Effect of oil content on the rheological and textural properties of mayonnaise

PETR ŠTERN - KAMILA MÍKOVÁ - JAN POKORNÝ - HELENA VALENTOVÁ

Summary

Two sets of mayonnaises with the oil content ranging from 66 to 82% and containing two different thickenings agents were analysed at 10 °C and 25 °C. The rheological analysis included the determination of flow curves, yield value, apparent viscosity, and viscoelastic parameters. Sensory characteristics were determined by manipulation of samples with a spoon, and in the mouth, testing the spreadability, and both texture and flavour acceptances were determined too. The oil content of a mayonnaise has substantial effect on rheological properties such as yield value, storage modulus and loss modulus, but no differences were observed due to the thickening agents. The pseudoplastic behaviour was confirmed. Temperature had no significant effect on the results of the sensory analysis. The effect of oil content on the viscosity perceived in the mouth and on spreadability was pronounced. The sensory acceptability increased with increasing oil content. Statistically significant relationships were observed between various rheological and sensory data, for instance between the yield value and the texture acceptability or between the storage modulus and the loss modulus and the spreadability. Rheological measurements were thus found useful for the rapid and cheap prediction of sensory texture, flavour and food acceptability of the product.

Keywords

mayonnaise; oil content; rheology; sensory characteristics; texture

Mayonnaises are appreciated food components and flavourings. They are oil-in-water emulsions, containing over 80% of oil in traditional mayonnaises, similarly as the lipid content in butter. The high acceptability of mayonnaises is due to their agreeable flavour, but also to their oil content, the latter increasing the viscosity of food morsel in the mouth after the ingestions, thus improving the mouthfeel of the respective meal.

Rheological and textural properties of mayonnaise are very complex, as the structure is semisolid with pronounced viscoelastic properties, but it grows liquid under applied shear, even if the shear is only moderate [1]. The elastic character prevails over the viscous flow character at the same frequency [2]. A power-law equation was used to express the relation between the complex viscosity and frequency, as well as the apparent viscosity and the shear rate [3]. The transient flow of mayonnaise can be described by a three-parameter model, consisting of the stress overshoot, stress magnitude, and time [4]. The transient flow can be described using the Wagner model, only the Soskey-Winter damping function should be introduced to describe the nonlinear relaxation modulus [5]. The complex viscosity decreased with frequency, and a light mayonnaise sample was less destroyed by the shear than full-fat mayonnaise samples [6]. The creep compliance-time response was a function of viscoelastic properties, as a function of a constant low shear stress [7]. Under steady shear, flow curves fit two first-order functions, therefore, the whole flow curve should be measured, not only the extreme (initial and final) values [8]. Dynamic viscosities are much larger than steady apparent viscosities so that neither the Cox-Merz rule, not the shift-factor type relationships are suitable to express viscoelastic properties [9]. The pseudoplastic behaviour of mayonnaise is also accompanied by time-dependent characteristics [10]. The presence of lipids containing long hydrocarbon chains results in thixotropic behaviour

Petr Štern, Institute of Hydrodynamics, Academy of Sciences of the Czech Republic, Pod Paťankou 30/5, CZ-166 12 Prague 6, Czech Republic.
Kamila Míková, Jan Pokorný, Helena Valentová, Department of Food Chemistry and Analysis, Faculty of Food and Biochemical Technology, Prague Institute of Chemical Technology, Technická 5, CZ-166 28 Prague 6, Czech Republic.

Correspondence author:
Petr Štern, e-mail: stern@ih.cas.cz

[11], perceptible in oil-in-water emulsions of mayonnaise even if such behaviour is less pronounced than in case of water-in-oil emulsions, such as margarines. Therefore, the determination of the storage modulus and the loss modulus were included in the program of experiments.

There exist many papers on the rheology of mayonnaise, but only little experimental evidence is found on the relation between instrumental evaluation (rheology) and the sensory texture of mayonnaise (both intensities of various sensory characteristics and the hedonic texture acceptance). In our previous paper [12] we compared relations between rheological and sensory characteristics in sets of traditional and light mayonnaises (70% and 30%, respectively). Several significant relationships between rheological and sensory characteristics were obtained, irrespective of the oil content.

