TEMPERATURE RELATIONS OF SOME MUSTARDS RHEOLOGIC PROPERTIES

Peter HLAVÁČ

Institute of Electrical Engineering, Automation, Informatics and Physics, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, SK- 949 76 Nitra, Slovak Republic

Abstract
In this article we compared apparent viscosity and density of three types of whole mustards from different producers (Boneco, SNICO, COOP). We performed measurements of both parameters in the temperature range (5 – 25) °C. Apparent viscosity was measured on rotational viscometer Anton Paar DV-3P and density was determined according to definition (exact volume of sample was weighted). We have found that apparent viscosity is decreasing exponentially, while the density decreases polynomially with increasing of temperature. Highest apparent viscosity was obtained for the mustard Boneco and lowest for the mustard SNICO. Highest density had mustard COOP, while other two samples had similar densities. We had also investigated the effect of storing on mustards apparent viscosity and all samples had a bit lower values after storing. Changes of rheological properties with temperature and storing time could be caused by internal structural changes and by destruction of bonds.

Key words: *whole mustards; apparent viscosity; density; storing; temperature.*

INTRODUCTION
One of the most used materials from mustard seeds is oil, which could be used in many areas e.g. in industry as a lubricant or diesel fuel additive, in traditional medicine as antitumor, antiviral and analgesic agent, as well as in food preparation as a condiment and a preservative (*Kostić et al., 2018*). *Rapp et al.* (*2021*) have reported the properties of biofuels and biolubricants made from Indian mustard.
Mustard paste is a non-Newtonian material for which must be applied apparent viscosity, defined as a ratio of shear stress and corresponding shear rate. It is expressed in physical unit Pa·s. Viscosity changes with temperature, for most of the liquids decreases with increasing temperature and can be described by an Arrhenius type equation

$$\eta = \eta_0 \, e^{-\frac{E_A}{R\,T}} \qquad (1)$$

where η_0 is reference value of viscosity, E_A is activation energy, R is gas constant and T is absolute temperature (*Figura & Teixeira, 2007*).
According to *Juszczak et al.* (*2004*) mustard is a pungent, spicy-tasting paste which is usually used as a condiment, and it is made from party deoiled mustard flour or mustard seeds, water, food acids, vinegar, salt, sugar and flavouring additives. There are many types of mustards that differ in its composition, for example: whole mustard, whole grain mustard, honey mustard, spicy mustard, American mustard (from yellow mustard), horseradish mustard, Dijon mustard, English mustard, French mustard, hot pepper mustard, etc.
Juszczak et al. (*2004*) had mentioned that the rheological properties of processed mustard are influenced by the size of solid phase particles, which could be controlled during the manufacturing (e.g. at the milling process). The rheological properties of mustard are also affected by other factors such as its dry matter content, the presence of oil fraction and the addition of thickeners (*Juszczak et al., 2004*). Authors studied the temperature relation of mustard apparent viscosity in the temperature range (8 – 30) °C and described this dependency with an Arrhenius equation. Authors (*Aguilar & Ziegler, 1990*) found that viscosity of dispersions of mustard seeds had decreased with increased temperature. *Aguilar et al. (1991)* compared mustards with different particle sizes obtained by milling (slightly coarse, standard, and fine). They observed higher apparent viscosity in no-mixing variants of mustard. Higher apparent viscosity of the fine milling variant, authors (*Aguilar et al., 1991*) explained by greater surface area and by increased chemical related particle-particle interactions due to the smaller particles. In case of slightly coarse milling variant, the higher apparent viscosity may be related to packing density or due to physical interactions between large particles of irregular shape (*Aguilar et al., 1991*). Differences in apparent viscosity after mixing could not be detected because the mixing had disturbed the formation of a soft structure or network of particles (*Aguilar et al., 1991*). Flow behaviour of processed mustard was described with

