Rheological characteristics of corn flour used during waterfowl feeding – influence of grinding and temperature

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ABSTRACT

In this study rheological characteristics of corn flour used in the over-feeding period for waterfowls, were investigated due to different composition and treatment of the feed.

A rheometer equipped with a plate-plate oscillation measuring system was used to measure rheological behavior of different blends of corn flour and water. Both, water content and particle sizes of the flour were objects of interest. In addition, the same corn flour mixes were used to study and measure eventually rheological changes during heat treatment.

One of the conclusions seem to be that the elastic properties in mixes of water and maize flour, are higher in mixes containing grinded corn of bigger particle sizes (1.0 mm), compared to less particle sizes (0.5 mm).

INTRODUCTION

There are numerous areas where rheological data are needed in the food and feed industry, like;

- determining ingredient functionality in product development.
- process engineering calculations which involve a wide range of equipment such as pipe-lines, pumps, extruders, mixers, coaters, heat- exchangers, homogenizers etc.
- intermediate- or final product control.
- shelf life testing and evaluation of texture[1]

The feeding of waterfowl for fatty liver production is largely based on the use of maize as an energy source, Table 1. This cereal is used during the rearing period. But it is mainly used during the overfeeding period, when maize represents more than 95% of the dried matter in the diet. During the overfeeding period, the diet is given as a mixture of maize whole grain, maize flour, water and a premix containing vitamins, minerals and additives. The mixture is homogenized and given using an automatic feed dispenser, during which a tube is placed in the esophagus in order to introduce a large amount of food in a few seconds. Normal feeding regime consist of 2 feedings pr. day for ducks, and 3-5 times for geese pr. day. This is going on during a period of 10-12 days for ducks, and 15-18 days for geese[2,3].

The tradition of force-feeding is very old, probably originating from Egypt; where there is early evidence in paintings. The Greeks and the Romans perpetuated the tradition, later expanded during the Middle Ages by Jewish populations. In 2002, 80% of the world foie gras production originated from France[4,5], although the genotypes used and the procedure itself have changed [4,5,6].

Table 1: Approximate composition of dried whole grain corn[7]

Constituent	Aver.	Std. Dev.	Range (calculated as ± 2 Std. deviations)
Dry matter	86.4 %	1.1	84.2-88.6%
Crude proteins	8.1 %	0.7	6.7-9.5 %
Crude fibre	2.2 %	0.4	1.4-3 %
Fat	3.7 %	0.4	2.9-4.5 %
Ash	1.2 %	0.1	1.0-1.4 %
Starch	64.1 %	1.9	60.3-67.9%
Sugars	1.6 %	0.5	0.6-2.6 %
Gross energy (kcal/kg)	3860	70	3720-4000
Lysine g/kg	2.4	0.4	1.6-3.2
Amylose g/100g starch	27		25-30
Amylopectin g/100g starch	73		70-75

Thus, the success in fatty liver production depends mostly on the overfeeding program and the ability of animals to receive increasing amount of the mixture along the overfeeding period. Thus it depends indirectly on the rheological properties of the mixture such as viscosity. However, rheological properties and its factors of variation are little known. Several factors are supposed to influence the viscosity of the mixture such as the maize/water ratio, the whole grain/flour ratio, the flour particle size, the water temperature and additives. But no clear recommendation is available. Farming practices varies among species (ducks vs geese), production systems (intensive, rational or farm production), season (water temperature), breeder and manufacturer of additives.

Rheological measurements are quite relevant in the food and feed industry as a tool for physical characterization of raw material prior to processing, for intermediate products during manufacturing, and for finished products[8]. In this context, it is useful to develop a standardized measurement method of viscosity and flow rate in an open tube of the mixture used during waterfowl overfeeding.

The objectives with this study were as follows:

- Characterize different mixes of water and milled-, dried whole corn, regarding rheological behavior and particle size variations.
- Investigate the feasibility of a rotational rheometer instrument equipped with a oscillaton plate plate measuring system[9,10] to study texture characteristics in feed mixes with different particle sizes and water content.

