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Keywords: Hydrothermal processing, Meal, Properties, Flow

Measuring the physical properties and flowability of steam-treated meal

1. Background and focus

Hydrothermal processing of animal meal has undergone significant development over the last few years aimed at improving meal flowability and reducing bacterial population.
Several methods can be used in laboratories to characterise the physical changes induced by this treatment process, i.e. particle size, Hausner ratio, angles of repose, etc.
As part of a research programme conducted jointly with ACTA, ITAVI, INRA – Nouzilly, ITCF and UCAAB, TECALIMAN assessed the ability of these methods to differentiate between heat-treated meals.

2. Apparatus and methods

2.1. Manufacturing and processing animal meals

The meals were manufactured and processed in a pilot workshop. Two broiler feed formulas were processed in each batch, in 2 mixers fitted with a steam injection system:

- a Lodige brand jacketed ploughshare mixer
- a Forberg brand blade mixer

Various processing scales were applied, such as temperatures ranging from 65 to 105°C and cycle times ranging from 20 to 450 seconds.
After processing, the feedstuffs were cooled and dried:

- in thin layers, in ambient air, for batches processed in the ploughshare mixer
- by circulating air through the mixer, for batches processed in the blade mixer.

This gave a total of 25 different batches of meal.

2.2. Measuring the physical properties and flowability of animal meals

The meals were characterised based on 8 variables: smallest flow diameter, bulk density, tap density, Hausner ratio, angles of repose (flow) (ATES, ATE10 and ATE20) and particle size (d50).

2.2.1. Smallest Flow Diameter (SFD)

The aim was to identify the smallest diameter (mm) of a circular aperture through which powder can flow (TECALIMAN, 1998, i'Tec_Q4). Flowability decreases as the flow diameter increases. This measurement was made once on each sample.

2.2.2. Median diameter (d50) or particle size of animal meals

The median diameter of the meals was calculated using the weights of the particle size test portions recovered by mechanical sieving (TECALIMAN, 1996, i'Tec_B6).
This measurement was made twice for each sample, and expressed in micrometres.

2.2.3. Bulk Density (BD), Tap Density (TD) and Hausner Ratio (HR)

The Hausner Ratio is the ratio between the tap and bulk densities of an animal meal (TECALIMAN, 1998, i'Tec_Q9).
Product flowability decreases as the Hausner ratio increases.
This measurement was made once on each sample.

2.2.4. Angle of repose (flow) (ATE)

The method consists in creating a cone-shaped pile of powder and measuring the angles that form (TECALIMAN, 1998, i'Tec_Q3) :

- Apex angle at the top of the pile: ATES
- Angle at 10 mm: ATE10
- Angle at 20 mm: ATE20

This measurement was made twice on each sample. A large angle of repose infers poor flowability.

3. Results

3.1. Selecting a method for characterising heat-treated meals

Figures 1 to 6 show the results obtained with the various methods. For heat-treated products, the results are illustrated as means that group all the treatment conditions.

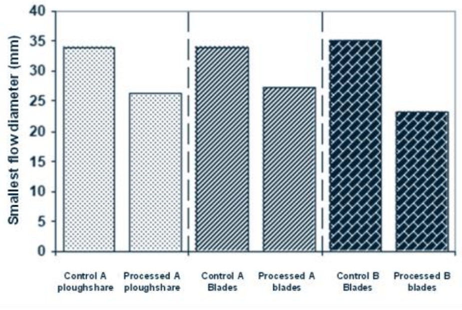


Figure 1: Smallest Flow Diameter (SFD)

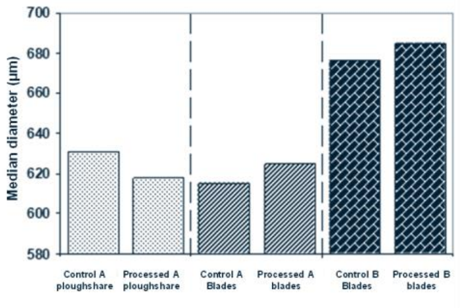


Figure 2: Median diameter

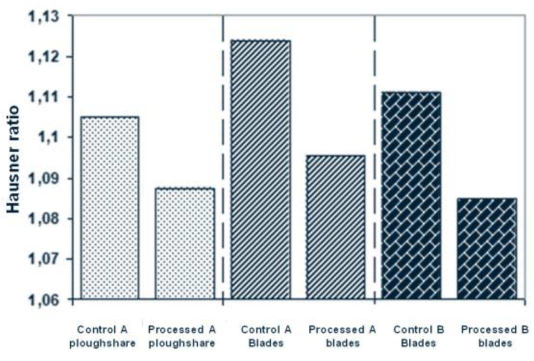


Figure 3: Hausner Ratio (HR)

