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Uniaxial compression as a model for studying the shaping of food powders

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ABSTRACT: A powder compressibility test was carried out on barley, maize and soybean meal in order to assess the solid shaping of flour foods. The test involves the application of uniaxial compression to flour in a mould. The strength and strain are recorded in order to determine the yield point of plasticity and to measure the work of compression. The bulk density of flour compressed at maximum specified pressure is a means of determining its compressibility. The compact is finally crushed between to two parallel plates and Young's modulus is deduced from it. The results obtained show that the method has satisfactory repetability. Moreover it is sufficiently sensitive to discriminate between and classify different primary food flours according to their nature, particle size of populations and their water content depending on surrounding conditions. A comparison with an industrial revolving die press using animal foodstuffs shows a rather good connection between the variables measured with both presses.

1 INTRODUCTION

The solid shaping of powders is a technology which is applied in numerous industries such as coal, fertilizers, or pharmacy. In the food industry, for example, one of the main aims is to get an animal to ingest a concentrated mixture containing all the constituents of a formula in quantities appropriate to its requirements. Moreover, the transport and handling of foodstuffs are made very much easier. Such technology often involves considerably high pressures of perhaps several hundred MPa in order to obtain sufficiently hard bonding between particles by agglomeration and fusion bridges and thus a great deal of energy is consumed. According to Beumer (1980) it alone represents two thirds of the energy consumed in the making of pelleted feedstuffs. Mastering such a technique requires greater knowledge of the densifying performance of the flour and the processes of cohesion which give the product the necessary mechanical strength.

When pressure is exerted on a flour there are several stages involved before final density: as a result of a slight pressure build-up, the particles slide up onto each other and reposition themselves in relation to each other; as the particles can no longer move, they then become distorted and shatter according to the degree of plasticity. The high pressure following this induces interparticulate bonding with gives cohesion to the compact that can no longer be deformed in the final stage, when interparticulate porosity is almost zero. The bulk density of the solid is then similar to that of the particles themselves. In certain cases, compression is followed by insertion into a die which produces flow resistance. When the solid is reposing, it recovers a certain volume due to retarded yield deformation.

Various authors have attempted to characterize the deformation of powders due to pressure; Heckel (1961), Cooper and Eaton (1962), Kawakita and Ludde (1971) in particular have studied the manufacture of pharmaceutical tablets. Their equations all establish links between the stress exerted and the physical properties of the powders, i.e. between pressure and volume on the one hand, and internal stress and deformation on the other. Kawakita's equation enabled Kumar (1973) to describe the pressurized behaviour of crushed maize.

The method for mesuring food flour compressibility (de Monredon 1989), which is used in the present study, is based on the above mentioned considerations and deliberatly disregards phenomena inherent in the passage through the die, and previously studied by means of a hydraulic press and a single passage die (Melcion 1974, Pedamond 1977, Vercauteren 1982). Indeed, it would appear that the phenomena observed under simple pressure may be compared to those produced in die. Moreover, this method is simple to follow and permits a thorough classification of the product.

2 PRINCIPLE

There are three steps involved in this test:

1. Putting the flour through bilateral uniaxial compression in a mould. The samples are compressed to one maximum specified strength or several determined maximum strengths (ISO 3927, 1985). Strength and deformation are plotted on graphs so as to obtain the pressure corresponding to the yield point of initial plasticity and the work of compression.
2. The bulk density of flour compressed under given pressure determines its compression capacities. In the event that several maximum pressures are applied, the flour compressibility curve is obtained by ascribing bulk density to maximum pressure. After removal of the mould, the bulk density of compacts is measured during the period leading up to repose and volume recovery is compared to the elastic deformation of the material.
3. The compact is crushed in a vertical position between two parallel plates and Young's modulus of elasticity is deduced from it.

3 EXPRESSION OF RESULTS

3.1 Compression of the flour

The yield point of initial plasticity is expressed in MPa and refers to the theoretical pressure required in order to change from a discontinuous divided state into a semi-continuous coherent state. it is situated on the curve F(d) at the point corresponding to both a drop in deformation and a rise in strength, and it gives an indication of the beginning of the plastic deformation of the powder. It is determined graphically on the point of intersection of slopes formed by the two tangents at the cure plotted from the initial and final points (Pedamond 1977).

