Rheological and textural characteristics of oil-in-water emulsions

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SUMMARY. Emulsions of the type oil-in-water, produced as bread spreads, were analysed at the temperatures of 15; 20 and 25 °C. The bread spreads (cheese spread, horse radish spread and garlic spread, ten samples each), which differed only a little from each other in their main components (55 % oil and 30–32 % water), contained different minor ingredients, especially flavourings. Rheological parameters intercorrelated in closer functional relations than sensory parameters. This was obviously due to relatively small differences in the consistencies of individual samples, and higher standard deviations of the sensory analysis compared to instrumental methods. Sensory assessors were unable to distinguish the effect of temperature differences, contrary to the rheoviscometer. Sensory viscosity perceived in the mouth showed the best correlation with rheological measurements. The relationship was semilogarithmic, but only little deviating from linear. Correlation coefficients ranged from 0.4 to 0.6, which may be considered as satisfactory at results of the sensory analysis.

KEYWORDS: bread spreads; emulsions O/W; rheology; sensory analysis; texture

Traditional bread spreads in Central and Western Europe used to be butter and pork lard, i. e. fats containing both solid and liquid fractions. Their main advantage is an excellent flavour, but their disadvantages are high price, high content of saturated fatty acids and of cholesterol. Another disadvantage is their texture. When they are kept in a refrigerator, as is the most common way of storage in households, they become too hard for easy cutting and spreading, while they become rather soft at a room temperature of about 25 °C.

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Modern bread spreads, such as soft margarines or mixtures of butter with margarine or edible oil, are more advantageous from the standpoint of their nutritional value and of their texture than the traditional spreads. The perceived texture does not depend much on the temperature, at least in the range of 5–25 °C [1]. They often contain less fat and more water than butter, their energy content is lower, but they still belong to water-in-oil (W/O) emulsions.

Still another brand of bread spreads has a composition similar to that of mayonnaise, consisting of edible oil, water and various other additives, but they are oil-in-water (O/W) emulsions. They do not contain solid fats. Such spreads have a very soft texture, perhaps unusual to more traditional consumers. Therefore, we found useful to compare rheological and sensory characteristics of such spreads in a way used in case of other food products [2], in order to correlate their acceptance with their texture.

Material and methods

Material

Cheese bread spread, horse radish bread spread and garlic bread spread samples were commercial plant-scale products, which differed only a little from one another in their main components (oil-in-water emulsions, containing about 55 % oil and 30–32 % water), but differed in other ingredients, flavourings in particular. Differences in rheological characteristics between samples were achieved using different amounts of thickening agents (modified starches). Hydrocolloids are generally used because of their effect on rheological properties [3]. Ten samples were prepared of each brand (the total of 30 samples) at time intervals of about a week in order to detect eventual variability in the technological process. The results thus reflect the variability of samples in an industrial plant. Only relations between instrumental and sensory characteristics were studied, while absolute values were considered as unimportant from this standpoint. Therefore, the relationships are applicable for O/W bread spreads generally.

Rheological measurements

Samples of bread spreads were measured in a rotational rheometer Rotovisco RT 10 (manufactured by Gebrüder Haake GmbH, Karlsruhe, Germany) at 15, 20 and 25 °C, similarly as in case of mayonnaise [4]. The rheometer was equipped with a vane rotor FL 20 and a Coaxial Cylinder

Sensor System (Cylinder Sensor Z 43/S and Z 38/S), which was ripped to reduce slipping [5,6]. The temperature was equilibrated for 15 min.

The yield value was determined by placing the structurally unchanged sample of bread spread in the rheometer. The shear stress was then recorded at a constant shear rate of 0.1 s^{-1}. The yield value τ_0 [Pa] represented the maximum value of the shear stress at the shear stress/shear time curve. At least 60 s were necessary to reach a constant value of shear stress and in another 60 s, the shear stress returned to zero [7].

Apparent viscosity η_A [Pa.s] was determined at the maximum shear rate of 150 s^{-1} from the flow curve. Flow curves were measured in the shear rate interval of 0–150 s^{-1} in such a way, that the inner cylinder (rotor) achieved its maximum rate in 60 s, and came back to rest in another 60 s. The shear rate used in rheological measurements corresponded to shear rates common during degustation of bread spreads.