The effect of oil content on both rheological and sensory characteristics of mayonnaise is rather complicated as low-fat mayonnaises usually contain various thickeners to achieve appearance and flavour of a traditional high-fat product. Xanthan gums and modified starches are generally used in low-fat mayonnaises [13]. Another common type of thickeners is β-glucans [14]. The effect of oil content was studied by WENDIN and co-workers. Light mayonnaises (15% and 30% oil) were compared with a traditional mayonnaise (82% oil). The authors concluded that both the thickener and the oil content have pronounced effect on the properties [15]. The flavour of the product was influenced by the oil content and thickeners as well [16]. The texture and the mouthfeel of mayonnaises were influenced by the oil content even in a range as narrow as 70–82% oil [17].

Mayonnaises with oil content reduced below 50% might have problems with emulsion stability [18]. Therefore, we applied our procedure used for large differences in oil content [12] for a substantially shorter range of 66–82% oil content, comparable with the set of samples studied by WENDIN [15]. Preliminary results, had been presented earlier [19] at an International Conference on Rheology, and encouraged us to give more detailed results on similar set of mayonnaises in this paper.

MATERIAL AND METHODS

Material

Mayonnaises prepared for two series of experiments consisted of the same aqueous phase, and the same refined soybean oil, differing only in the ratio between the oil phase and the aqueous phase. The ingredients included egg yolk, mustard, sugar, salt, stabilizer, preservative agent, and modified starches, either E 1422 (starch monophosphate) or E 1410 (starch acetylated adipate) in the two series, respectively, EDTA, and water. The ingredients were mixed, and oil was added. Vinegar was added as the last ingredient. The finished sample was packed in 0.5 kg containers, and stored at 6–7 °C for a week in order to obtain a stable product.

Preparation of the emulsion

Mayonnaises were prepared using the pilot-plant equipment Stephan UMC 5 Electronic homogenizer (Stephan Machinery, Hameln, Germany), using the procedure recommended by the manufacturer. The oil content varied between 66–82% (m/m). The total of 14 samples containing different amounts of oil was prepared in the same way.

Rheological measurements

Rheological parameters (yield value τ_0, apparent viscosity η_a, and visco-elasticity moduli - storage modulus *G*' - elastic component, loss modulus *G*" - viscous component, *G** - complex modulus) were determined using the Rheoviscometer Rotovisco RT 10 (ThermoHaake, Karlsruhe, Germany), equipped with a vane rotor and of coaxial ribbed cylinders. The visco-elasticity moduli were determined by means of dynamic tests with forced oscillation by frequency 0.1 Hz (index $_{0.1}$) and 1 Hz (index $_{1.0}$).

Flow curves, apparent viscosity η_a and viscoelastic parameters were determined using coaxial cylinders, ribbed to prevent slipping. A vane rotor FL 20 was used for measuring the yield value τ_0. Flow curves were determined with the RV 20 over the shear rate range of 0–150 s^{-1}, and the apparent viscosity was calculated at the highest shear rate applied (150 s^{-1}).

Determination of the oil content

The oil content was determined using the standard method by RÖSE und GOTTLIEB [20]; because of lower stability of lipid phase, the solvents were removed under reduced pressure in a rotating evaporator.

Sensory Analysis

The procedure of sensory evaluation (sample preparation and serving pattern, design of the test room) was in agreement with the respective international standards [21, 22]. Samples were evaluated by persons selected, trained, and monitored according to the respective international standard [23]. The texture profile was designed using the international standard [24]. In all cases, unstructured graphical scales were used, designed according to the respective international standard [25].

Texture descriptors were based on previous experience with similar products [12]. Their list is given in Table 1. Some descriptors were evaluated using a category scale (such as colour or appearance). When possible, unstructured graphical scales were used. The texture was evaluated firstly on a porcelain dish (shuffling the sample with a spoon, pouring of the sample from a turned up spoon, shape changes of the sample on a dish on standing, consistence perceived on touching the sample with a spoon, elasticity perceived on repeated pressing the sample with a spoon). The sample was then put in the mouth, and evaluated immediately after the ingestion, after 5 s, and by pressing the morsel with the tongue against the palate. The determination of breakdown rate of the sample in mouth was reported as very important for the perception of mouthfeel [26]. The creamy mouthfeel, smooth and thick texture substantially contribute to the sensory acceptability of mayonnaise [27]. The spreadability was tested on a slice of white bread, and on a piece of a finely textured cartoon.