The compression work of the flour up to maximum pressure considered, W=F.d, is proportional to the total surface area under the curve.

The bulk density (D) of the compact is measured to the nearest 0.001 g.cm-3 with an accuracy of $\pm$0.002 g.cm^{-3} for n=5. It must always be accompanied by the corresponding maximum applied stress.

The compressibility curve of a flour is plotted using points representing one or the average of several measurements of the bulk density at each of the maximum pressures determined between 200 and 500 MPa. It can then be compared to a straight line by assessing the correlation, with the gradient and intersection to the origin being characteristic of the flour involved. Kumar (1973) has also put forward the following equation:

$$LnD = Bcf\ P + LnDo$$

where P is the applied pressure and D the compact density for pressure considered, read or measured graphically; Bcf, curve gradient, is the compressibility factor, LnDo, extension of the curve towards ordinate to the origin, is compared to piling factor and Do, initial apparent density of the piled powder.

The delayed elastic deformation of the compact is the differed and retarded deformation which arises when the pressure is removed. It is equal to :

$$((D1 - D2) / D1)100$$

where D1 bulk density of compact ex: press and D2 bulk density of compact 24 hours after.

3.2 Crushing of compact

The apparent elastic modulus (Young's modulus) is equal to :

$$E = (F/S) / (\Delta L/L)$$

where, L initial length of compact in mm, S flat surface of compact and F strength in N corresponding to ΔL taken at a characteristic point on the curve. The constraint-deformation ratio is not linear in this case and thus the apparent modulus is defined in terms of the tangent modulus on the most significant gradient before the point of inflexion.

The maximum strength may be a quantitative criteria of compact hardness to be considered by analogy with a traditional measurement used in animal feedstuffs (Delort-Laval and Drevet 1970).

4 APPLICATION OF METHOD

4.1 Raw materials

As regards food flours, it is a known fact that shaping depends on several factors, related to the chemical composition of the raw material (Afma 1966; Holmen 1981), to the geometry of the particles populating it (Melcion 1974, Pedamond 1977, Stevens 1987) and its water activity, Aw (Bouchet 1982, Nivet et al 1984). For this reason, the suitability of this method of study using uniaxial compression has been tested with three raw materials of entirely different chemical composition, i.e. barley, maïze and soybean meal, by varying particle size through crushing and the moisture by appropriate conditioning.

Three series of tests were carried out on these raw materials.

The analysis of results from the preliminary series (Sauret, 1986), enabled the most signifiant ones to be observed. The compressibility curves of flours with comparable granulometry classifies barley, soybean meal and then maize in order of shaping capacity (figure 1). The Kumar equation used from results recorded on the maximum compression curve of 500 MPa for each of the three raw materials with two different particle size, also puts barley into first place, with soybean meal second and then maize. Although fine flours are more energy-consuming, they are denser when piled and more suitable for compression (table 1). Post compression volume resumption of the compacts is illustrated in figure 2. This differs according to both raw materials and flour particle size. Comparing soybean meal to maize and barley, and coarse flours to fine flours, both soybean meal and coarse flour have greater volume recovery when compacted.

The following stage consists in studying the influence of hygrometry of the air on the compressibility of the same primary products. These flours are conditioned by three different water activities (Bouyer 1987) and have a controlled particle size spectrum. When compressed (200 MPa), their behaviour varies differently according to the raw material involved (table 2). In a dry atmosphere (Aw = 0.46), shaping requires maximum energy; that of soybean meal is double that of barley and maize. In a moist atmosphere (Aw = 0.82), compression is actually made easier, above all with soybean meal, which is due to its high water absorbing properties. Compacts with a high water content are less dense and have a greater elastic recovery rate which thus weakens their mechanical strength. When considering the power consumed and the physical quality of the product, the optimum is found in a intermediary atmosphere (Aw = 0.69), for barley. For soybean meal and maize, this optimum can probably be found in a water activity between 0.46 and 0.69, bearing in mind that maize is rich in oil and reacts poorly with water.