Herschel-Bulkley model by *Aguilar et al. (1991). Bhattacharya et al. (1991)* had observed pseudoplastic behaviour with yield stress for three types of mustard pastes (paste with whole mustard seeds; paste with dehulled kernels; paste from meal). Authors used Herschel–Bulkley model for all three types of mustard pastes. *Bhattacharya et al. (1991)* found that yield stress, consistency index and apparent viscosity of the mustard pastes increased, but the flow behaviour index decreased with a moisture content decrease. Authors identified that the mustard pastes from meal showed the highest apparent viscosity, followed by the pastes with whole mustard seeds, and lowest apparent viscosities were observed for pastes with dehulled kernels (*Bhattacharya et al., 1991*). *Kang et al. (2020)* had analysed the flow profiles of yellow mustard mucilage and its two fractions (water soluble and water insoluble fraction). Authors had observed shear-thinning flow behaviour. *Cui et al. (1994)* investigated rheologic behaviour of water-soluble yellow mustard and observed pseudoplastic (shear thinning behaviour). *Repin et al. (2018)* studied the flow behaviour of yellow mustard mucilage at different concentrations. Authors observed shear thinning behaviour in all cases.
Similar observations were performed on various materials. *Ahmed et al. (2013)* had analysed flow properties of purees from rocket leaves. From their research is clear that the flow behaviour of puree sample could be well described by the Herschel–Bulkley model. *Baslingappa Swami et al. (2004)* investigated flow characteristics of black gram batter and found that batters exhibited shear thinning behaviour, and it could be described by the Herschel–Bulkley model. Authors also determined the bulk density of the batters by weighing the exact volume of sample. *Morales-Tovar et al. (2020)* observed that the chan mucilage exhibits a non-Newtonian behaviour of the pseudoplastic type. Authors applied the Ostwald de Waele equation for characterising the flow behaviour of the chan mucilage. *Oliveira et al. (2019)* indicated that the flow behaviour of biodegradable films based on Pereskia aculeata Miller mucilage exhibited shear thinning behaviour and described it by power law model (Ostwald – de Waele equation). Decrease in the apparent viscosity caused by increased shear rate authors explained by the fact that when stress is applied the molecules of the solution begin to become ordered, thus, high applied stress produces higher ordering, and consequently, lower apparent viscosity (*Oliveira et al., 2019; Steffe, 1996*). *Orcajo et al. (2013)* had compared flow curves for hydrolysed and non-hydrolysed granules mayonnaise with the commercial mayonnaise sample. Authors observed that the apparent viscosity decreases with increments in the shear rate, which is a feature of shear thinning products. *Orcajo et al. (2013)* found that non-hydrolysed granules mayonnaise reached highest values of apparent viscosity, while hydrolysed granular and commercial mayonnaise had comparable values. *Jouki et al. (2014)* mentioned that apparent viscosity besides the temperature depends also on chemical composition and structure. *Kishk & Elsheshetawy (2013)* also observed decrease of apparent viscosity during the storage of mayonnaise. *Hakimian et al. (2022)* had examined microbial and physicochemical properties of mayonnaise. Authors investigated the effect of storing time on these properties and found that apparent viscosity had decreased with storing time.
It is very hard to find information about physical properties of mustards and how are they affected by selected properties. That is why the aim of this article was to investigate the effect of temperature and storing time on the rheologic properties of mustards.

MATERIALS AND METHODS

In our article we compared apparent viscosity and density of three types of whole mustards from different producers (Boneco, SNICO, COOP). Composition of mustards was similar, only small differences were in used ingredients like vinegar and sugar. We performed measurements of both parameters in the temperature range (5 – 25) °C. Apparent viscosity was measured on rotational viscometer Anton Paar DV-3P and density was determined according to definition (exact volume of sample was weighted on scales with precision 0,0001 g). Presented are averages of two values. Sample cooling was performed in cooling box and measurements were realized after the temperature stabilization. Heating of the sample was performed in water bath. Measurements of apparent viscosity were repeated also after three weeks of storing. There were constructed dependencies of rheological properties on temperature and storage time and evaluated by the regression equations and the coefficients of determination.
Temperature dependency of mustard apparent viscosity can be modelled by decreasing exponential function (2).