The hedonic scale (0% of the scale = bad texture, 100% = excellent texture) was used for the evaluation of texture acceptability. An analogous scale was used for flavour evaluation. Descriptors of individual flavour notes were evaluated using graphical intensity scales (0% = not perceived; 100% = extremely strong).

The ranking test was performed according to the respective international standard [28].

Statistical Methods

One-way ANOVA, cluster analysis, and linear, semilogarithmic and double-logarithmic regression analyses were used (Statistica 7.0, Statsoft, Tulsa,

Tab. 1. Analytical methods used and standard deviations of experimental data.

Code of the method	Analytical method	Number of replicates	Standard deviation of the mean value
A	Yield value [Pa]	4	5
B	Storage modulus $G'_{0.1}$ [Pa]	4	2
C	Storage modulus $G'_{1.0}$ [Pa]	4	2
D	Loss modulus $G''_{0.1}$ [Pa]	4	2
E	Loss modulus $G''_{1.0}$ [Pa]	4	2
F	Colour [points]	27	< 1
G	Appearance [points]	27	< 1
H	Operation with spoon [points]	27	<< 1
J	Operation with spoon [%]	27	4
K	Pouring from spoon [points]	27	< 1
L	Keeping on spoon [points]	27	< 1
M	Behaviour on plate [%]	27	3
N	Consistence on touching [%]	27	4
O	Elasticity on touching [%]	27	4
P	Viscosity after ingestion [%]	27	3
Q	Viscosity after 5 s [%]	27	4
R	Viscosity by pressing [%]	27	4
S	Overall texture rating]%]	27	4
T	Overall flavour rating [%]	27	4
U	Intensity of oily flavour [%]	27	4
V	Intensity of acidic flavour [%]	27	3
W	Intensity of salty flavour [%]	27	4
X	Intensity of off-flavours [%]	27	4
Y	Spreadability on bread [%]	27	2
Z	Spreadability on cardboard [%]	27	3

Tab. 2. Rheological data of mayonnaise samples.

Sample code No.	Oil content [%]	Yield value[a] at 10 °C	Yield value[a] at 25 °C	Storage modulus $G_{0.1}$	Storage modulus $G'_{1.0}$	Loss modulus $G''_{0.1}$	Loss modulus $G''_{1.0}$
1A	82	2.90	2.77	3.55	2.70	3.68	2.85
2A	77	2.84	2.75	3.45	2.64	3.57	2.81
3A	75	2.79	2.74	3.34	2.61	3.51	2.77
4A	72	2.14	1.95	2.99	2.56	3.29	2.68
5A	70	2.46	2.34	2.57	2.47	3.02	2.61
6A	68	2.07	1.91	1.81	2.36	2.57	2.57
7A	66	2.04	1.76	0.70	1.99	2.42	2.55
8B	82	2.95	2.85	3.51	2.69	3.64	2.74
9B	77	2.81	2.78	3.41	2.61	3.52	2.71
10B	75	2.71	2.62	3.31	2.59	3.44	2.67
11B	72	2.57	2.47	2.87	2.56	3.25	2.59
12B	70	2.21	2.15	2.60	2.56	2.93	2.49
13B	68	2.05	1.83	1.81	2.43	2.41	2.41
14B	66	1.81	1.62	0.00	1.92	1.72	2.39

A, B - thickening agents; a - decadic logarithms of the respective values.

Oklahoma, USA), and the results were statistically evaluated on the basis of $P = 0.95$ probability level. Average differences between the samples evaluated by category tests were calculated after GINI [29]. For the evaluation of average differences in case of methods using graphical scales, recommendations by MCBRIDE [30] were used. Results of the ranking tests were evaluated as described in the literature [28, 31].