Thixotropy [Pa.s^{-1}] was determined as the area between the upward and the downward parts of the flow curve.

Bread spreads would show, of course, a viscoelastic behaviour, which could be correlated with sensory parameters, but the elasticity could not be measured because of small solid particles present in some samples.

The repeatability of the rheological measurements was about 5.0 % of the result.

Sensory analysis

Samples were analysed under conditions specified by the international standard [8] in a standard test room provided with 6 test booths [9]. The panel of assessors consisted of 18 persons selected, trained and monitored in agreement with the respective standard [10]. Unstructured graphical scales (150 mm long, provided by descriptions at the two ends). The samples were maintained at the stated temperature overnight. A sample amount of 20–30 g allowed the determination of the sensory profile (in 40 s) within temperature changes not greater than 1 °C. The samples were served on white coded porcelain dishes in 2–3 min intervals. Slices of white bread were consumed between samples. A maximum of 3 samples were served in a session.

A sensory profile was constructed on the basis of our experience from previous experiments on the evaluation of mayonnaise [4]. It consisted of the following descriptors: A = manipulation of the sample on a dish with a knife (0 % = difficult; 100 % = very easy); B = spreadability on a piece of smooth cupboard (0 % = bad; 100 % = excellent); C = spreadability on a slice of white bread (0 % = bad; 100 % = excellent); D = appearance of the layer after spreading on bread (0 % = bad; 100 % = excellent); E = flavour of spread bread (0 % = bad; 100 % = excellent); and F = viscosity perceived in the mouth, when about 5 g of sample were ingested from a spoon, and the viscosity was rated after 2–3 movements of the tongue (0 % = thin; 100 % = thick). Average difference between two ratings of the same sample by different assessors at the same session was 10–30 mm; the average difference between two ratings of the same assessor of the same sample, but at different sessions, was 5–22 mm, and the average repeatability of the mean value from the ratings of the whole group was 3–6 mm. Lower values were observed at lower intensities of the acceptance rating. Acceptability was rated using an unstructured graphical scale (0 % = very bad; 100 % = very good). As the ratings varied between 10 and 140 mm of the graphical scale, they could be treated as interval scales.

Statistical analysis

Minimum, maximum and medium values of the entire set of results were determined, regression expressions and the respective correlation coefficients were calculated from the values, their reciprocal values and their decadic logarithms. Cluster analysis and multivariate analysis were used for expressing relationships between the rheological and sensory parameters. The probability value was P = 0.05. For the above calculations, Microsoft Statistica 3.1 software was used.

Results and discussion

Ranges of rheological and sensory properties of the analysed samples

Medians, maximum and minimum values of individual rheological and sensory characteristics are summarised in tab. 1 for the entire set of samples and for all the three temperatures tested. As the distribution of results obtained by repeated sensory analysis of the same sample slightly differed from a normal distribution, medians are given instead of means. Relatively narrow ranges are the cause of lower number of significant relationships and/or relatively low correlation coefficients between rheological and sensory characteristics. The dependencies between the logarithm of yield value and thixotropy were double logarithmic as shown in fig. 1 for the cheese spread. In case of other spreads and in the entire set of samples, the situation was very similar. All relationships were statisticaly significant (r = 0.75 for the entire set of values, $P \leq 0.05$).

TAB. 1. Summary of the measurement results for 90 samples of bread spreads.
TAB. 1. Souhrn výsledků měření 90 vzorků pomazánek.