$$\eta_a = A\, e^{-B\left(\frac{t}{t_0}\right)} \qquad (2)$$

where η_a is apparent viscosity (Pa·s), t is temperature (°C), t_0 is 1 °C, A and B, coefficients of regression equation (2), are constants dependent on kind of material, and on ways of processing and storing. Similar dependency of mustard density can be characterized by decreasing polynomial function of second degree (3)

$$\rho = C\left(\frac{t}{t_0}\right)^2 - D\left(\frac{t}{t_0}\right) + E \qquad (3)$$

where ρ is density (kg·m^{-3}), C, D and E, coefficients of regression equation (3), are constants dependent on kind of material, and on ways of processing and storing.

RESULTS AND DISCUSSION

In this article we compared apparent viscosity and density of three types of whole mustards from different producers (Boneco, SNICO, COOP). Temperature dependencies of mustards apparent viscosity is presented on Fig. 1.

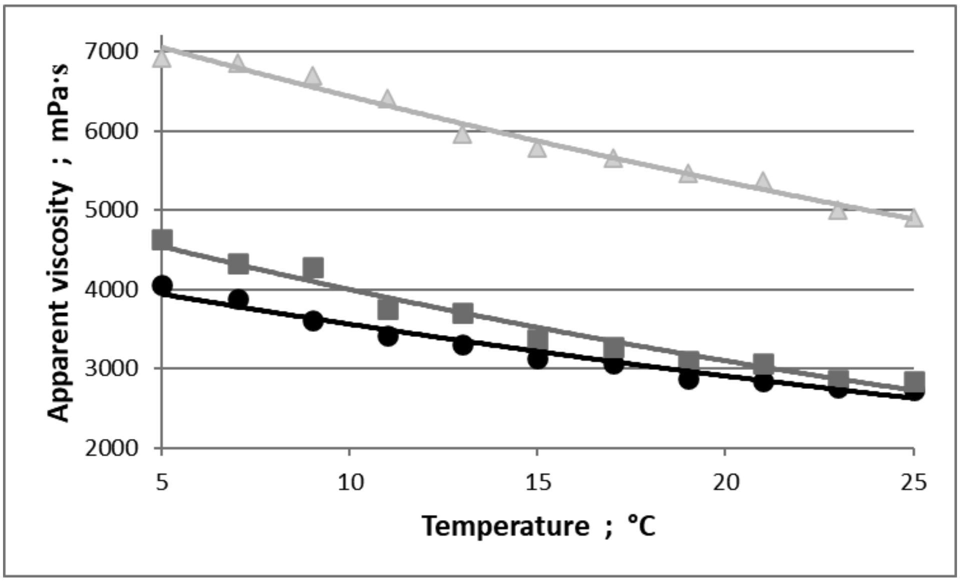

Fig. 1 Temperature dependency of mustard apparent viscosity: Boneco (▲), COOP (■), SNICO (●)

