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MULTIDIMENSIONAL ANALYSIS OF THE PELLETABILITY OF FEEDS AND FEED MIXTURES

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A b s t r a c t. Principal component analysis (PCA) was applied to laboratory measurements of eight descriptive parameters of the pelletability of six raw materials (maize, rice, soybean, cassava, alfalfa and meat meal) and of mixtures of the first three. The two-fold aim was to select the most relevant criteria for classifying the raw materials and to verify the additivity of the mixtures. The best criterion was the work of compression by an axial load (up to 200 MPa) applied to the meal in a cylindrical cell. Maize and rice mixtures were additive. The compression of soybean was improved by the presence of maize and rice.

K e y w o r d s: pelletability, ingredient, multicomponent analysis

INTRODUCTION

Milled raw materials and the various ingredients of an animal feed exhibit specific behaviour during pelleting. This behaviour directly conditions the production rate, energy consumption, machine wear and cohesion of the pellets. Despite numerous studies [1,4,5,8, 10-12,16], it is still not possible to predict satisfactorily the behaviour of raw materials during compression or to incorporate this parameter when calculating formulations. Too many parameters, which are poorly controlled in practice, are called into play, principally chemical composition, moisture and particle size [7,17]. Prediction should also recognise that in practice the feed comprises various constituents and that the behaviour of mixtures is not always additive [3].

A recent laboratory study of the pelletability of raw materials used in the production of compound feeds in Guinea has provided extensive data on chemical composition, physical characteristics, compression parameters and mechanical properties [15]. Here we analyse these results statistically, with the aim of comparing the raw materials and assessing the additivity of the behaviour of mixtures upon compression.

MATERIALS AND METHODS

Raw materials

Maize, rice, whole soybean, cassava, alfalfa and meat meal were crushed in a hammermill fitted with a screen with 2 mm diameter holes and were then wetted to final moisture contents of 10, 12, 14, 16 and 18 %. The higher moisture content were designed to simulate steam addition during compression. Binary mixtures 75/25, 50/50, 25/75 and ternary mixtures 50/25/25, 25/50/25, 25/25/50 (w/w) were prepared from rice, maize and soybean, since the behaviour of these raw materials had been shown to be sufficiently characteristic in previous tests (data not shown). The chemical composition and physical characteristics of the milled raw materials are shown in Table 1.

Table 1. Ingredient chemical and physical analysis

	Ash (%)	Crude protein (%)	Crude fat (%)	Crude fiber (%)	Bulk density (g/l)	dgw (μm)
Maize	1.17	11.11	4.42	2.36	595	825
Rice	1.13	7.29	2.01	0.8	774	719
Soybean	5.65	37.67	18.84	5.78	568	929
Cassava	1.39	1.62	0.89	0.72	346	411
Alfalfa	7.59	13.7	3.17	21.5	182	782
Meat meal	37.28	32.41	13.98	0	621	956

Measurement of compressibility

The compressibility of the raw materials, individually and in mixtures, was measured at the five stated moisture contents by using a laboratory-built hydraulic press to compress axially 20 g of meal in a 25 mm diameter cylindrical cell [6]. Forces of 0 to 100 kN were applied at a speed of 0.3 mm s^{-1}. The force/

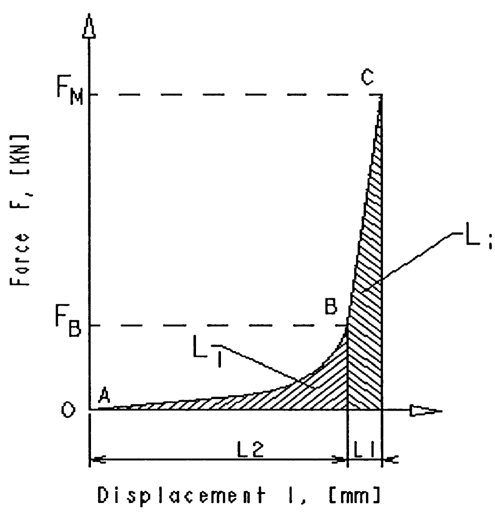

Fig. 1. Description of the different compression stages.

displacement curve (Fig. 1) was analysed in terms of changes in meal density [11,12], force (FB) and work (L1 and L2) at characteristic points corresponding to the yield point of plasticity (B) and the maximum compression (C) with respect to the starting point (A) [5]. The bulk density and ultimate strength of the pellets crushed between two parallel plates were determined under controlled conditions, 24 h after ejection from the press.