Measured characteristics[1]	Median value[2]	Minimum value[3]	Maximum value[4]
Rheological characteristics[5]:			
Yield value[6] [Pa]	184	60	390
Apparent viscosity[7] [Pa.s]	1.83	0.98	2.88
Thixotropy[8] [$Pa.s^{-1}$]	4.35	2.51	12.94
Sensory characteristics[9] [mm]:			
A = manipulation with a knife[10]	112	89	136
B = spreading on cardboard[11]	121	97	136
C = spreading on bread[12]	123	101	138
D = appearance of spread layer[13]	112	80	140
E = flavour when spread on bread[14]	103	66	136
F = viscosity in the mouth[15]	80	48	106

1 - měřené charakteristiky, 2 - medián, 3 - minimální hodnota, 4 - maximální hodnota, 5 - reologické charakteristiky, 6 - mez toku, 7 - zdánlivá viskozita, 8 - tixotropie, 9 - sensorické charakteristiky, 10 - manipulace s nožem, 11 - roztíratelnost na lepence, 12 - roztíratelnost na plátku chleba, 13 - vzhled natřené vrstvy, 14 - chuť pomazánky natřené na plátek chleba, 15 - viskozita hodnocená v ústech.

Effect of the brand of bread spreads on rheological and sensory testing

All the three examined brands were very similar from the standpoint of their rheological and textural properties because of their very similar technological processing and oil content. They differed mainly in flavourings, which do not affect the texture. No differences were observed in case of the apparent viscosity; some differences could be probably found at very low shear rates, which however deviate substantially from those encountered at real consumption. On the contrary, the the three brands behaved differently in their yield values (correlation coefficient $r = -0.44$, number of samples $N = 90$), and, in their thixotropies ($r = -0.70$, $N = 90$). The three brands were characterized by same sensory ratings of their texture, even though they could be easily distinguished visually or by taste.

Effect of temperature on rheological values and sensory ratings

From each brand, 10 samples were measured at 3 temperatures (15, 20 and 25 °C, respectively). The temperature range was selected to allow the measurement shortly after removal of the sample from a refrigerator, and after longer time of storage at ambient temperature, which occurs during ser-

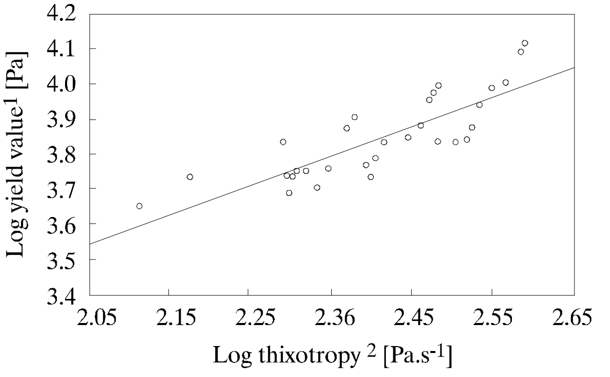

FIG. 1. Relationship between the yield value and thixotropy of cheese spreads.
OBR. 1. Vztah mezi mezí toku a tixotropií u sýrových pomazánek.
1 - logaritmus meze toku, 2 - logaritmus tixotropie.

ving the spreads in practical life. If spreads are frequently used, they are often stored outside the refrigerator. The resulting sets of 30 values were tested for their temperature dependence, using the regression analysis. Semilogarithmic regressions were obtained as the best fitting: $\log Y = aT + b$, where Y is a rheological parameter, T = temperature [°C], and a and b are constants. The total combined results of all the three brands (90 cases) were statistically analysed, too.

The entire set of results was treated by regression analysis (the complete matrix of 36600 results is available at the authors). Statistically significant correlation coefficients (P = 0.05) were obtained for all the three brands separately, and for the total set of 90 samples (tab. 2). Logarithms gave slightly better correlation coefficients, but differences between the linear and semilogarithmic plots were only small. The temperature dependence was most pronounced in case of the yield value. In some cases, the correlation coefficient was slightly higher if reciprocal value of the temperature was used, but the differences were negligible. Correlation coefficients of linear regressions of rheological characteristics and the temperature were slightly lower than those of semilogarithmic plots, but the differences were again negligible, which was caused by narrow intervals studied, as has been already mentioned above.

The effect of temperature on sensory characteristics was far less pronounced, which is due to higher variance of the sensory rating compared with the instrumental measurements, and of more rapid changes by tasting in the mouth. Surprisingly, it was less pronounced even in case of manipula-

TAB. 2. Correlation coefficients (r) of the temperature dependence: log R = *a*T + *b*, where R is a rheological parameter, T - temperature [°C]; *a*, *b* - constants.
TAB. 2. Korelační koeficienty (r) závislosti: log R = *a*T + *b*, kde R je reologický parametr, T - teplota [°C], *a*, *b* - konstanty.