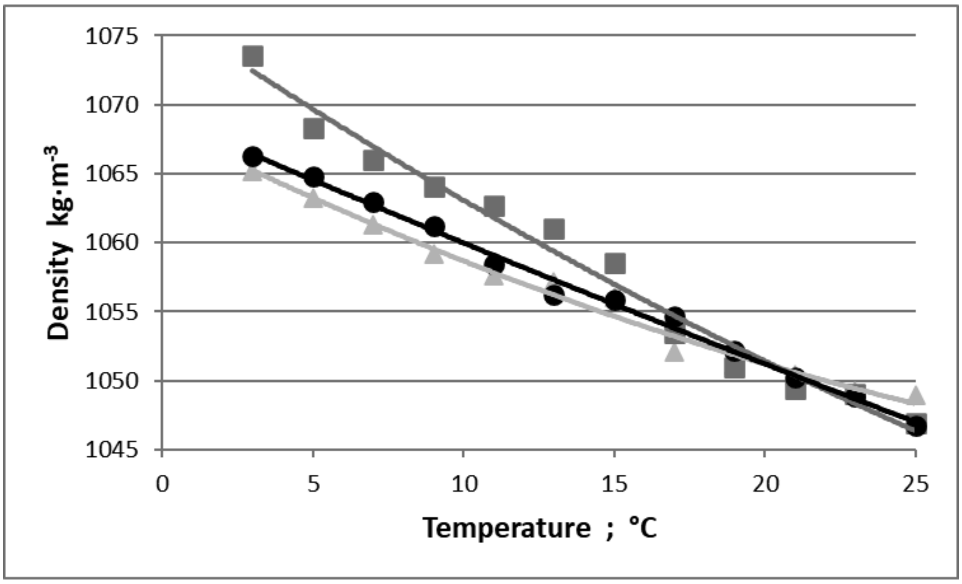

Fig. 2 Temperature dependency of mustard density: Boneco (●), COOP (■), SNICO (▲)

It could be seen that for all examined samples the apparent viscosity decreases with increment of temperature. This is in accordance with the Arrhenius equation (1). Coefficients of regression equation (2) and coefficients of determination are summarized in Tab. 1. Similar observations were obtained by other authors (*Aguilar & Ziegler, 1990*; *Juszczak et al., 2004*). Highest apparent viscosities were observed for mustard Boneco, lowest values for sample SNICO.
Effect of temperature on mustard density is shown on Fig. 2. For all samples was applied decreasing polynomial function of second degree. Decreasing of density with temperature were also obtained for other materials *(Kumbár & Nedomová*, 2015; *Thomas et al., 2015*). Density of the mustard COOP was highest, while other two samples had similar densities. Coefficients of regression equation (3) and coefficients of determination are summarized in Tab. 1.
We had also investigated the effect of storing on apparent viscosity of mustards. Samples of mustards were stored in cooling box and next measurements were performed after three weeks. On Fig. 3 are shown differences in apparent viscosity of mustard Boneco caused by storing. For all three samples we obtained a bit lower values after storing. Changes of rheological properties with temperature and storing time could be caused by internal structural changes and by destruction of bonds. Decrease of apparent viscosity after storing was observed by other authors (*Hakimian et al., 2022*; *Kishk & Elsheshetawy, 2013*).

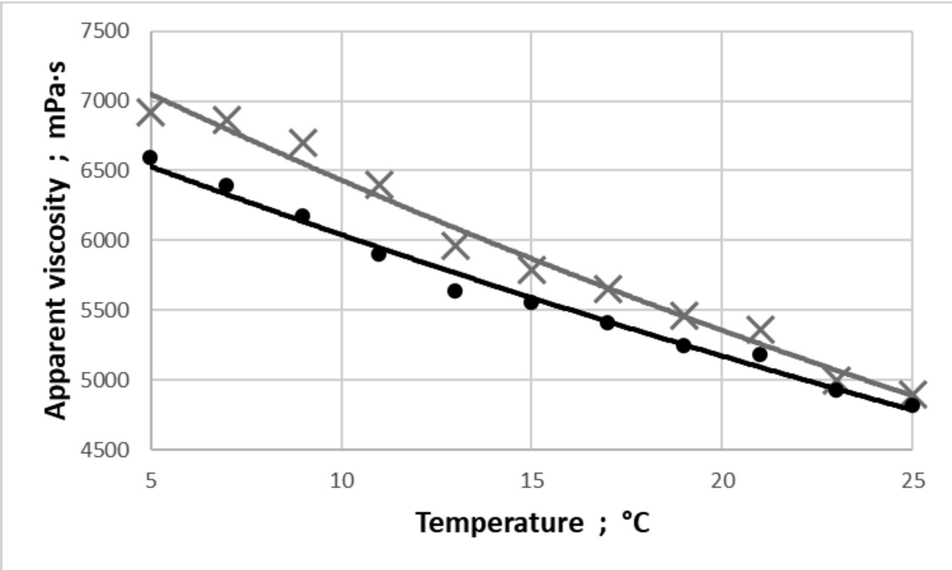

Fig. 3 Temperature dependency of mustard Boneco apparent viscosity: first measurement (×), next measurement after three weeks of storing (●)