RESULTS AND DISCUSSION

Set of samples prepared for analysis

Two sets of samples were prepared, containing 66–82% refined oil, and the same aqueous phase consisting of water, vinegar, sugar, ascorbic acid, sodium chloride, and minor ingredients (antioxidants and preservation agents). Egg yolk was used as an emulsifier in both sets of samples. These sets of samples differed in the thickening agent used (modified starch E 1410 and E 1422, respectively). The use of modified starches is common in mayonnaises with reduced oil content [32]. The composition of the aqueous phase and of the oil phase remained the same so that the samples differed only in the ratio of the two phases. The samples were stored at 6–8 °C for at least a month prior to the analysis in order to achieve equilibrium values.

The oil content and some basic rheological characteristics are shown in Table 2. All rheological analyses were carried out four times, and the means are given in the Table 2.

The rheological analysis was carried out at the same time as the sensory evaluation in order to eliminate the influence of changing stability of mayonnaise on storage [33].

Errors of the analytical results

The standard deviations of the analyses are summarized in Table 1, as well as average differences between duplicate analyses. Standard deviations of the mean value of those sensory analyses, which were evaluated with the use of graphical scales are given in the lists of sensory methods (in parentheses), too. Analytical results were almost identical in case of parameters, where category scales were used so that average differences were much lower than a category point. No systematic effect of the oil content was observed, therefore, the results will not be further discussed.

Flavour profile is very important for the acceptability of mayonnaises by the consumers. The average difference between the results of a duplicate analysis by the same assessor was equal to 17% of the graphical scale in case of overall flavour acceptance. Similar values were obtained in the evaluation of acidic and salty tastes (15% and 16%, respectively). Smaller average difference of only 9% was observed in the evaluation of off-flavours, obviously due to low intensity of off-flavours. The determination of oily flavour was obviously difficult (the average difference of 22%), which could be explained partially by lack of significant differences among flavour acceptances of the samples, and the identical composition of the oil phase. The oily flavour percept is mainly influenced by the sample viscosity in the mouth, and partially by the off-flavour oxidation products present in oil. The ingestion of a sample containing oil reduces the sensitivity required for evaluation of other oil samples within 10–15 minutes [34].

Relationships of rheological data

Average data are summarized in Tab. 2 (the respective standard deviations can be found in Tab. 1). The increasing oil content in mayonnaise decreased the elasticity *G*' more than the viscosity *G*", but decreased the yield value. The thickening agent had no significant effect on the yield value in spite of literature data to the contrary [15]. However, the range of rheological properties was rather narrow, and the structure of thickening agents related in our study, which could reduce their effect on rheological behaviour was similar. The yield values decreased with the increasing temperature as expected, and decreased with the increasing content of soybean oil, as expected ($r = 0.89$, $N = 28$). Difference in the temperatures of measurement had no influence on either elasticity or viscosity.

The pseudoplastic behaviour of mayonnaise samples [10] was confirmed, as characterized by pronounced yield stress and time-dependent changes. The elasticity was measured at two frequencies, 0.1 and 1.0 Hz, which gave different results. The storage modulus and the loss modulus were independent of the temperature in the studied range, so that only the results obtained at 25 °C have been included. The storage modulus *G*' decreased with the decreasing oil content, and the relationship was almost linear ($r = 0.98$ and 0.99, respectively; $N = 28$), but the slopes for $G'_{0.1}$ and $G'_{1.0}$ were different (241 and 302, respectively). Changes of the loss modulus *G*" with the increasing oil content were smaller, and contrary to the storage modulus, slopes of $G''_{0.1}$ and $G''_{1.0}$ were nearly the same (23 and 24, respectively), so that differences were pronounced only in the intercept. In both cases, semilogarithmic relationships were very close to linear. The respective correlation coefficients were 0.85, 0.80, 0.88, and 0.86, $N = 28$. The complex modulus of elasticity G^* also increased with the increasing oil content, and its change was also almost linear (Fig. 1). The slopes were independent of the thickening agent used.

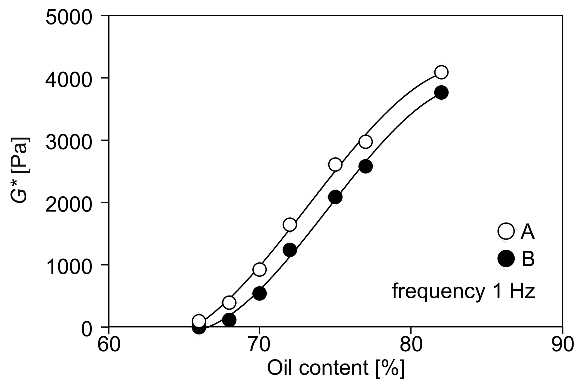

Fig. 1. Dependence of complex modulus of elasticity G^* on oil content.
A - thickening agent E 1422, B - thickening agent E 1410.

