ANNUAL TRANSACTIONS OF THE NORDIC RHEOLOGY SOCIETY, VOL. 23, 2015

Rheology of fine- and large particulated feed used during waterfowl overfeeding characterized by a ball measuring system

Elling-Olav Rukke[1], Laurence Fortun-Lamothe[2], Corinne Pautot[2], and Reidar Barfod Schüller[1]

[1]Dept. of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O.Box 5003, N-1432 Aas, Norway.
[2]UMR 1388 GenPhySE, INRA/INPT, 31326 Castanet Tolosan, France.

ABSTRACT

Corn and blends of grinded corn and whole grain is traditionally used as feed for waterfowls both as ordinary feed and during overfeeding periods. In this study rheological characteristics in feed used in the over-feeding period, were investigated due to different composition and treatment of the feed.

A rheometer equipped with a ball measuring system was used to measure the viscosity of different corn feed products. In addition the particle size and the size distribution in different dried grinded corn samples were characterized by use of laser diffraction particle size measurements.

All the tested mixtures have almost similar pseudoplastic behaviour in all the tested mixtures regarding content of water (42% and 49%), ratio maize flour/maize whole grain and the particle sizes of the flour.

The Mastersizer managed to group the different grinded corn samples according to size and size distribution below 3 mm.

INTRODUCTION

France is the main producer (73%) of foie gras (fatty liver) of ducks or geese in the world[1]. French foie gras is a traditional product, a coveted dish with a high added value. 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[1,2], although the genotypes used and the procedure itself have changed [1,2,3,4].

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[4,5].

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.

Table 1: Approximate composition of dried whole grain corn[6]

Constituent	Aver.	Std. Deviat.	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	3860 kcal/kg	70	3720-4000 kcal/kg
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

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 blends of milled- and dried whole corn, regarding rheological behavior and particle size measurements.
- Characterize blends of milled- and dried whole corn after different mixing methods; manually and mechanically.
- Investigate the feasibility of a rotational rheometer instrument equipped with a Ball Measuring system[7,8] to study texture characteristics in feed emulsions with different particle sizes and water content.
- Investigate the feasibility of using a laser diffraction particle size measurement instrument to characterize and distinguish between particle sizes prepared after milling of whole dried corn.

MATERIALS AND METHODS

Dried whole- and grinded corn

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

Figure 1: Dried whole grain- and grinded corn (0.5mm and 1 mm) prepared by INRA-Toulouse.

The flour and the whole grain, **Table 1**, 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**.

Table 2: Mixing setup for the 8 mixtures tested of grinded corn (G 0.5 mm and G1.0 mm), whole grains and water (42% and 49%)

Mix of flour grind 0.5 mm, 49% H_2O, Ingredients (g/100g)	F49 G0.5	GF49 G 0.5
Maize whole grain		12.75
Maize grinded at 0.5 mm	51	38.25
Water	49	49
Sum	100	100
Mix of flour grind 1.0 mm, 49% H_2O, Ingredients (g/100g)	F49 G 1	GF49 G 1
Maize whole grain		12.75
Maize grinded at 1 mm	51	38.25
Water	49	49
Sum	100	100
Mix of flour grind 0.5 mm, 42% H_2O, Ingredients (g/100g	F42 G0.5	GF42 G0.5
Maize whole grain		17.4
Maize grinded at 0.5 mm	58	40.6
Water	42	42
Sum	100	100
Mix of flour grind 1.0 mm, 42% H_2O, Ingredients (g/100g)	F42 G 1	GF42 G 1
Maize whole grain		17.4
Maize grinded at 1 mm	58	40.6
Water	42	42
Sum	100	100

Mixing was carried out in two ways; manually by a tablespoon or mechanically via an electric mixer – speed 5 in 5 minutes (Bosch, Enr. MUM54240/01 CNUM 51, Slovenia). The mixes of flour (0.5 and 1.0 mm) and whole grain in the ratio 70:30 added 42% water, were also used as standard.

Instrumental analysis & experimental set-up

The Physica MCR301 rheometer (Paar Physica, Anton Paar, Stuttgart, Germany, 2010) fitted with a ball measuring system BM 12/72.5, D 12 mm, serie No 16978 was used for viscosity measurements; **Figure 2**. The ball stirrer was positioned with 20 mm clearance from the bottom to the center of the ball. Viscosity of the emulsions was measured during one rotation ($< 360^0$).

The measurements were recorded at $+20^oC$, three replicate measurements of each mix (blend) were carried out. Viscosity (η) was meadured as a function of shear rate λ(1/s).[8]

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 2: The ball measuring system connected to a Physica MCR 301 rheometer. Temperature sensor at left side of the picture.