Tab. 1 Coefficients of regression equations (2 – 3) and coefficients of determination

Mustard / measurement	A mPa·s	B mPa·s	R^2	
SNICO / first	4360.8	0.020	0.9685	
SNICO / next	4031.3	0.016	0.9748	
COOP / first	5158.5	0.025	0.9724	
COOP / next	4478.4	0.018	0.9676	
Boneco / first	7724.7	0.018	0.9821	
Boneco /next	7056.8	0.016	0.9889	
Mustard	**C kg·m^{-3}**	**D kg·m^{-3}**	**E kg·m^{-3}**	**R^2**
SNICO	0.0113	1.0855	1068.4	0.9846
COOP	0.0102	1.4718	1076.8	0.9808
Boneco	0.0023	0.9452	1069.2	0.9938

CONCLUSIONS

Food materials composition is different, so their physical properties are very complex. Physical properties of food materials depend on the manipulation, external conditions and on other factors, which determine their behaviour. Rheological properties of whole mustard were measured and analysed in this paper. Mustard paste is a non-Newtonian material, so for this material is relevant apparent viscosity. Effect of temperature and storing time on measured samples of whole mustard was investigated and comparison of used samples was made. We found out that apparent viscosity of samples decreased exponentially with increasing temperature, so the Arrhenius equation is valid. Coefficients of determination reached high values in the range (0.967 – 0.994). Comparable rheological results for mustard were reported by *Juszczak et al. (2004)*. Proportion of the curves in Fig. 1 could be caused by different composition of analysed samples (*Aguilar et al., 1991*). Apparent viscosity had decreased with storage time, which can be caused by structural changes in samples during storing (*Hakimian et al., 2022*; *Kishk & Elsheshetawy, 2013*). The rheological characteristics can be used for designing of technological equipment or containers for distribution of the product to the final users. The knowledge of flow behaviour is also important for the development of new recipes and direct qualitative assessment of the products. Further analysis of samples is needed for the characterization of mustard flow behaviour.

ACKNOWLEDGMENT

This publication was supported by the Operational Program Integrated Infrastructure within the project: Demand-driven research for the sustainable and innovative food, Drive4SIFood 313011V336, co-financed by the European Regional Development Fund.

REFERENCES

1. Aguilar, C. A., & Ziegler, G. R. (1990). Effect of temperature and electrolytes on the viscosity of aqueous dispersions of mustard seed (Sinapsis alba) mucilage. *Food Hydrocolloids*, 4(2), 161-166.
2. Aguilar, C., Rizvi, S. S. H., Ramirez, J. F. & Inda, A. (1991). Rheological behavior of processed mustard. I. Effect of milling treatment. *Journal of Texture Studies*, 22, 59-84.
3. Ahmed, J., Al-Salman, F., & Almusallam, A. S. (2013). Effect of blanching on thermal color degradation kinetics and rheological behavior of rocket (Eruca sativa) puree. *Journal of Food Engineering*, 119, 660-667.
4. Baslingappa Swami, S., Das, S. K., & Maiti, B. (2004). Effect of water and air content on the rheological properties of black gram batter. *Journal of Food Engineering*, 65, 189-196.
5. Bhattacharya, S., Vasudha, N. & Krishna Murthy, K. S. (1991). Rheology of mustard paste: a controlled stress measurement. *Journal of Food Engineering*, 41(3–4), 187-191.
6. Cui, W., Eskin, N. A. M., & Biliaderis, C. G. (1994). Yellow mustard mucilage: chemical structure and rheological properties. *Food Hydrocolloids*, 8(3–4), 203-214.
7. Figura, L. O., & Teixeira, A. A. (2007). Food Physics, Physical properties – measurement and applications (1st ed.), Verlag, Berlin, Heidelberg, New York: Springer
8. Hakimian, F., Emamifar, A., & Karami, M. (2022). Evaluation of microbial and physicochemical properties of mayonnaise containing zinc oxide nanoparticles. *LWT - Food Science and Technology*, 163, 10 p.
9. Jouki, M., Mortazavi, S. A., Tabatabaei Yazdi, F., & Koocheki, A. (2014). Optimization of extraction, antioxidant activity and functional properties of quince seed mucilage by RSM. *International Journal of Biological Macromolecules*, 66, 113-124.
10. Juszczak, L., Witczak, M., Fortuna, T., & Banyś, A. (2004). Rheological properties of commercial mustards. *Journal of Food Engineering*, 63(2), 209-217.
11. Kang, J., Guo, Q. & Cui, S. W. (2021). Other emerging gums: Flaxseed gum, yellow mustard gum, and psyllium gums (Chapter 20). In *Handbook of Hydrocolloids* (Third Edition) (pp. 597-624), Elsevier Ltd.
12. Kishk, Y. F. M., & Elsheshetawy, H. E. (2013). Effect of ginger powder on the mayonnaise oxidative stability, rheological measurements, and sensory characteristics. *Annals of agricultural science*, 58(2), 213-220.
13. Kostić, M. D., Djalović, I. G., Stamenković, O. S., Mitrović, P. M., Adamović, D. S., Kulina, M. K., & Veljković, V. B. (2018). Kinetic

