

Grinding and pelleting behaviour of diverse maize batches

Prediction tables, based on the behaviour of raw materials in the pelleting press, are used to assess how the latter affect pellet quality, press yield and abrasiveness (MacMahon and Payne, 1983). A given raw material may not always behave in the same way in a press, resulting in variable pellet quality, with manufacturers indicating that maize and soybean meal are particularly susceptible to this behavioural variability. However, Cavalcanti and Behnke (2005) demonstrated that differences in maize composition in terms of various nutritional fractions (starch, protein, fibre and fats) had no impact on physical pellet quality. Nathier-Dufour et al. (1994) reported similar findings, for wheat in this case, with few links between NIR analyses and the behaviour of wheat grains in the press.

In 2023, Tecaliman, in partnership with Polytech Sorbonne, carried out a study to investigate the relationship between the physicochemical properties of 9 maize batches, their behaviour during grinding or in the press, and the cohesion of the resulting pellets. This i'Tec documents the methodologies used to achieve these objectives and the results obtained.

1. Principle

To achieve this objective:

- A literature review was carried out to identify the physicochemical properties likely to influence the behaviour of raw materials in the press.
- NIR analysis was used to characterise maize batches according to their composition.
- The maize batches were milled using identical mill settings, and a comparison was made of their physical properties.
- The 9 maize meals obtained were pelleted pure under identical conditions, and then characterised (specific power consumption, increase in die temperature).
- Standard measurements (grain size, durability and hardness, moisture content, etc.) and measurements of other physicochemical properties identified in the literature were made on each batch at each stage.

2. Equipment and methods

The 9 maize batches were obtained as grains from 4 manufacturers in 2022, and were most likely harvested in 2021. The grains were analysed to provide input and output data for the 2 processing techniques tested: grinding and pelleting.

2.1. Tested operations

2.1.1. Grinding

The maize batches were ground using a Retsch SR300 pilot rotor beater mill, 2.5 kW (Figure 1) equipped with a sieve and 6 rotors. The grinding chamber is fed by an adjustable speed hopper and is depressurised by an adjustable suction system. A cyclone unit provides air filtration. A data logger measures and records the power demand of the mill's drive motor every second.



Figure 1: Retsch SR300 rotor beater mill and grinding chamber

The 9 maize batches were ground using identical feed rates (Position 20 on the hopper) and suction rates (Position 1) under the following conditions:

- 2 mm sieve
- Rotor speed: 5000 rpm

2.1.2. Pelleting

The 9 'fine' ground maize meal samples were pelleted on a Kahl pilot pelleting line, model 14-175, fitted with a 3 kW drive motor (Figure 2).

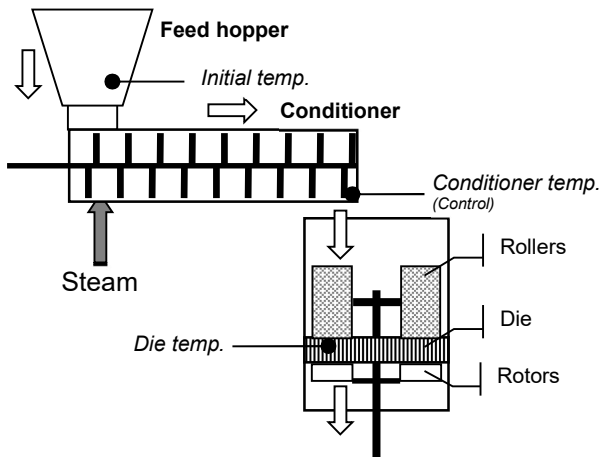


Figure 2: Kahl pilot pelleting line

This press was instrumented to measure and record second-by-second:

- Temperature at conditioner output (°C)
- Die temperature (°C)
- Power demand of the press drive motor in kW (+/- 0.6%)
- Control valve travel (%)

The 9 maize batches were pelleted at 40 kg/h using a 4/16 die (with diameter 4 mm and length 16 mm) with setpoints 60°C and 70°C, and 1.5 bars of steam pressure.

2.2. Measurements

2.2.1. Grain maize

The grain maize was visually assessed to identify the variety mainly present in each batch (flint, dent or flint-dent hybrid), and the percentage of broken grains was analysed.

Standard NIR analyses were also carried out to quantify: **moisture, protein, starch, cellulose, fat and ash contents.**

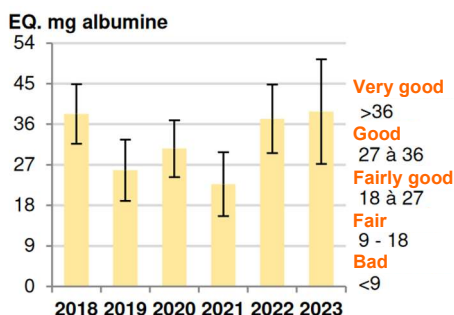


Figure 3: Average maize Promatest values according to year of harvest (France AgriMer, Arvalis, Qualit@lim n° 71 2024)

NIR analysis also provides an indicator, "Promatest", for the thermal shock affecting maize grains during post-harvest drying. Expressed as mg albumin

equivalent, this indicator quantifies temperature sensitive proteins in maize. The higher the value, the better the quality, and the fewer heat shock proteins in the maize (Figure 3). In our study, the Promatest value was obtained using the NIR method with the same equipment.