Rheological characteristic[1]	Cheese spread[2]	Garlic spread[3]	Horse radish spread[4]	Total set of spreads[5]
Apparent viscosity[6]	-0.54	-0.75	-0.54	-0.41
Yield value[7]	-0.84	-0.96	-0.94	-0.65
Thixotropy[8]	-0.67	-0.67	-0.68	-0.40

1 - reologická charakteristika, 2 - sýrová pomazánka, 3 - česneková pomazánka, 4 - křenová pomazánka, 5 - celá sada pomazánek, 6 - zdánlivá viskozita, 7 - mez toku, 8 - tixotropie.

tion on a dish or at spreading. With the use of this method, the effect of temperature is lower than when testing in the mouth, and is in about the same order as rheological measurements (for example, r = –0.42, N = 90 or r = –0.60, N = 30 for the cheese spread). In the mouth, the temperature of the sample rapidly increases, but the heat necessary to warm up the sample could be obviously well perceived and caused that the temperature dependence was significant.

Relations between rheological parameters and sensory characteristics

Relations between rheological variables and those sensory characteristics observed by manipulation of the sample on a plate with a knife are characterized by their correlation coefficients (tab. 3). The closest fit was found in case of semilogarithmic regressions. No significant relation was observed with the thixotropy, which is in agreement with the expectation. The depen-

TAB. 3. Relations between rheological and sensory variables.
TAB. 3. Vztahy mezi reologickými a sensorickými proměnnými.

Logarithm of rheological characteristics[1]	A - manipulation with a knife[2]	D, E - spreadabilities on both cardboard and bread[3]	F - viscosity after ingesting the sample[4]
Yield value[5]	-0.36*	0.04	0.43*
Apparent viscosity[6]	-0.37*	0.12	0.39*
Thixotropy[7]	-0.16	0.03	0.32*

1 - logaritmus reologické charakteristiky, 2 - manipulace nožem, 3 - roztíratelnost na chlebě i na lepence, 4 - viskozita po vložení do úst, 5 - mez toku, 6 - zdánlivá viskozita, 7 - tixotropie.

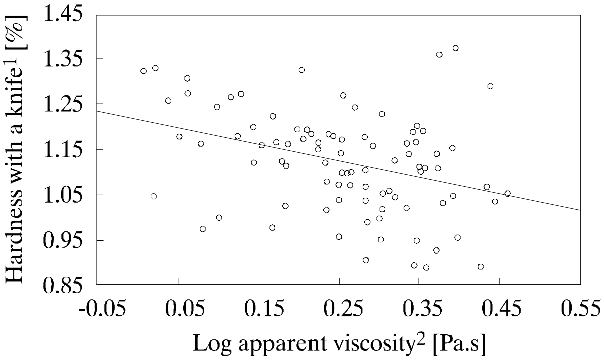

FIG. 2. Relationship between the apparent viscosity and the hardness determined by manipulation with a knife.
OBR. 2. Vztah mezi zdánlivou viskozitou a tvrdostí měřenou při manipulaci s nožem.
1 - tvrdost při manipulaci s nožem, 2 - logaritmus zdánlivé viskozity.

dence between the logarithm of apparent viscosity and the hardness measured sensorically by manipulation of the sample with a knife is shown in fig. 2 ($r = -0.36$ for the entire set of 90 samples).

Another important characteristic of a bread spread is its spreadability, which was tested by the application of a knife either on smooth cardboard or

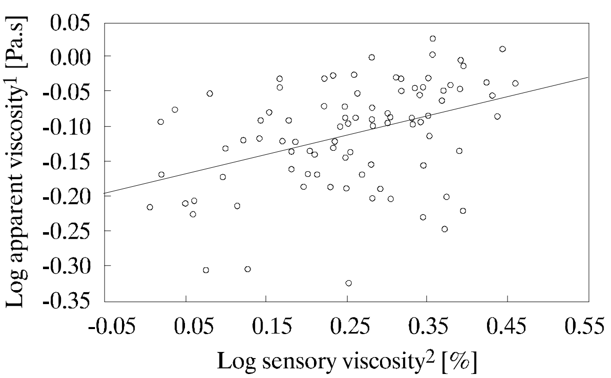

FIG. 3. Relationship between the apparent viscosity and the sensory viscosity measured in the mouth.
OBR. 3. Vztah mezi zdánlivou viskozitou a sensorickou viskozitou měřenou v ústech.
1 - logarimtus zdánlivé viskozity, 2 - logaritmus sensorické viskozity.