Relations between the oil content and sensory characteristics of mayonnaises

Most sensory characteristics, except pouring from a spoon and touching the sample on a plate with a spoon were significantly dependent on the oil content, correlation coefficients varying between 0.43 and 0.85 ($N = 28$). However, the effect of temperature was not significant. The degree of whiteness depends on homogenization degree, which was the same in all samples in our experiments, more than on the oil content [17], therefore, no effect of oil content on the colour hue could be expected, as it was confirmed in our experiments. The effect of oil content on the evalua-

Tab. 3. Relationships between the oil content (*A*) and sensory characteristics.

Sensory characteristic	Experimental expression	R^2
Viscosity after ingestion (*P*)	$P = 12150 \exp(0.081A)$	0.71
Viscosity after a few movements in the mouth (*Q*)	$Q = 2936 \exp(-0.056A)$	0.72
Viscosity by pressing against the palate (*R*)	$R = 1855 \exp(-0.047A)$	0.69
Spreadability on a slice of bread (*Y*)	$Y = 1529 - 762 \log A$	0.76
Spreadability on a piece of cardboard (*Z*)	$Z = 1061 - 515 \log A$	0.72
Texture acceptance (*S*)	$S = 284 - 490 \log A$	0.56

tion of viscosity in the mouth was very pronounced. The relationships were exponential (Tab. 3) with relatively high correlation coefficients.

The behaviour of the sample in mouth during the test should be the same in all samples, as the perceived viscosity depends on movements of the tongue [35]. Naturally, both the sensory and the instrumental viscosity are affected by thickeners [16, 36] so that additives could influence the relationships studied. On the contrary, relationships between the oil content and spreadability were semilogarithmic (Tab. 3). The texture acceptability (in spite of its hedonic character) was linearly dependent on the oil content, increasing with the increasing oil content. These relationships could be expected as they were in agreement with the literature data on mayonnaise [24]. The positive effect of fats and oils in the diet is inborn as lipids were the most important source of energy on humanoid and primitive human ancestors. All these sensory characteristics were interrelated. The sensory viscosity in modern low-fat mayonnaises depends more on the thickener than on moderate differences in oil content [15], but in our experiments, the thickeners used were of similar chemical structure, as mentioned above, so that their effect was not crucial. A positive relationship between the oil content, rheological viscosity, and sensory acceptability was observed in a set of Polish commercial mayonnaises [37].

The flavour acceptability was not affected by the oil content of mayonnaises in the range of 66–82% oil ($r = 0.16, N = 28$). Viscosity affects the taste [38], but the viscosity range was probably not sufficiently wide to influence the sensory percept. The reason was probably not the lack of sensitivity, but great variability of taste preferences. The same assessors were able to distinguish dependence of oily taste intensity on the oil content ($r = 0.46$) and decreasing acidic taste ($r = -0.58$), due to changing ratio of oily and aqueous phases. It is interesting that the acidic taste in mayonnaises of similar interval of oil content was higher with increasing oil content in other experiments [17]. Changes of salty taste and intensity of off-flavours were not recorded.

The complex of sensory characteristics, rated with the use of graphical scales, was by ranking ($P = 0.99$). The sample containing 82% oil was rated as better than the rest of the samples by the method of Kramer [31], while the samples containing 70–66% oil where worse. The oil content was determined as an important factor by the method described by Page [28].

Relationship between rheological and sensory data

Very complex effects due to semisolid structure and pronounced elastic component were observed [1], but in our experiments, the range of conditions studied was relatively small, which simplified the evaluation of the behaviour of mayonnaise under stress. Relationship between rheological and sensory characteristics depends very much on the material tested and on the methods used [39]. Procedures were tested in our earlier studies, and were found satisfactory. The relations were either semilogarithmic or double logarithmic, but in almost all cases, at least in the range of temperature and oil content studied, so that they were statistically significant as linear functions, even if there were slight deviations from linearity.