2.2.2. Ground maize

The **particle size distribution** of ground meal was analysed using a set of 9 standard sieves: 3150, 2000, 1250, 800, 500, 315, 200, 125, 80 µm. The measurement was obtained from a 50-100 g sample over a period of 10 minutes (a single measurement). The **median mesh size (D50)** and **geometric deviation (Sg)** were then calculated (iTec B6) along with the percentage of particles under 200 µm and above 2000 µm.

To measure the amount of **starch damage** in each maize batch, possibly due to drying, these ground samples underwent **SDmatic** (Chopin) analysis (single operation).

Starch grains, which have a semi-crystalline structure, may be damaged during unitary operations. As damaged starch absorbs more water than native starch (Dubat, 2004), such damage can increase the stickiness of the moistened meal.

The measurement involves placing each meal sample in contact with an iodine solution. As iodine binds to starch in greater quantities as starch damage increases, the amount of free iodine in the remaining solution will decrease accordingly. The device quantifies free iodine by measuring the strength of the electrical current in the solution in µA.

Based on the assumption of a possible link between pelleting and mixing behaviour, tests were carried out using the **Mixolab**, a mixer in which a dough is produced from a water/flour mixture (115% hydration) and then heated, in these tests, to 90°C. The device takes real-time measurements of the torque (Nm) produced by the dough between 2 rotary blades. The data output provides a torque vs. time graph (Figure 4).

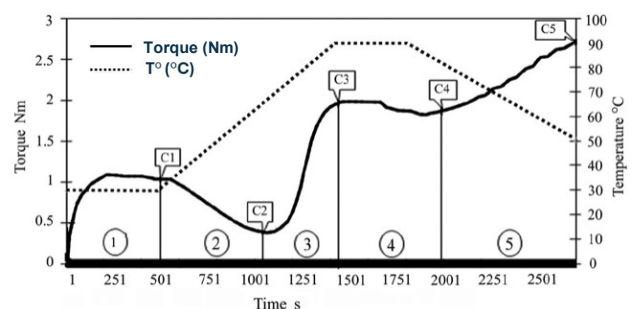


Figure 4: Torque versus time as measured during a Mixolab test (example).

Phase 3, marked ③ on the curve, corresponds to the starch gelatinisation phase. The C3-C2 indicator, the variation between maximum and minimum torque during the dough heating phase, would therefore correspond to the amount of starch gelatinisation.

2.2.3. Pelleted maize

Pellets were measured for:

- **hardness** using the Sotax MT50 hardness tester, fitted with a 3 mm jaw. Average pellet hardness is expressed in Newtons (N) (36 measurements per batch) (see I'Tec G2 or G16).
- **durability**, represented by the percentage of 500 g of sieved pellets that withstands a 20-second passage through the Eurotest, collected on a 3.2 mm sieve that corresponds to 80% of pellet diameter (measured twice) (see I'Tec G7).

A portion of the pellets, sampled at the cooler outlet, were 'cold' ground (cylinder mill or mortar/pestle), and then measured in the same way as the fine ground maize, i.e. for starch damage using the **SDmatic** and amount of gelatinisation using the **Mixolab**.

Variations in starch damage (SDmatic) and amount of gelatinisation, measured with the Mixolab (C3-C2) before and after pelleting, were calculated to assess the impact of pelleting on starch.

3. Results

3.1. Grain maize

Seven biochemical characteristics of grain maize determined using NIR (Table 1).

Batch	Moisture content (%)	Proteins (%)	Starch (%)	Cellulose (%)	Fats (%)	Ashes (%)	Promatest
1 D	12.7	7.1	67.0	2.8	3.2	1.2	33.0
2 D	11.4	7.8	67.4	2.5	3.2	1.2	50.3
3 D	13.2	7.3	67.3	2.5	2.8	1.1	44.0
4 D	13.2	7.6	66.4	2.6	2.9	1.2	43.6
5 D	12.8	7.9	65.6	2.7	3.4	1.3	36.3
6 D	13.9	7.4	65.8	2.7	3.1	1.2	34.2
7 C	13.1	7.3	66.8	2.6	3.2	1.2	24.4
8 C	13.4	7.5	64.9	2.9	3.6	1.2	32.6
9 CD	12.3	7.9	66.0	2.7	3.2	1.2	44.9
Avg.	12.9	7.5	66.4	2.7	3.2	1.2	38.1
CV (%)	5.7	3.7	1.3	4.7	8.0	4.2	21.2

Table 1: Results of NIR measurements on the 9 maize batches (D: Dent – C: Flint)

Average moisture content was 12.9%, ranging from 11.4 to 13.9%. Component contents were fairly uniform. The most standard was starch content, averaging 66.4%.