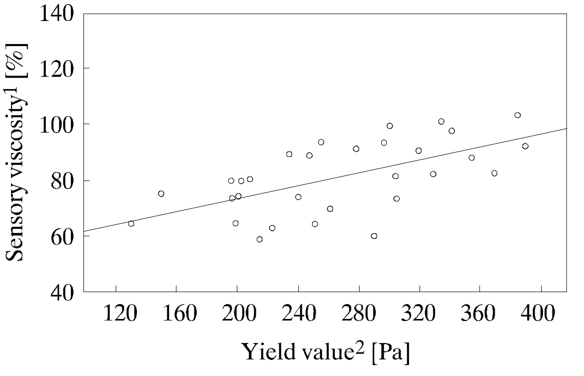

FIG. 4. Relationship between the yield value and the sensory viscosity measured in the mouth.
OBR. 4. Vztah mezi mezí toku a sensorickou viskozitou měřenou v ústech.
1 - sensorická viskozita, 2 - mez toku.

a slice of bread. The results of spreadabilities obtained in case of both of these closely related tests were closely correlated ($r = 0.76$; $N = 90$). Correlation coefficients were nearly identical, and only means are given in the table. Neither test was correlated with any rheological characteristic. This lack of significant relations was probably due to relatively narrow interval of values

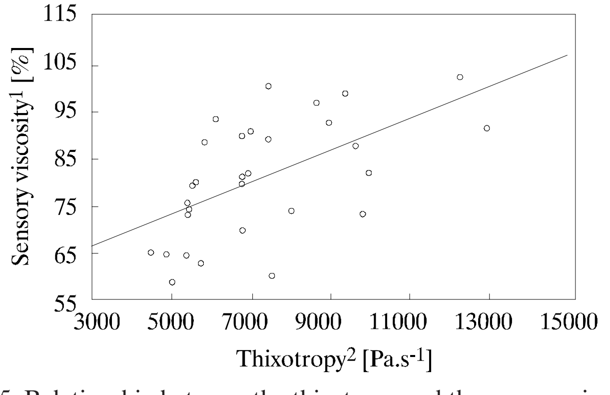

FIG. 5. Relationship between the thixotropy and the sensory viscosity measured in the mouth.
OBR. 5. Vztah mezi tixotropií a sensorickou viskozitou měřenou v ústech.
1 - sensorická viskozita, 2 - tixotropie.

among the samples (tab. 1), and to the difficulty connected with the spreading of very soft samples, where yield values were rather low. All samples were thus perceived as almost identical, irrespective of the temperature.

All the three rheological characteristics were significantly correlated with the viscosity perceived immediately after ingesting the sample (tab. 3). The double logarithmic relationship was the best fit for the whole set of results in case of the apparent viscosity and the sensory viscosity (r = 0.40, N = 90) (see fig. 3). In some cases, the linear relationships were also relati-