The sensory viscosity, when tested with a spoon touching the sample on a porcelain plate was a semilogarithmic function of the loss modulus *G*'' and storage modulus *G*' (Fig. 2) with correlation coefficients of $r = -0.56$ and -0.57, respectively. Sensory characteristics determined by manipulation of the sample on a plate with a spoon (i.e. before the ingestion) were in a nearly linear correlation with the yield value ($r = -0.86$).

Sensory evaluations after sample ingestion were

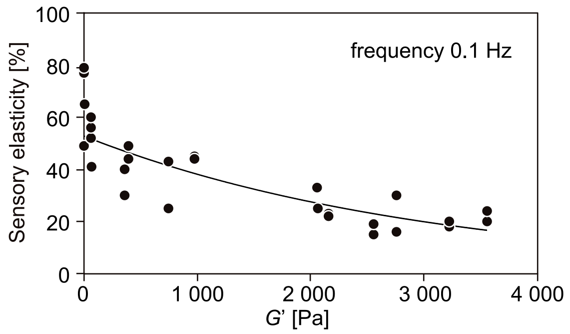

Fig. 2. Relationship of storage modulus *G*' on the elasticity tested with a spoon.

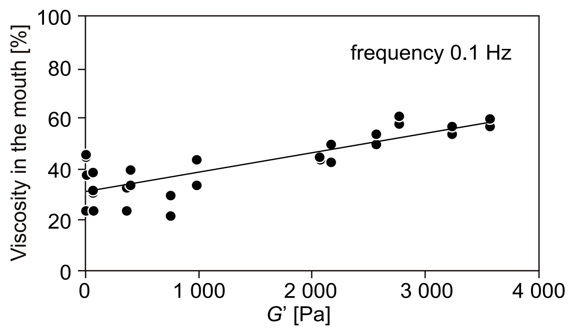

Fig. 3. Relationship between storage modulus *G*' and the viscosity measured after ingestion in the mouth.

affected by contact with warm mucosa of the mouth cavity and gradually diluted with saliva so that the experimental conditions differed from those measured using the viscometer. Nevertheless, sensory viscosities measured in the mouth (procedures *P*, *Q*, and *R* described in Tab. 3) were correlated with the yield value (e.g. $P = 57 - 0.55\tau$), and with the storage modulus *G'* (Fig. 3), the relation being strictly linear in the last case.

The overall texture acceptability (*S*), being a hedonic variable, was still a nearly linear function of the yield value (a measure of intensity, not the hedonics):

$$S = 28.3 + 0.035, r = 0.82, N = 28$$

without any distinct maximum in the interval studied. Similar linear relations were observed in case of storage modulus *G'* ($s = 30.9 + 0.0073\ G'_{0.1}$) or the loss modulus *G"*:

$$S = 25.1 + 0.0474\ G''_{0.1}$$

Nearly linear relationships were observed in case of spreadabilities (procedures *Y* and *Z* described in Tab. 3), however only very flat shoulders were observed at the yield values of 250–600 Pa. When plotting the elasticity storage modulus and the loss modulus against spreadability (both on a slice of bread - *Y*, or on a piece of cardboard - *Z*), the relations were again nearly linear ($r = 0.6$–0.7, $N = 28$), e.g. $Y = 119 - 0.0117\ G''_{0.1}$, but still very flat shoulders of spreadability were observed at medium elasticity values.

Richardson et al. [40] showed factors affecting the oral thickness viscosity in such weak gels as mayonnaises, but these weak influences were not significant in our experiments because of a rather narrow range of properties investigated in our samples.

CONCLUSIONS

The oil content in mayonnaise has an important effect not only on rheological characteristics, such as the yield value and the elasticity of the product, but also on the sensory texture, but not on flavour. Many statistically significant relationships were observed between rheological and sensory data, e.g. the relation between the yield value and the data obtained by manipulation of the sample with a spoon. As a few among them have high correlation coefficients, the expensive and time-consuming sensory evaluations could be replaced in some cases with fast and cheap rheological measurements. Even hedonic characteristics, such as texture acceptability, could be predicted with use of instrumental analysis, e.g. the texture acceptability on basis of the yield value.