MATERIALS AND METHODS

Dried whole- and grinded corn

Dried whole grain corn traditionally cultivated in the southwest of France were prepared by INRA-Toulouse. The maize whole grain, Table **1**, was grinded using hammermill grinding with a grid of 0.5 or 1mm.

The flour were transported from INRA Toulouse to Norway. These products were stored at +4°C in partial vacuumed plastic bags until use at The University of Life Sciences, Aas, Norway according to the mixing set up in Table **2**.

Mixing of water and flour was carried out via an electric mixer – speed 5 in 5 minutes (Bosch, Enr. MUM54240/01 CNUM 51, Slovenia).

Instrumental analysis and experimental set-up

The Physica MCR301 rheometer (Paar Physica, Anton Paar, Stuttgart, Germany, 2010) fitted with a plate-plate measuring system PP50/P2-SN9573 was used for viscosity measurements; Figure **1**.

Table 2: Mixing setup for the 2 mixes tested of grinded corn (0.5 and 1.0 mm) and 49% water.

Mix of flour grind 0.5 mm, 49% H_2O, Ingredients (g/100g)	F49 G0.5
Maize grinded at 0.5 mm	51
Water	49
Sum	100
Mix of flour grind 1.0 mm, 49% H_2O, Ingredients (g/100g)	F49 G 1
Maize grinded at 1 mm	51
Water	49
Sum	100

The instrument was programmed to perform the following;

- Measurements recorded at non-destructive oscillation conditions at +20°C for one hour at 0.1% strain and angular frequency of 10 rad/s. Normal force on sample was set to 40 N.
- An amplitude sweep was carried out at 10 rad/s with strain varying from 0.1 to 200%. The normal force on the sample was fixed at 40 N. Hence the gap varied slightly during the test.
- Temperature scans at constant strain (γ) of 0.1% with angular frequency (ω) = 10 rad/s in the temperature range from 20ºC to 80 ºC. Every scan took place in 30 min with measurements at every 2.0 ºC increase of temperature in the range 20- 80 ºC.
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The viscosity (η) was measured as a function of shear rate ($\dot{\gamma}$).

The Malvern Mastersizer 3000 (S.nr. MAL1083189, Malvern, UK, 2013) fitted with a Aero S dispersion unit, was used to measure particle sizes in the different grinded corn products investigated.

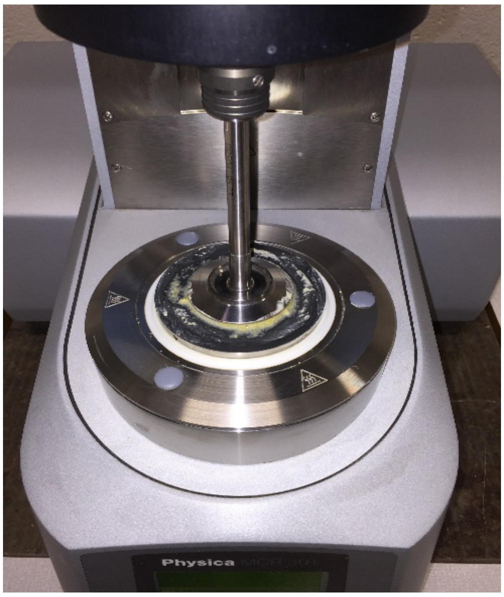

Figure 1: The plate-plate oscillation measuring system connected to a Physica MCR 301 rheometer.

<u>Statistical treatment</u>

All rheological measurements were carried out as screening tests to investigate connections between viscosity levels, particle distributions, water content and temperature influences in the samples tested.

RESULTS

Results of the viscosity determination for the corn feed samples, using a plate-plate measuring system, are shown in Fig. 2, 3, 4, 5 and 6.