Multidimensional statistical analysis

Means were calculated for triplicate measurements for all moisture contents taken together (n = 15). Principal component analysis (PCA) was performed on tabulated data comprising lines of 15 'items', represented by the 3 principal raw materials and their mixtures, for which were measured 8 quantitative variables, seven describing behaviour on compression, one describing the mechanical properties of the manufactured product:

- density at point B (DB),
- density at point C (DC),
- density of the finished product (DF),
- yield point of plasticity (YP),
- work of compression from point A to point B (WAB),
- work of compression from point B to point C (WBC),
- work of compression from point A to point C (WAC),
- ultimate strength of the finished product (US).

Cassava, alfalfa and meat meal were not used in mixtures and were analysed as additional items. Crude protein (CP) and crude fat (CF) were included in the analysis as additional 'explanatory' variables.

RESULTS

PCA is an essentially descriptive statistical method designed to present tabulated data graphically [14]. We investigated the most pertinent explanatory parameters of compressibility and the behaviour of raw materials, individually and in mixtures.

Analysis of variables

The variables were represented in a circle of correlations in a plane with two axes (Fig. 2). The horizontal axis 1 represents 70.8 % of the total information provided by the analysis, and the vertical axis 2 represents 18.2 %. The further the variables are from the centre, the better they are represented. Positive correlation is indicated by proximity, negative correlation by separation.

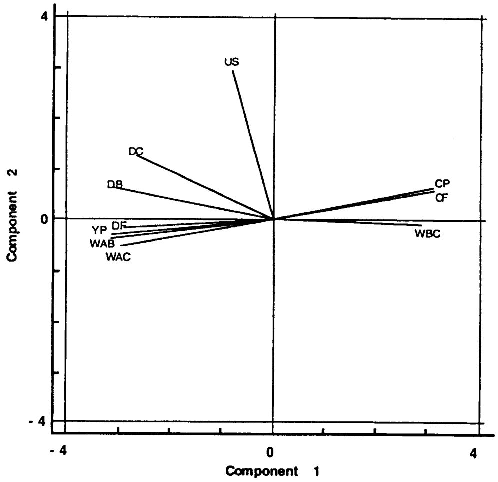

Fig. 2. PCA: square correlation between variables and axes.

Four variables were closely grouped: the yield point of plasticity (YP), the work up to the yield point of plasticity (WAB), the total work (WAC), and the density of the finished product (DF). These variables were strongly correlated and therefore of identical significance. It is interesting to note the link between product density and the energy criteria for compression of maize, rice and soybean. Density at the yield point of plasticity (DB), and to a lesser extent density at the maximum force (DC), were quite close to the group of the four most representative variables. The ultimate strength of the pellets (US), essentially represented on axis 2 (r = 0.92), was not correlated with any other criterion analysed here. This may be due in part to the special behaviour of the ternary mixtures, in which the cohesion of the compressed products was far superior to that of the separate constituents.

The additional variables of chemical composition (CP and CF) contrast with the group of the most representative criteria for compressibility: the higher the fat or nitrogen content of a product, the easier it is to compress. This was seen with soybean. It is significant that these criteria of chemical composition were close to the work of compression between B and C, WBC (Fig. 2). Indeed, it is at this stage of compression that the elastic behaviour of the material, and hence its resistance to compression, intervene.