Acknowledgements

The research was supported by a grant No. IAA2060404, Grant Agency of the Academy of Sciences, Czech Republic. A part of the results was presented at the Annual Conference of the Czech and Slovak Chemical Societies, Ústí nad Labem, Czech Republic, 4–7 September, 2006.

REFERENCES

1. García-Navarro, F. B. - Berjano-Nunez, M. - Gallegos-Montes, C.: Rheology of mayonnaises. Grasas y Aceites, *39*, 1988, pp. 181-285.
2. Berjano, M. - Munoz, J. - Guerrero, A. - Flores, V. - Gallegos, C.: Comportamiento viscoelástico dinámico de mayonasas comerciales. Revista de Agroquímica y Tecnología Alimentaria, *30*, 1990, pp. 481-491.
3. Berjano, M. - Munoz, J. - Guerrero, A. - Flores, V. - Gallegos, C.: Comparison of steady and dynamic shear viscosities of commercial mayonnaise. Revista de Agroquímica y Tecnología Alimentaria, *31*, 1991, pp. 400-410.
4. Campanells, O. H. - Peleg, M.: Analysis of transient flow of mayonnaise in a coaxial viscometer. Journal of Rheology, *31*, 1987, pp. 439-452.
5. Gallegos, C. - Berjano, M. - Guerrero, A. - Munoz, J. - Flores, V.: Transient flow of mayonnaise described by a nonlinear viscoelasticity model. Journal of Texture Studies, *23*, 1992, pp. 153-168.
6. Munoz, J. - Sherman, P.: Dynamic viscoelastic properties of some commercial salad dressings. Journal of Texture Studies, *21*, 1990, pp. 441-426.
7. Kiosseoglou, V. D. - Sherman, P.: Influence of egg yolk lipoproteins on the rheology and stability of O/W emulsions and mayonnaise. I. Viscoelasticity of groundnut oil oil-in-water emulsions and mayonnaise. Journal of Texture Studies, *14*, 1983, pp. 397-417.
8. Figoni, P. I. - Shoemaker, C. F.: Characterization of time dependent flow properties of mayonnaise under steady shear. Journal of Texture Studies, *14*, 1983, pp. 431-442.
9. Bistany, K. L. - Kokini, J. I.: Comparison of steady shear rheological properties of fluid food materials. Journal of Texture Studies, *14*, 1983, pp. 113-124.
10. Tiu, C. - Boger, D. V.: Complex rheological characterization of time dependent food products. Journal of Texture Studies, *5*, 1974, pp. 329-336.
11. Kozin, N. I. - Darchiev, B. H.: Rheological properties of mayonnaise. Maslozhirovaya Promyshlennost, *38*, 1972, pp. 14-15.
12. Štern, P. - Valentová H. - Pokorný, J.: Rheological properties and sensory texture of mayonnaise. European Journal of Lipid Science and Technology, *103*, 2001, pp. 23-28.
13. Solowiej, B. - Gustav, W. - Mieko, S. - Andruszczak, S.: Rheological properties of mixtures of xanthan gum