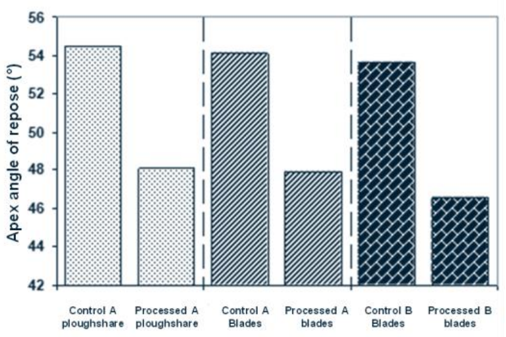


Figure 4: Apex Angle of repose (flow) (ATE)

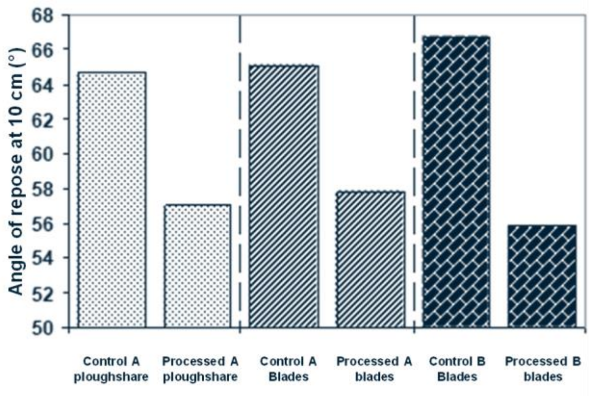


Figure 5: Angle of repose (flow) at 10 cm (ATE10)

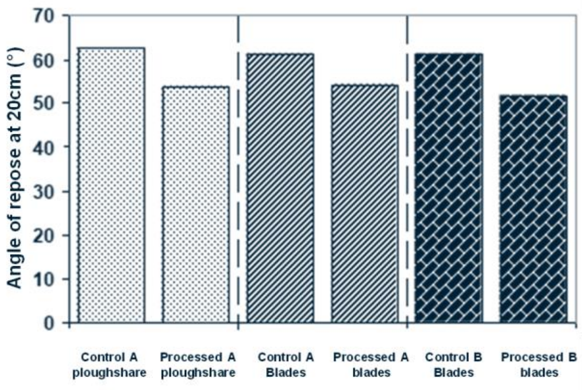


Figure 6: Angle of repose (flow) at 20 cm (ATE20)

To identify the most discriminating criterion for differentiating between treated and untreated meals (control), several statistical methods were run on the entire dataset (25 batches of meal) and on the variables SFD, d50, BD, TD, HR and ATES:

- A study of variability in the data obtained with the various methods
- A study of the correlations between variables
- A principal component analysis.

3.1.1. Study of standard deviations and the coefficient of variation for the measured variables

The methods that would be most useful in differentiating these products could be identified by determining which of the 25 batches of meal and which of the variables show the largest standard deviations or coefficients of variation.
Table 1 shows that three methods fall into this category - median particle size diameter (d50), smallest flow diameter (SFD) and apex angle of repose (flow) (ATES).

Variables	Mean	Standard deviation	C.V.
ATES	48.217	2.765	5.73
BD	0.694	0.027	3.89
TD	0.757	0.025	3.30
HR	1.091	0.015	1.38
SFD	26.560	3.689	**13.89**
d50	635.720	30.950	4.87

Table 1

3.1.2. A study of the correlations between variables

This statistical analysis was run in order to identify possible relationships between the variables, and then select from among the correlating variables the ones that would be the simplest to measure.
Table 2 shows these correlations (R), expressed as a percentage. The results demonstrated that:

- Bulk and Tap Densities correlated with each other (R = 94.4%), as well as with the Apex Angle of Repose (Flow) and the Smallest Flow Diameter.
- The Apex Angle of Repose (Flow) correlated with the Smallest Flow Diameter (R = 90.7%).
- The Hausner Ratio and the median diameter (d50 showed no correlation, either with each other or with the other variables.