Statistical treatment

All measurements were carried out as screening tests to investigate connections between viscosity levels and mixture receipes in the samples tested. Three replicate measurements were taken of each mix. One-way ANOVA, Minitab 16.2.2, Tukey 95% simultaneous confidence intervals all pairwise comparisons, was used as statistical test method in order to confirm eventually rheological statistical significance of differences among the samples tested ($p<0.05$).

RESULTS

Results of the viscosity determination for the corn feed samples, using a ball measuring system, are shown in **Figure 3**, **Figure 4**, **Figure 5** and **Figure 6**. All figures except the photos, are focusing on viscosity (η) as a function of shear rate (γ)[9].

Figure 3: Rheology test of a corn feed sample measured by the ball measuring system connected to the Physica MCR 301 rheometer. Temperature sensor at left side of the picture. Start of test.

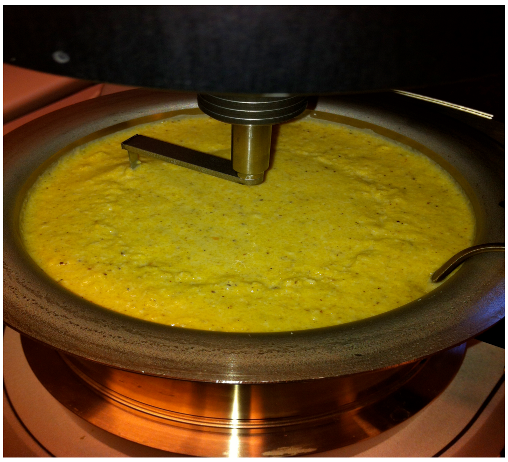

Figure 4: Rheology test of a corn feed sample measured by the ball measuring system connected to the Physica MCR 301 rheometer. End of test.

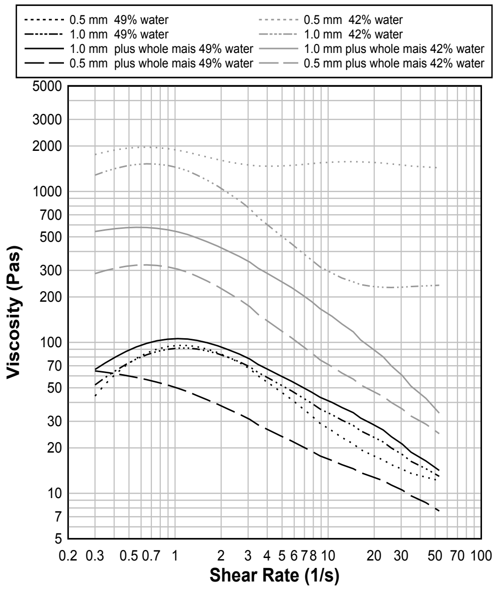

Figure 5: Rheology test of a corn feed samples measured (49% and 42% H_2O) by a ball measuring system (BM 12/72.5, D 12 mm) connected to a Physica MCR 301 rheometer at 20°C (curves smoothed in DPlot using a 5% smoothing window).

Table 3: Slope values of curves showed in Fig. 5. Shear rate area between 1 and 6 (1/s). Results of corn feed samples measured (49% and 42% H_2O) by a ball measuring system (BM 12/72.5, D 12 mm) connected to a Physica MCR 301 rheometer at 20°C.

Sample	Slope value $Pas/(1/s)$	Std. Dev. 3 replica
0.5 mm 42% H_2O	-2.49	2.78
1 mm 42% H_2O	-1.46	0.28
0.5 mm 42% H_2O + whole grain	-1.31	0.24
1 mm 42% H_2O + whole grain	-2.03	0.24
0.5 mm 49% H_2O	-1.50	0.03
1 mm 49% H_2O	-1.84	0.036
0.5 mm 49% H_2O + whole grain	-1.20	0.37
1 mm 49% H_2O + whole grain	-1.56	1.03
AVERAGE	-1.67	

Figure 6 and **Table 4** characterize the particle size distribution in the different grinded corn samples. The results are all obtained from the Malvern Mastersizer 3000 measurements using the Aero S unit.