Analysis of constituents and mixtures

In the representation of plane 1,2 (Fig. 3), maize, rice and soybean fall at distinct points,

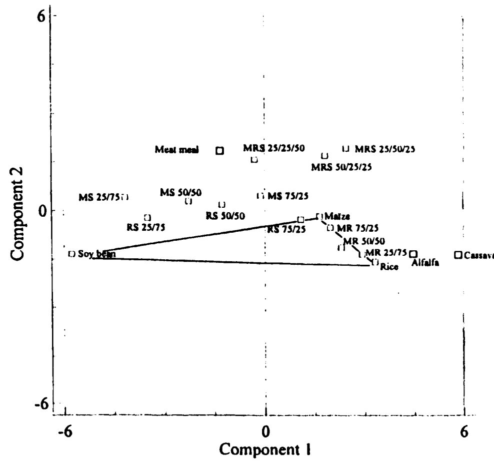

Fig. 3. PCA: similarity map of Principal Components 1 and 2.

and the separateness of soybean in particular reflects its special behaviour. Axis 2 (vertical) is essentially representative of the ultimate strength and is therefore descriptive of the mechanical behaviour of the finished product. Axis 1 (horizontal) represents the compressibility. Of the three other raw materials in the analysis, cassava was situated near rice and maize, possibly because of the high starch content of these three constituents, as was alfalfa, whereas meat meal was removed (Fig. 3). Soybean and cassava behaved differently during compression, as indicated by their locations on opposite sides of the horizontal plane. Soybean meal is oil-rich and has a pronounced plastic behaviour and therefore required little work of compression. Cassava is starch-rich and required much work of compression because it resisted the plastic state. The vertical axis reveals that soybean and rice had the lowest cohesion, followed in rising order of cohesion by alfalfa, cassava, maize and meat meal.

By linking maize, rice and soybean to form a triangle it is possible to analyse the behaviour of mixtures. The binary maize/rice mixtures fell on the line linking their constituents, in an order related to their relative proportions. It can therefore be concluded that their behaviour is additive. The same was not true for the soybean containing binary mixtures. The influence of soybean on the behaviour of mixtures is dominant but unpredictable and therefore difficult to control in industrial practice. Soybean oil is adsorbed by the other constituents, thereby greatly improving the cohesion of the mixtures, notably the ternary mixtures of maize, rice and soybean.

If the results for two representative variables (work of compression of the meal, cohesion of compressed products) are plotted on the same graph, three zones can be distinguished in the cluster of points. Each zone corresponds to a particular type of behaviour (Fig. 4). Meat meal, and the ternary mixture of maize, rice and soybean, exhibited the best compressibility. The compressibility of soybean, rice and alfalfa was poorer, due to problems of cohesion (soybean), work (alfalfa), or both (rice). Maize and cassava were in the intermediate zone, together with most binary mixtures.

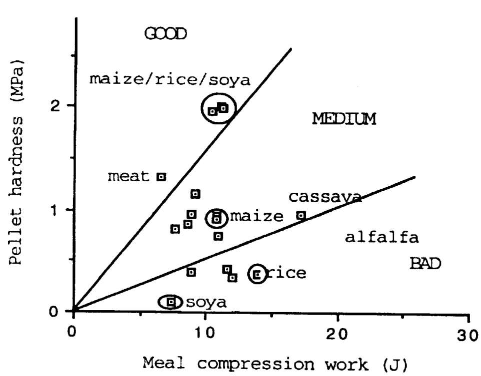

Fig. 4. Compressibility of ingredients.

These findings agree with the few literature values available for the pelletability of animal feeds, whether measured or estimated from the chemical and physical composition. Nathier-Dufour *et al.* [11] used an industrial press to show that the inclusion of maize in mixtures improved energy efficiency, unlike cassava. Maize and cassava lowed pellet durability. According to David and Lefumeux [1], rice is of moderate compressibility and increases cohesion, as does meat meal, which exhibits good compressibility. MacMahon and Payne [9] report a good compression yield and poor pellet quality for soybean, and the reverse for alfalfa.