and starches of various types. Żywność, *11*, 2004, Suppl., pp. 184-196.
14. Supachai, W. - Manop, P. - Surinya, P. - Pimon, J.: Glucan prepared from spent brewer's yeast as a fat replacer in mayonnaise. Food Hydrocolloids, *20*, 2006, pp. 68-78.
15. Wendin, K. - Aaby, K. - Edris, A. - Ellekjaer, M. P. - Bergenstahl, B. - Johansson, L. - Willers, E. P. - Solheim, R.: Low-fat mayonnaise: influences of fat content, aroma compounds and thickeners. Food Hydrocolloids, *11*, 1997, pp. 87-99.
16. Wendin, K.: Sensory dynamics in emulsion products differing in fat content. SIK Report, *679*, 2001, pp. 1-160.
17. Wendin, K. - Risberg-Ellekjaer, M. - Solheim, R.: Fat content and homogenization effects on flavour and texture of mayonnaise with added aroma. Lebensmittel-Wissenschaft und –Technologie, *32*, 1999, pp. 377-383.
18. Chouard, G.: Be in phase, bring connectivity to your low fat mayonnaise. Innovations in Food Technology, *29*, 2005, pp. 989-100.
19. Štern, P. - Valentová, H. - Pokorný, J. - Panovská, Z. - Míková, K.: Relations between the rheological parameters and the textural characteristics of mayonnaise samples containing different levels of oil phase. In: Münstedt, H. - Kaschta, J. - Merten, A. (Ed.). Proceedings of the Sixth European Conference on Rheology. Erlangen : Germany, 2002, pp. 597-598.
20. Davídek, J.: Laboratorní příručka analýzy potravin. Praha : SNTL, 1981. 719 pp. ISBN 044-814-81.
21. ISO 6658:1985. Sensory analysis - Methodology - General guidance. Geneva : International Organization for Standardization, 1985. 14 pp.
22. ISO 8589:1988. Sensory analysis - General guidance for the design of test rooms. Geneva : International Organization for Standardization, 1988. 15 pp.
23. ISO 8586:1989. Sensory analysis - General guidance for the selection, training and monitoring of assessors - selected assessors. Geneva : International Organization for Standardization, 1989. 22 pp.
24. ISO 11036:1994. Sensory analysis - Methodology - Texture profile. Geneva : International Organization for Standardization, 1994. 25 pp.
25. ISO 4121:1983. Sensory analysis - Evaluation of food products by methods using scale categories. Geneva : International Organization for Standardization, 1983. 7 pp.
26. Terpstra, M. E. J. - Janssen, A. M. - Prinz, J. F. - De Wijk, R. A. - Weenen, H. - Van der Linden, E.: Modelling of thickness in semisolid foods. Journal of Texture Studies, *36*, 2005, pp. 213-233.
27. Weenen, H. - Jellema, R.-H. - DeWijk, R. A.: Sensory sub-attributes of creamy mouthfeel in commercial mayonnaises, custard desserts and sauces. Food Quality and Preference, *16*, 2005, pp. 163-170.
28. ISO 8587:1993. Sensory analysis - Methodology - Ranking. Geneva : International Organization for Standardization, 1993. 13 pp.
29. Gini, G.: Variabilita e mutabilita contributo allo studio dello distributioni e delle relationi statistiche. Bologna : Universita degli Studi, 1912. 128 pp.
30. McBride, R. L.: Sensory measurement: an introductory review. CSIRO Food Research Quarterly, *45*, 1985, pp. 59-63.
31. Kramer, A.: Revised tables for determining significance of differences. Food Technology, *17*, 1963, pp. 124-125.
32. Gorecka, A. - Niepytalska, N. - Krygier, K.: Application of modified starches in the production of low-fat and cholesterol free mayonnaise emulsions. Żywność, *11*, 2004, Suppl., pp. 77-86.
33. Karas, R. - Škvarca, M. - Zender, B.: Sensory quality of standard and a light mayonnaise during storage. Food Technology and Biotechnology, *40*, 2002, pp. 119-127.
34. Valentová, H. - Pokorný, J.: Effect of edible oils and oil emulsions on the perceptions of basic tastes. Nahrung, *42*, 1998, pp. 406-408.
35. DeWijk, R. A. - Engelen, L. - Prinz, J. F.: The role of intraoral manipulation in the perception of sensory attributes. Appetite, *40*, 2003, pp. 1-7.
36. Aström, A.: The influence of some key ingredients on the sensory characteristics of mayonnaise. European Food and Drink Review, 1998, No. Spring, p. 43-48.
37. Juszack, L. - Fortuna, T. - Kosla, A.: Sensory and rheological properties of Polish commercial mayonnaise. Nahrung, *47*, 2003, pp. 232-235.
38. Baryłko-Pikielna, N. - Martin, A. - Mela, D. J.: Perception of taste and viscosity of oil-in-water and water-in-oil emulsions. Journal of Food Science, *59*, 1994, pp. 1318-1321.
39. Bourne, M. C.: Calibration of rheological techniques used for foods. Journal of Food Engineering, *16*, 1992, pp. 151-163.
40. Richardson, R. K. - Morris, E. R. - Ross-Murphy, S. B. - Taylor, L. J. - Dea, C. M.: Characterization of the perceived texture of thickened systems by dynamic viscosity measurements. Food Hydrocolloids, *3*, 1989, pp. 175-191.

Received 20 September 2006; revised 30 October 2006; accepted 24 January 2007.