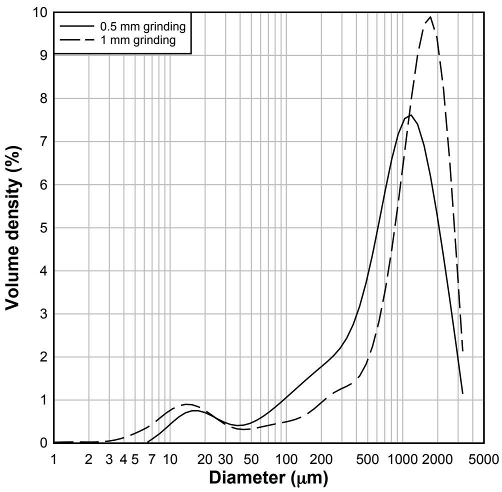

Figure 6: Size distribution of particles in the grinded corn samples measured by the Malvern Mastersizer 3000 using the Aero S unit.

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

Table 4: Groups of particle sizes expressed in the different grinded corn samples measured; 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

Regarding the rheology tests, the viscosity of the tested recepeis are a bit different. But all the samples exhibit pseudoplastic behaviour shown by having almost similar negative slopes (Pas/(1/s)); **Figure 5** and **Table 3**. The negative slopes are all due to calculations of the slopes in the shear rate area between 1 and 6 (1/s).

All results shown, are based on samples mixed using an electric mixer – speed 5 in 5 minutes. The results indicate reduced viscosity in all feed blends containing 49% H_2O after mechanically mixing compared to the same feed manually blended (measurement after 60 min at 20^{o}C).

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, when 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 4**.

CONCLUSIONS

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

- The main factor influencing the viscosity level of the characterized corn feed products seems to be the composition of the mixture. Namely the water content, the ratio maize flour/maize whole grain and the particle size.
- All the tested mixtures have almost similar pseudoplastic behaviour in all the tested mixtures regarding content of water (42 and 49%), ratio maize flour/maize whole grain and the particle sizes of the flour.

- The viscosity is lower in mixtures containing whole corn.
- The viscosity is higher in feed containing grinded corn of bigger particle sizes (1mm) compared to less particle sizes (0.5 mm).
- The results indicate reduced viscosity in all feed blends containing 49% H_2O after mechanically mixing compared to the same feed manually blended (measurement after 60 min at 20^oC).
- Using these blends as feed – positive with reduced viscosity after mechanical mixing according to the force feeding regime.

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

- Mastersizer measurements are feasible to characterize and distinguish between particle sizes of grinded corn up to about 3 mm in diameter.
- The Mastersizer managed to group the different grinded corn samples according to size and size distribution below 3 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 optimal storing of these products.

REFERENCES

1.CIFOG Comité Interprofessionnel des palmipèdes à Foie Gras, (2013), "Rapport économique de l'année 2012", Assemblée Générale du 21/06/2013, Sarlat, France, 82

2. Arroyo, J., Fortun-Lamothe, L., Dubois, J.-P., Lavigne, F and Auvergne A. (2012), "Schedule and management of food transitions in geese for the production of foie gras", INRA Prod. Anim., 25, 5, 419-430

3. Marie-Etancelin, C., Basso B., Davail S., Gontier K., Fernandez X., Vitezica Z.G., Bastianelli D., Baéza E., Bernadet M.D., Guy G., Brun J.M. and Legarra A. (2011), "Genetic parameters of product quality and hepatic metabolism in fattened mule ducks", J. Anim. Sci., 89 (3), 669-79.

4. Robin N., Babilé R., Peuhorgue A., Dubois J.P. and Leprettre S. (2004), "Facteur de production et qualité des foies gras d'oies et de canards", 6èmes Journ. Rech. Palmipèdes à foie gras, Arcachon, France, 157-166.

5. Arroyo, J., Fortun-Lamothe, L., Dubois, J.P., Lavigne, F., Bijja, B. and Molette, C. (2014), "The influence of choice feeding and cereal type (corn or triticale) during the finishing period on performance of mule ducks", Poult. Sci. 93 (9): 2220-2226.

6. Sauvant D., Perez J.M., Tran G. (2004), "Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses and fish", 2nd Edition INRA Editions, Paris, France,

7. Schatzmann, M., Bezzola, G.R., · H.-E. Minor, H.E., Windhab, E.J. and Fischer, P. (2009), "Rheometry for large-particulated fluids: analysis of the ball measuring system and comparison to debris flow rheometry", Rheol Acta 48, 715-733

8. Schatzmann, M., Peter Fischerand, P. and Bezzola, G.R. (2003**), "**Rheological Behavior of Fine and Large Particle

Suspensions", Journal of hydraulic engineering, 129 (10),796-803.

9. Steffe, J. F. (1996), "Rheological methods in Food Process Engineering", Freman Press, 2807 Still Valley Dr. East Lansing, MI 48823, USA, ISBN 0-9632036-1-4.