CONCLUSIONS

Multidimensional analysis can be used to assess the relevance of criteria and to select them for determination of the pelletability of raw materials, either individually or in mixtures. The work corresponding to the axial load of 0 to 200 MPa applied to the meal in the cylindrical cell seemed the most appropriate criterion of energy consumption. Through differentiation along the two axes of the criteria of pelleting and of pellet cohesion, it was possible to compare the behaviour of raw materials and to assess the additivity or otherwise of mixtures thereof. Although other factors should also be taken into account in industrial production, such as ambient and pelleting conditions, our understanding would be enhanced by tests on a wider range of raw materials, both individually and in mixtures. Confirmation of our results on an industrial scale would allow more effective formulation.

REFERENCES

1. **David L., Lefumeux J.:** Pratique de la compression. Ed. L. David, La Jarrie, 1972.
2. **Friedrich W., Robohm K. F.:** Aptitude au pressage des composants et des mélanges; 1re partie: Influence des céréales, technique de mesure et interprétation. Industries des céréales, 24, 27-33, 1983.
3. **Friedrich W., Robohm K. F.:** Aptitude au pressage des composants et des mélanges; 2e partie: Influence des sous-produits d'huilerie. Industrie des céréales, 25, 33-38, 1983.

4. **Friedrich H.P., Simon E.:** Prüfverfahren zum Prebverhalten feinkörniger Stoffe und deren Mischungen. Die Mülhe + Mischfuttertechnik, 127 Jahrgang Heft 15, 183-184, 1990.
5. **Laskowski J., de Monredon F., Skonecki S., Melcion J.P.:** Testing procedure of pelletability of ingredients and compound feeds. Int. Agrophysics, 8, 643-648, 1994.
6. **Le Deschault de Monredon F.:** Axial compression as a model for studying the granulation of feed powders. 1. Methodology. Sci. Aliments, 10, 189-202, 1990.
7. **Le Deschault de Monredon F.:** Axial compression into a die as a model for studying the granulation of feed powders. 2. Application to the study of moisture content and particle size effects. Sci. Aliments, 11, 321-340, 1991.
8. **Le Marchand P.:** Application des techniques d'analyse par les données aux systèmes physiques. Exemple industriel agro-alimentaire. Thèse de docteur en troisième cycle. Universitè de Nantes, 1986.
9. **MacMahon M.J., Payne J.D.:** Holmen pelletability handbook. Holmen Chemicals Ltd ed., Basingstoke, G.B.,1981.
10. **Melcion J.P.:** Testing procedures for pelleting research. Feed Mix, 3 (5) 33-37, 1995.
11. **Nathier-Dufour N.:** Prédiction de l'aptitude à l'agglomeration des aliments composés pour animaux par des méthodes physiques. Thèse de docteur de l'école doctorale de chimie-biologie, Université de Nantes, 1994.
12. **Nathier-Dufour N., Bertand D., Robert P., Le Marchand P.:** Prédiction de l'aptitude à l'agglomeration de mélanges alimentaires par spectroscopie proche infrarouge. Sci. Aliments, 12, 543-561, 1992.
13. **Nathier-Dufour N., Bertrand D., Devaux M.F., Robert P.:** Etude de spectres proche-infrarouges de mélanges par analyse multidimensionnelle. 2èmes Journées Européennes "Agro-industrie et Méthodes Statistiques" Nantes, France, 1991.
14. **Saporta G.:** Probabilités. Analyse des données et statistique. Editions Technip, Paris, 1990.
15. **Soumah A.T.:** Studies of pelletability of raw materials used in Guinea for feed production (in Polish). Ph D. Thesis, University of Agriculture, Lublin, 1994.
16. **Tylzanowski J.:** Electric control of steam temperature in pelleting (in Polish). Biul. Inf. Przem., 3, 35-42, 1975.
17. **Vercauteren W.C.P.:** Future developments in feed production technology. Holmen Feed Prod. Symp., Holmen ed. London, (UK), C1-C22, 1982.