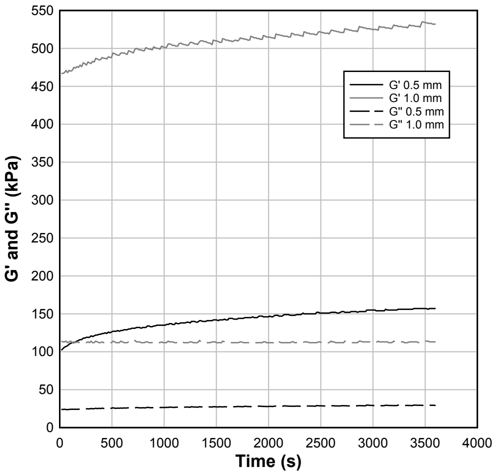

Figure 2: Development in storage modulus G' (elastic properties) and loss modulus G'' (viscous properties) at 20 ºC during 60 minutes holding time for tested corn flour mixes (0.5 and 1.0 mm) containing 49% water. Results from plate-plate oscillation measuring system connected to the Physica MCR 301 rheometer at constant strain.

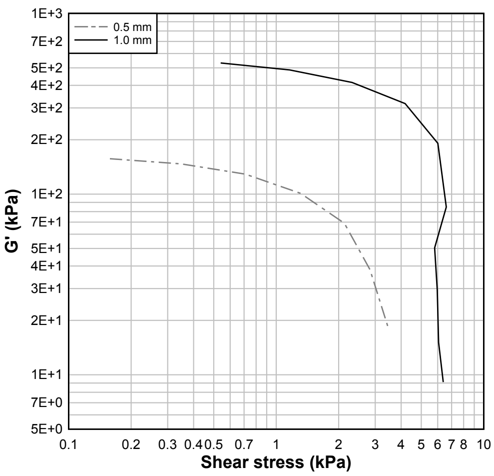

Figure 3: Storage modulus G' versus shear stress for samples of corn flour mixes containing 49% water (0.5 and 1.0 mm) measured at 20 ºC.

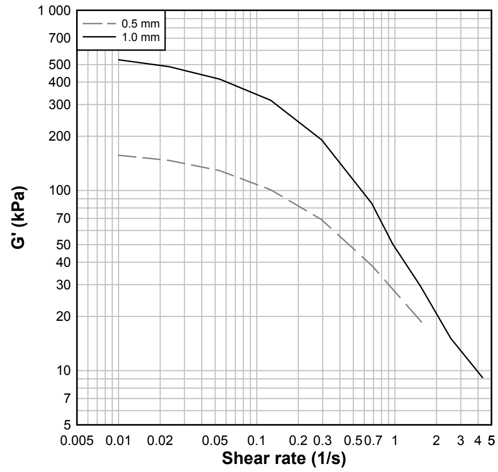

Figure 4: Storage modulus G' versus shear rate for samples of corn flour mixes containing 49% water (0.5 and 1.0 mm) measured at 20 ºC.

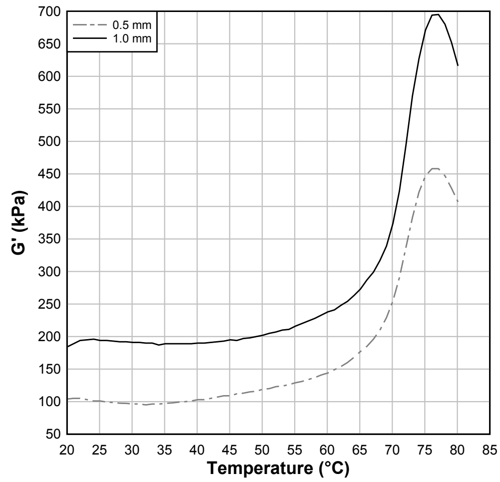

Figure 5: Development of storage modulus G' in corn flour samples containing 49% water (0.5 and 1.0 mm) within one temperature/time cycle. Every cycle took place in 30 min. Measurements at every 2 ºC increase of temperature in the range 20-80 ºC at constant 0.1% strain using a non-destructive oscillatory plate-plate measuring system.

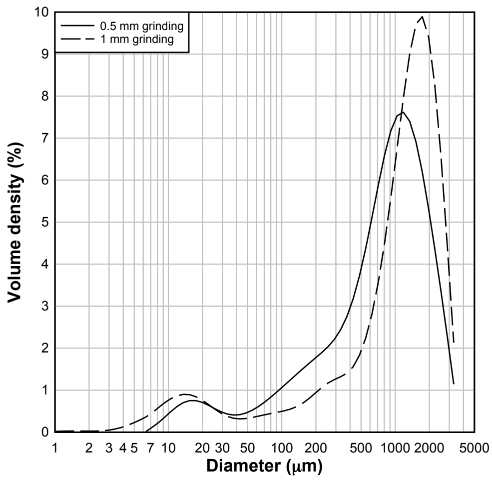

Figure 6: Size distribution of particles in the grinded corn samples measured by the Malvern Mastersizer 3000 using the Aero S unit.

