a small break down in emulsion with low temperatures. The bigger stability was showed at 25°C.

Brand IV do not show difference between its traditional and light form (VI and VI light, respectively) at 1% of significance level (Tukey test, LSD). It is the bestselling brand which means it can be used as a standard for hardness comparison since its texture is already well accept by consumers.

Most brands show biggest hardness values at 25°C which demonstrate more stability since this is a normal storage temperature before selling. Market offers mayonnaises with a big variety of textural characteristics.

Conclusion

The back extrusion method to determine rheological properties of mayonnaises showed sensible and very efficient for providing quantitative and qualitative characteristics. However, it is necessary a standardization of samples to get repeatability of measurements. Most results showed no differences between traditional and light mayonnaises texture, meaning the standardization and quality of the formulations.

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