The Promatest value varied between batches (CV of 21.2%). As all values were above 18, this test indicates that all batches can be considered to be of acceptable quality. Values ranged from 24.4 to 50.3, with an average of 38.1.

No relationship between the test results and other component contents, moisture content in particular, was identified.

While these grains were also subjected to physical characterisation tests (Table 2), it was not possible to identify any link between these characteristics. It should be noted that, regardless of batch moisture content, some batches contained a great quantity of broken grains and a very slight variability in bulk density, with an average of 391 g/l.

Batch	Percentage of broken grains (%)	Grain durability (%)	Density (g/l)
1	14.6	79.2	756.2
2	20.7	75.5	807.9
3	6.3	87.1	785.5
4	13.6	87.5	805.2
5	13.3	77.8	804.3
6	16.1	87.0	755.7
7	31.4	77.6	745.3
8	11.5	82.5	741.5
9	13.9	88.9	836.1
Avg.	15.7	82.6	782.0
CV (%)	44.5	6.3	4.3

Table 2: Physical characterisation of grains

3.2. Ground maize

After grinding, there was minimal variation both in median diameters: 644.4 µm on average (CV 4.6%), and in the Sg distribution index. There was a significant variation in fine and coarse fractions; however, this could not be explained by any of the other criteria measured.

Batch	D50 (µm)	Sg	% < 200 µm	% > 2000 µm	SPC (KWh/kg)	SDmatic (%)	Mixolab
1	594.0	2.0	6.2	0.6	5.7	65.0	0.77
2	627.4	1.9	4.3	0.3	5.9	59.2	0.55
3	674.4	1.9	3.8	0.4	6.9	60.6	0.67
4	693.4	2.0	4.5	0.6	6.1	58.7	0.74
5	637.9	1.9	3.5	0.3	/	60.0	0.67
6	648.6	2.0	4.9	0.4	7.8	65.8	0.75
7	618.3	1.9	4.4	0.2	7.0	68.2	0.82
8	657.2	1.9	3.7	0.2	8.4	59.5	0.76
9	648.1	2.0	5.4	0.2	7.4	58.8	0.59
Avg.	644.4	1.9	4.5	0.4	6.9	61.8	0.7
CV (%)	4.6	2.2	19.6	41.5	13.6	5.8	12.7

Table 3: Grain size characteristics of maize meals and starch damage

Specific power consumption links weakly to only one parameter: starch content (Figure 5). This result indicates that maize with a high starch content would be slightly easier to grind. This result needs to be checked against further data.

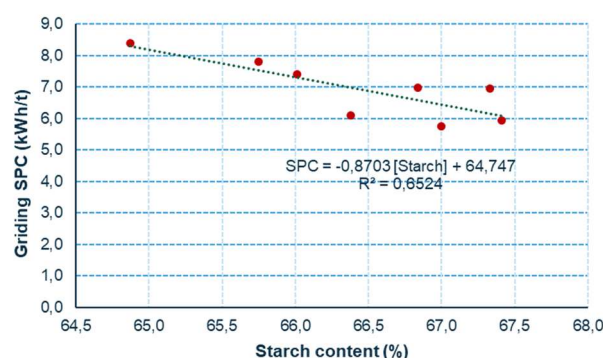


Figure 5: Relationship between the starch content of the 9 maize batches and specific power consumption during grinding

The SDmatic and Mixolab results varied between batches (CVs of 5.8% and 12.7%), but less than those of the Promatest (CV of 21.2%). These various tests could provide further insight on the 'thermal degradation' status of maize after drying. It would therefore be useful to conduct further study of their relationships.

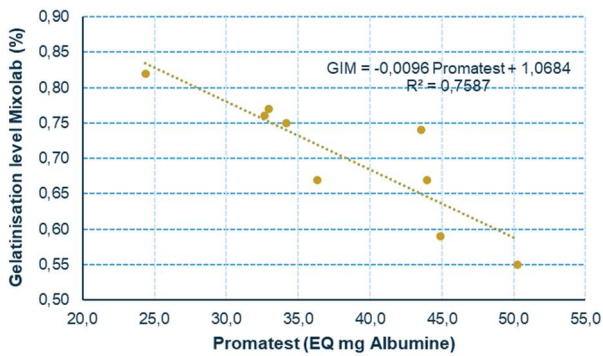


Figure 6: Relationship between Promatest and Mixolab values for the 9 maize batches

While these characteristics appear to be fairly closely related, the relationship between Promatest and Mixolab (starch gelatinisation) appears stronger (Figure 6 - R^2 0.76 compared with 0.61 for the relationship with SDmatic). The good starch quality revealed by the Promatest value suggests less starch damage and a lower gelatinisation capacity.