Regarding the Dx values expressed in Table **3**; Dv 10 – the particle size below which 10% of the sample lies. Dv 50 – the particle size below which 50% of the sample lies. This value is also known as the Mass Median Diameter (MMD), or the median of the volume distribution. Dv 90 – the particle size below which 90% of the sample lies.

Table 3: Groups of particle sizes expressed in the different grinded corn samples measured (0.5 and 1.0 mm), expressed as Dx values (μm).

Dx expressed as μm	Grinding corn at 0.5 mm	Grinding corn at 1 mm
Dx (10)	100	66.8
Dx (50)	849	1250
Dx (90)	2060	2440

DISCUSSION

One advantage with viscoelastic measurements is the extremely small deformation of the sample, only as much as required for performing a measurement and yet so little as the material does not change. Because of this, it is possible to perform repeated measurements on the same sample and follow the changes occurring in the sample over time.

Figure **2** shows more or less the same progress for the two corn flour mixes (0.5 and 1 mm). But the 1 mm mix got highest values, especially regarding elastic properties (G') of the mix. In contrast to the viscous properties (G'') of the mix which seemed to be at a constant level, the storage modulus increased in value during 60 min holding time at 20 ºC.

Figure **3** shows G' versus shear stress. The coarser ground mixture (1 mm) exhibits a higher G' value, being stiffer than the finer ground mixture (0.5 mm). The coarser ground mixture also has a larger strength shown by the larger values of the shear stress.

Figure **4** shows G' versus shear rate. Again it is seen that the coarse ground mixture exhibits a higher G' value.

Figure **5** demonstrates a type of testing which is very useful when studying problems that involves temperature induced changes in rheological behaviour. This thickening development of the mixes are probably mostly based on starch gelatinization of the mixes. This reaction take mainly place from about 60 ºC. But as demonstrated in fig. 5, a limited increase in thickening is observed over a broader temperature interval below 60 ºC. Most probably this phenomenom depends on the different types of starch and proteins which are present in corn.

Figure **5** also illustrate the phenomenom of decrease in thickening when passing the max point at about 75 ºC . This study of time-dependent flow behaviour resulting from chemical induced reactions such as demonstrated, is often called chemorheology. Again the courser ground mixture exhibits higher G'values than the finer ground mixture.

When using the Malvern Mastersizer 3000 to measure the size distributuion in the two different grinded flour samples (0.5 and

1.0 mm), the instrument was able to measure all particles in the 0.5 mm flour.

However, wehen measuring the 1 mm flour, some of the particles were even bigger than 3.0 mm. These particles were not included in the results given in Figure **6** and in Table **3**.

CONCLUSIONS

Using a oscillation plate-plate measuring system to characterize different mixes of milled dried corn and water regarding rheological behavior, the conclusions from this study can be summarized as follows:

- The elastic properties in mixes of water and maize flour, are higher in mixes containing grinded corn of bigger particle sizes (1mm), compared to less particle sizes (0.5 mm).
- Regarding temperature and mixing of flour and water – the temperature of the water benefits to stay below 60 ºC to avoid starch gelatinization of the mixes in front of feeding.

Based on the laser diffraction particle size measurements, the conclusions can be summarized like:

- The Mastersizer managed to group the two different grinded corn samples according to size and size distribution below 1 mm.
- The Mastersizer also calculated the amount of particles according to the diameter (µm) of the particles. This knowledge may be of importance regarding production of different feed emulsions; either during product development or as a regular product control.

ACKNOWLEDGEMENTS

The authors would like to thank the staff of J. Arroyo (Ferme de l'oie et du canard, Coulaures, France) for providing maize and M. Moulis (UE PECTOUL, INRA, France) regarding grinding corn at different particle sizes. We are also grateful to the staff at the Pilot Plant at IKBM, Norway for storing of these products.

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