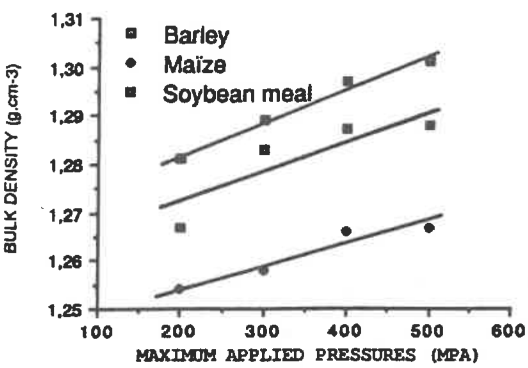

Fig.1 bulk density of compressed flours versus maximum applied pressures

Table 1. Piled density and compressibility factor of barley, maïze and soybean meal flours under maximum compression of 500 MPa

Flours	Piled density Do(g.cm-3)	C. factor Bcf(MPa10-5)
FINE BARLEY	1.197	6.0
COARSE BARLEY	1.173	4.0
FINE MAIZE	1.161	2.3
COARSE MAIZE	1.136	1.6
FINE SOYBEAN MEAL	1.123	4.0
COARSE SOYBEAN M.	1.082	3.8

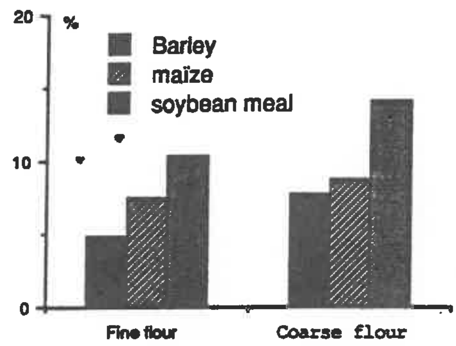

Fig. 2 Volume recovery of compacts after compression

Table 2. Influence of relative moisture on compressed shaping of barley, maize and soybean m. flours

Primary product		Barley	Maize	Soybean m.
H. (%)	Aw = 0.46	10.2	9.7	7.7
Y. P. I. P. (MPa)		106	86	112
C. W. (J)		117	120	210
B. D. C. (g.cm-3)		1.176	1.139	1.178
D. E. D. (%)		5.8	7.5	5.9
Y. M. (MPa)		42	14	37
H	Aw = 0.69	14.1	13.4	14.1
Y. P. I. P.		76	63	31
C. W.		94	91	80
B. D. C.		1.164	1.124	1.075
D. E. D.		9	10.7	17.2
Y. M.		57	14	12
H	Aw = 0.82	17.5	16.5	20.6
Y. P. I. P.		39	42	13
C. W.		68	69	58
B. D. C.		1.097	1.077	1.039
D. E. D.		11.4	12.4	14.1
Y. M.		29	12	5

H.= Humidity of the product
Y.P.I.P.=Yield point of initial plasticity
C.W.= Compression work
B.D.C.= Bulk density of compacts
D.E.D.= Delayed elastic deformation
Y.M.= Young's modulus

Table 3. Influence of the particle size of flours* on their compressed shaping (P = 200 MPa, Aw = 0.7)

d gw** (µ)	175	192	417	469
S gw**	2.25	1.30	2.12	1.32
Y.P.I.P.(MPa)	17.1	18.4	19.7	19.9
C.W.(J)	80	79	88	93
B.D.(g.cm-3)	1.150	1.113	1.106	1.056
D.E.D.(%)	10.2	11.3	12.2	15.6
Y.M.(MPa)	25.8	18	18.6	15.2

*Barley,maize and soybean m.,pure and mixed flours
** Geometric log-normal mean diameter (d gw) and standard deviation (S gw) of sample estimated by weight distribution

The influence of flour particle size on the shaping capacity of barley, maize and soybean meal is studied from two angles: the average size of the particles and the spread of the average diameter on either side (Boidé 1988). Four different spectra are re-formed articially by assembling sieved fractions of each of the materials and binary and ternary mixtures. For a controlled water activity equal to 0.7, the results obtained (table 3), indicate that the yield point of initial plasticity and compression work of the coarse flours are higher than those for fine flours and particularly for maize. One explanation would be to attribute a part of the energy consumed to the crushing of the particles. The apparent density of the compacts is higher because the particles are fine and spread around the average diameter. In the contrary case, there is noticeably greater volume recovery after compression and a lower elasticity in the compacts expressed by Young's modulus.