Among these relatively related parameters, Promatest appears to be the most effective, as it is easier to measure using NIR on native grains and may be more discriminating (higher CV).

3.3. Pelleted maize

Measurement of pelleting behaviour and impact on starch (Table 4).

Batch	SPC (KWh/t)	Die temp. rise (°C)	Hardness (N)	Durability (%)	SDmatic (%)	Mixolab	Variation SDmatic (%)	Variation Mixolab (%)
1	43.4	26.1	25.9	78.1	98.9	0.37	33.9	51.9
2	38.5	27.3	31.8	82.3	97.9	0.27	38.7	50.9
3	33.1	25.2	30.0	80.6	97.6	0.30	37.0	55.2
4	33.0	22.6	28.2	80.1	97.4	0.30	38.7	59.5
5	37.9	23.3	24.7	78.2	97.5	0.20	37.5	70.1
6	36.4	23.7	22.0	75.2	97.9	0.36	32.1	52.0
7	32.5	21.2	18.8	74.1	97.9	0.36	29.7	56.1
8	30.8	25.1	25.2	80.2	97.2	0.39	37.6	48.7
9	40.8	20.6	30.1	81.6	97.0	0.25	38.2	57.6
Avg.	36.3	23.9	26.3	78.9	97.7	0.3	35.9	55.8
CV (%)	11.7	9.3	15.9	3.5	0.6	20.5	9.0	11.5

Table 4: Output data for pelleting behaviour and impact on starch

Despite the variations, it proved impossible to link power consumption or die temperature rise with the other measured criteria. This pelleting did, however, result in a significant increase in starch damage: + 35.6%, giving an SDmatic value close to 100%. This resulted in a decrease in the gelatinisation capacity of Mixolab starch of almost 56%. This suggests that the heat treatment and friction involved in the pelleting process have a real impact on maize components, and starch in particular.

Fortunately, hardness and durability are closely related with an R^2 close to 0.91.

These pellet quality characteristics would appear to be affected by the increase in starch damage (Figure 7). This might seem logical given the assumption that such damage may lead to the creation of inter-particle

bonds that are stronger after drying, via a bonding phenomenon referred to as solid bridges.

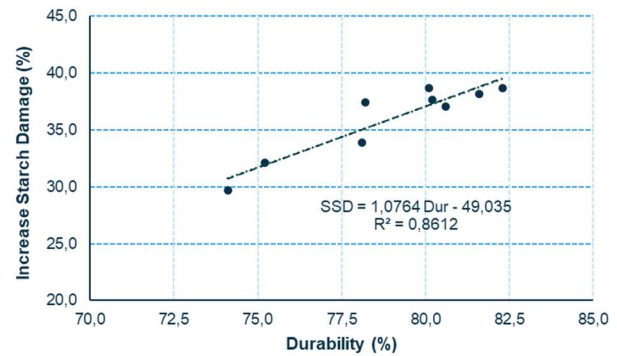


Figure 7: Relationship between increased starch damage during pelleting and increased durability for the 9 maize batches

More surprisingly, the best linear relationship obtained for this study as a whole (excluding the hardness/durability relationship) is that between the result of the Promatest on the initial grains and final pellet hardness (Figure 8). This suggests that **grains subjected to less thermal impact during drying would lead to better quality pellets.**

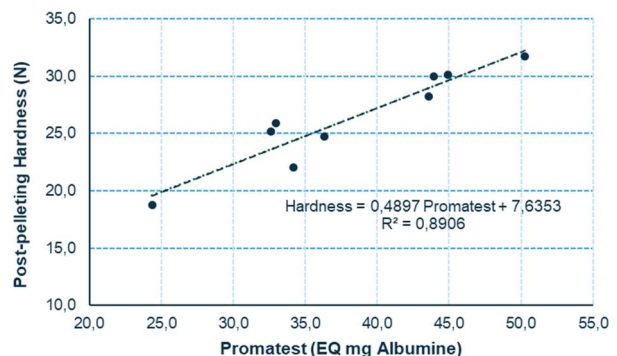


Figure 8: Relationship between post-pelleting hardness and the initial Promatest values for the 9 maize batches.

4. Conclusions

To sum up, variations were observed between maize batches. This study did not make it possible to clearly identify indicators that could be used to predict pelleting difficulties with maize. However, it did make it possible to identify parameters that could be used to predict pellet quality, the Promatest being the most significant. This would suggest that maize that has suffered less drying damage would give higher quality pellets. Further tests are needed in order to verify this trend.

Bibliography

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