modeling and optimization of biodiesel production from white mustard (Sinapis alba L.) seed oil by quicklime-catalyzed transesterification. *Fuel*, 223, 125-139.
14. Kumbár, V. & Nedomová, Š. (2015). Viscosity and analytical differences between raw milk and UHT milk of Czech cows. *Scientia Agriculturae Bohemica*, 46, 78-83.
15. Morales-Tovar, M. E., Ramos-Ramírez, E. G., & Salazar-Montoya, J. A. (2020). Modeling and optimization of the parameters affecting extraction of the chan seed mucilage (Hyptis suaveolens (L.) Poit) by mechanical agitation (MA) and ultrasound-assisted extraction (UAE) in a multiple variables system. *Food and Bioproducts Processing*, 120, 166-178.
16. Oliveira, N. L., Rodrigues, A. A., Oliveira Neves, I. C., Teixeira Lago, A. M., Borges, S. V., & de Resende, J. V. (2019). Development and characterization of biodegradable films based on Pereskia aculeata Miller mucilage. *Industrial crops and products*, 130, 499-510.
17. Orcajo, J., Marcet, I., Paredes, B., & Díaz, M. (2013). Egg yolk hydrolysed granules: Characteristics, rheological properties and applications. *Food and bioproducts processing*, 91, 457-463.
18. Rapp, G., Garcia-Montoto, V., Bouyssiere, B., Thiebaud-Roux, S., Montoya, A., Trethowan, R., Pratt, P., Mozet, K., Portha, J. F. & Coniglio, L. (2021). Indian mustard bioproducts dry-purification with natural adsorbents - A biorefinery for a green circular economy. *Journal of cleaner production*, 286, 18 p.
19. Repin, N., Cui, S. W., & Goff, H. D. (2018). Rheological behavior of dietary fibre in simulated small intestinal conditions. *Food Hydrocolloids*, 76, 216-225.
20. Steffe, J. F. (1996). Rheological method in food process engineering, 2nd ed., Freeman Press, East Lansing (USA), 428 p.
21. Thomas, M. J., Bramblett, K. A., Green, B. D., & West, K. N. (2015). Thermophysical and absorption properties of brominated vegetable oil. *Journal of Molecular Liquids*, 211, 647 – 655.

Corresponding author:
doc. Mgr. Peter Hlaváč, Ph.D., Institute of Electrical Engineering, Automation, Informatics and Physics, Faculty of Engineering, Slovak University of Agriculture in Nitra, Tr. A. Hlinku 2, SK- 949 76 Nitra, Slovak Republic, phone: +421 37641 4749, e-mail: Peter.Hlavac@uniag.sk