Correlations (%)	ATES	BD	TD	HR	SFD	d50
ATES	100	**82.8**	**70.7**	64.6	**90.7**	24.7
BD	**82.8**	100	**94.4**	55.0	**89.2**	58.8
TD	**70.7**	**94.4**	100	24.4	**77.2**	58.5
HR	64.6	55.0	24.4	100	66.7	22.4
SFD	**90.7**	**89.2**	**77.2**	66.7	100	33.0
d50	24.7	58.8	58.5	22.4	33.0	100

Table 2

Out of the three variables that were selected during the previous analysis (study of standard deviations), two variables were selected: median diameter (d50) and apex angle of repose (flow) (ATES).
The smallest flow diameter (SFD) was rejected as it correlated with the apex angle of repose (flow) (ATES) and would be complicated to measure.

3.1.3. Principal Component Analysis (P.C.A.).

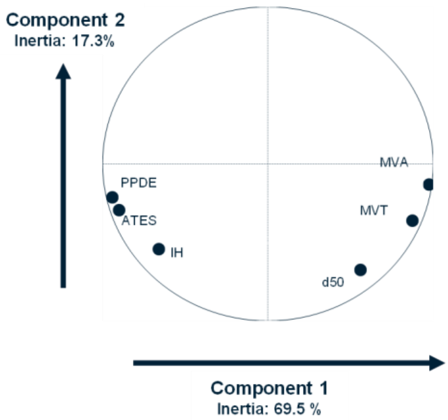
This statistical method is used to represent measured variables in a multi-component or multi-axis space.
In this space, component 1, referred to as the principal axis, provides the greatest amount of data for differentiating animal meals; in the case under study, 69.5% of the entire dataset (Figure 9).

Among the two variables selected above, median diameter (d50) shows the least correlation (Table 3) and lies furthest from the principal component, meaning that it provides little data that would be of use in differentiating meals. This observation is probably due to the fact that the median diameter of animal meal tends to increase when processed in the blade mixer and decrease in the ploughshare mixer (Figure 2).

Variables	Correlations (%)
ATES	**89.9**
BD	**97.9**
TD	**87.6**
HR	65.9
SFD	**94.3**
d50	55.8

Table 3: Correlation of variables with component 1

Conversely, the apex angle of repose (flow) (ATES) is the variable that shows the greatest correlation (Table 3) and lies closest to component 1. This makes it the best variable to use to differentiate feed meals according to flowability; it was therefore chosen to characterise this property in steam-treated meals.



3.2. Study of apex angle of repose (flow) measurement accuracy

To determine how many measurements to make on a given sample to obtain an ATES value that is representative of the sample, 11 measurements were taken on a feed sample (Table 4) and the accuracy of the mean value calculated (Biostatistique Sherrer 1984).

Angles (degrees)	ATES
Mean	46.1
Standard deviation	0.46

Table 4: Accuracy of the angle of repose (flow) measurement

Based on these results, and to obtain a mean that is accurate to 3.8% with a 1% risk, it would be best to take 4 apex angle measurements on each sample.

3.3. Using the angle of repose (flow) measurement to characterise various animal meals

3.3.1. Characterised samples

The apex angle of repose (flow) was measured on 32 feed samples:

- 12 animal meals, processed in a pilot workshop (batch treated in a blade mixer).
- 20 animal meals, processed in plants (continuous treatment)

The measurements were repeated 4 times on each sample.

3.3.2. Results

The results (Table 5) confirmed that measuring the Apex Angle of Repose (Flow) (ATES) makes it possible to differentiate between the various animal meal batches based on their flowability.

Treatment process and location	Animal meal	ATES (°)	
		Untreated control	Treated product
Ploughshare mixers - pilot	A	58.1	51.4
			50.6
	B	54.8	39.8
			42.9
	C	53.7	39.8
			43.9
	D	50.7	36.5
			39.4
Continuous treatment – plant 1	E	52.2	47.7
	F	53.3	46.5
	G	46.9	41.0
	H	46.9	40.6
	I	48.0	41.6
	J	53.2	41.6
	K	52.5	45.0
	L	51.1	45.7
Continuous treatment – plant 2	M	53.4	43.7
	N	54.9	44.1
	O	53.5	45.5
	P	51.8	42.9

Table 5

4. Conclusion

It was decided to characterise the meals using the apex angle of repose (flow) (ATES), as this method:

- has an excellent discriminating power
- is accurate
- is quick and simple to implement.

5. Bibliography

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Tecaliman, 1998 – i'Tec_Q9
Method for measuring bulk density, tap density and the Hausner ratio for additives and feedstuffs.

Tecaliman, 1998 – i'Tec_Q4
Measuring the smallest flow diameter found in animal feed additives.