4.2 Feedstuffs

Finally, this model for studying the shaping of flours by uniaxial compression, has been compared with the pelleting obtained through a revolving die press which is used in the animal feed industry for producing compound feed. In order to achieve this, 20 different compound flour feedstuffs used for rabbits (8) and poultry (12) were pressed both in a laboratory hydraulic press and on an industrial die press in order to test the effects of adding bounds of mineral (sepiolite) and organic (calcium lignosulphite) origin on food shaping (de Monredon and Giboulot 1988). The efficiency of the treatment of the pellets was checked by measuring the electric energy used by the press (KWH/T) and the hardness of the pellets (MPa). As regards to poultry feeds, the results obtained from the compression model foresaw the benefical effect due to energy-saving, which resulted from the addition of fat, and a less specific effect due to the added bonds. In fact, 2% of the formula was calcium lignosulphite, which caused a slight drop in the energy consumption rate, while the sepiolite appeared to be the cause of increase, above all when the dose was 4%. Such observations are confirmed by the results obtained on a full size die press, except for feedstuffs containing 2% sepiolite. Comparing the total sum of data for energy consumption for compression and pelleting together, the correlation coefficient equal 0.93 (figure 3). The mechanical properties of the compacts are largely reduced by the amont of added fat, while the presence of bonds in the food improves them in all cases. The same applies to the pellets despite the fact that the presence of a large amount of fat in the formula tends to hide the beneficial effect of the bond. The relationship between Young's modulus of the compacts and the hardness of the pellets bears a substantial correlation, R = 0.98 (figure 4). It may be concluded that, in this case, the compression model might have been used in order to predict what was going to occur in the full size industrial die press. As far the "rabbit" feed are concerned, although they are not contradictory, the results obtained are less convincing. The comparisons concern 8 feeds only, instead of 12 as before, and one result obtained with the pelleting appeared illogical. This primary data must be confirmed by further tests on other feeds before concluding that this model of prediction is sufficiently reliable for studying the shaping of flours into solids.

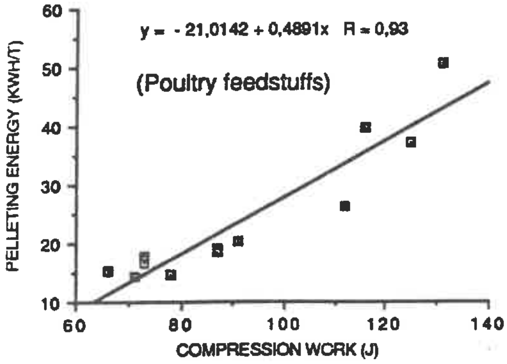

Fig.3 Pelleting energy versus compression work at 200 MPa

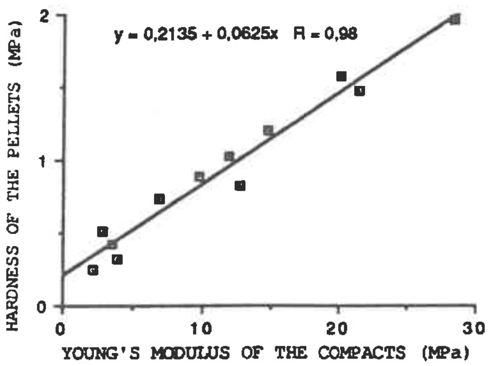

Fig. 4 Hardness of the pellets versus Young's modulus of the compacts

5 CONCLUSION

The results obtained by the uniaxial compression model showed that it was possible to quantify the energy consumed, to a certain extent, by exploiting the strength-deformation curve recorded during the compression of the flour; the quality of the product becomes known by verifying the changes in its bulk density over a period of time and by measuring its elasticity when it is crushed. The method was sufficiently sensitive to discriminate barley, maize and soybean meal, and to reveal the importance of the chemical composition of the material and particle size of flours, and of the water which is likely to be absorbed under different conditions. An optimal solution must be found in order to limit the energy consumed while making high quality produce. This entails crushing and adequate mixing together of several primary products. Futhermore it must be remembered that water is of primary importance as it saves energy for the shaping and is most often prejudical to the mechanical resistance of the product. The flour is made up of particles which must be sufficiently fine and heterogenous to obtain a dense and hard material. It has therefore been possible to adapt the results of this laboratory test on compound poultry feedstuffs to those obtained with a pilot revolving press-die.

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