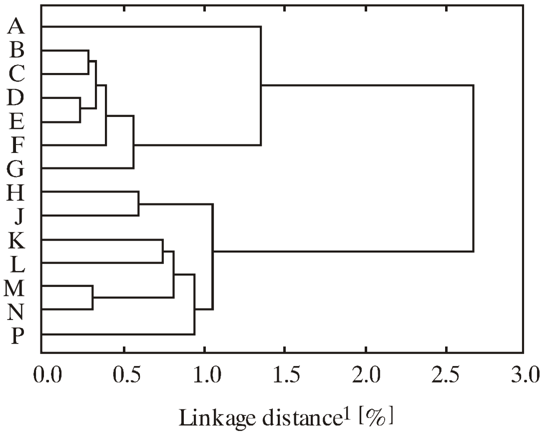

Fig. 6. Cluster analysis of the results: tree diagram (samples of cheese spreads).
A - logarithm of apparent viscosity, B - logarithm of the hardness determined by manipulation with a knife, C - logarithm of the appearance of spread sample, D - logarithm of spreadability on a smooth cardboard, E - logarithm of spreadability on a slice of bread, F - logarithm of flavour intensity of a sample spread on a slice of bread, G - logarithm of viscosity as perceived in the mouth, H - logarithm of thixotropy, J - rating of viscosity as perceived in the mouth, K - hardness rated by the manipulation of the sample with a knife, L - appearance when spread on a slice of bread, M - rating of spreadability on a piece of cardboard, N - rating of spreadability on a slice of bread, P - rating of flavour when spread on a slice of bread.

Obr. 6. Shluková analýza: stromový diagram vzorků sýrových pomazánek.
A - logaritmus zdánlivé viskozity, B - logaritmus tvrdosti stanovené nožem, C - logaritmus vzhledu natřeného vzorku, D - logaritmus roztíratelnosti na lepence, E - logaritmus roztíratelnosti na plátku chleba, F - logaritmus chuti vzorku natřeného na plátku chleba, G - logaritmus viskozity stanovené v ústech, H - logaritmus tixotropie, J - hodnota viskozity měřené v ústech, K - hodnota tvrdosti hodnocené pomocí nože, L - vzhled vzorku natřeného na plátek chleba, M - roztíratelnost na lepence, N - roztíratelnost na plátku chleba, P - chuť vzorku natřeného na plátek chleba.
1 - vzdálenost [%].

vely satisfactory, in particular for individual brands as shown on the example of the yield value and the sensory viscosity (fig. 4), where r = 0.45, or the thixotropy and the sensory viscosity (fig. 5) in case of the cheese spread (r = 0.35).

Factor analysis of results

The entire set of results (a 90 x 55 matrix) was analysed using the factor analysis to evaluate differences between individual characteristics. Results obtained by using the cluster analysis of cheese spread are shown in fig. 6 as an example. In the entire set of three brands, the logarithm of the apparent viscosity forms a cluster with logarithms of all the six sensory characteristics. Another cluster is formed from the logarithm of thixotropy and all sensory characteristics (the original values in this case, no logarithms). The logarithm of thixotropy was most closely related to the sensory viscosity as perceived in the mouth.

Conclusions

Both consumers and producers are interested in the optimum properties of spreads connected with manipulation during spreading; they can be predicted on the basis of rheological determination of the apparent viscosity. Another important information concerns the optimum perception of viscosity in the mouth, which could be predicted on the basis of the yield value, apparent viscosity or thixotropy with an approximately equal accuracy.

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Reologické a texturní charakteristiky emulzí typu olej ve vodě

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Souhrn. Emulze typu olej-ve-vodě (O/V), vyráběné jako pomazánky, byly zkoumány při teplotách 15, 20 a 25 °C. Tyto pomazánky (sýrová, křenová a česneková, každá po 10 vzorcích) se lišily jen nepatrně v obsahu hlavních složek (55 % oleje a 30–32 % vody), zato se lišily ve vedlejších složkách, hlavně ochucovacích přísadách. Reologické parametry byly navzájem v těsnějších vztazích než sensorické texturní parametry, protože sensorické metody jako méně přesné poskytovaly často neprůkazné vztahy vzhledem k úzkému intervalu vlastností jednotlivých vzorků. Podobné závěry se týkaly vlivu teploty. Hodnotitel prakticky nerozlišil rozdíly způsobené malými rozdíly teplot. Ze sensorických parametrů koreluje s reologickými především sensorická viskozita hodnocená v ústech. Její funkční závislosti jsou semilogaritmické, ale málo odlišné od lineárních. Koeficienty korelace se pohybují mezi 0,4 a 0,6, což je možné považovat za uspokojivé hodnoty u výsledků sensorické analýzy.

Klíčová slova: emulze O/V; pomazánky; reologie; sensorická analýza; textura