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# Functionality of raw materials and feed composition

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**SUMMARY –** Animal feeds are formulated by means of least cost formulation. This requires the composition of the diet to be correct in terms of amino acids, minerals, energy and raw materials used. Up to date, it is not possible to adequately present a model which also takes into account specific properties of certain raw materials and which exert their effect on the physical quality of the manufactured feed. For example, one can think of hardness and durability of the feed, oil-binding properties, in case of fish-feed; water stability and (non-) buoyancy. This article will discuss the costs and benefits of using specific ingredients in relation with formulation and feed processing. Examples will be presented to show the various trade-offs that can be expected in terms of costs of raw materials, costs of manufacture and commercial benefits.

**Key words:** Feed composition, feed processing, least cost formulation.

***RESUME –*** *"Fonctionnalité des matières premières et composition des aliments". Les aliments pour animaux sont fabriqués en suivant une formulation au moindre coût. Ceci exige que la composition du régime soit correcte en termes d'acides aminés, minéraux, énergie et matières premières utilisées. Jusqu'à présent, il n'est pas possible de présenter de façon appropriée un modèle qui tienne également compte des propriétés spécifiques de certaines matières premières qui exercent un effet sur la qualité physique des aliments fabriqués. Par exemple, on peut envisager la dureté et durabilité de l'aliment, les propriétés des huiles comme liants, dans le cas des aliments-poisson ; la stabilité dans l'eau et la (non) flottabilité. Cet article étudie les coûts et les bénéfices de l'utilisation d'ingrédients spécifiques en liaison avec la formulation et les processus des aliments. Des exemples seront présentés pour montrer les différents compromis que l'on peut trouver en termes de coût des matières premières, coûts de fabrication et bénéfices commerciaux.*

***Mots-clés :*** *Composition des aliments, processus alimentaire, formulation à moindre coût.*

## Introduction

The use of least cost formulation to formulate diets, leads to a large number of feedstuffs incorporated at different inclusion levels. This may lead to variation in physical quality of the feeds after pelleting, although the calculated nutritional requirements are met.

### Raw material properties

In order to predict pellet quality, a pragmatical approach is often used, as for example proposed by MacMahon and Payne (1991). They tried to relate different raw materials to pelleting criteria used in animal feed manufacturing. For certain raw materials a classification was made according to type of raw material, e.g. cereals, oilseeds or by-products. They estimated the effect of inclusion of a specific raw material on the physical quality of pellets, pelleting capacity of the pellet press and wear of the die. These three physical factors were scaled; so, that virtually all raw materials fell in a range between 0 and 10, exceptions being fat and binding agents (Table 1). These figures are estimates from literature and experience and one should carefully interpret these data since origin, storage and processing conditions may alter the raw material properties and their related binding actions. Israelsen *et al.* (1981) used linear regression to relate pellet quality to different diet ingredients. They estimated the effect of inclusion of different diet ingredients on pellet durability (%) and energy consumption (kWh/t) of the pelleted raw material (Table 2) by substituting barley or cotton seed meal

Table 1. Feedstuffs and their respective nutritional and pelleting properties (modified after MacMahon and Payne, 1991)

| Raw material | Constituents[†] | | | | Bulk density ($kg/m^3$) | Physical factors [-][††] | | |
|---|---|---|---|---|---|---|---|---|
| | Crude protein (g/kg) | Crude fat (g/kg) | Crude fibre[†††] (g/kg) | Starch[†††] (g/kg) | | Pellet quality | Press capacity | Die wear |
| **Milling by-product** | | | | | | | | |
| Barley meal | 107 | 22.0 | 47 | 490 | 480 | 5 | 6 | 5 |
| Maize meal | 87 | 38.0 | 21 | 585 | 610 | 5 | 7 | 6 |
| Milo meal | 90 | 28.0 | 40 | 580[*] | 540 | 4 | 6 | 7 |
| Oat meal | 112 | 48.0 | 106 | 378 | 520 | 2 | 3 | 7 |
| Rice | 78 | 20.0 | 88 | 580[*] | 480 | 5 | 5 | 4 |
| Wheat meal | 119 | 17.0 | 23 | 555 | 540 | 8 | 6 | 3 |
| **Oilseeds and derivatives** | | | | | | | | |
| Coconut cake | 207 | 82 | 130 | 5 | 480 | 7 | 8 | 6 |
| Cotton decorticated | 403 | 308 | 28 | 0 | 640 | 7 | 8 | 6 |
| Cotton meal extracted | 436 | 30 | 118 | 8 | 610 | 8 | 6 | 7 |
| Groundnut cake dec. | 469 | 79 | 54 | 63 | 620 | 7 | 8 | 4 |
| Groundnut meal extracted | 503 | 5 | 125 | 20 | 670 | 8 | 6 | 5 |
| Linseed meal extracted | 334 | 31 | 94 | 16 | 560 | 7 | 6 | 5 |
| Palm kernel cake expeller | 146 | 91 | 188 | 4 | 480 | 6 | 7 | 4 |
| Palm kernel meal extracted | 152 | 21 | 189 | 3 | 700 | 6 | 5 | 5 |
| Palm kernel (whole) | 93 | 478 | 102 | 0 | 750 | 3 | 8 | 3 |
| Rapeseed meal extracted | 343 | 22 | 114 | 11 | 510 | 6 | 6 | 6 |
| Sesame meal expeller | 451 | 114 | 62 | 14[*] | 560 | 7 | 7 | 4 |
| Soyabean meal extracted | 449 | 18 | 53 | 8 | 500 | 4 | 5 | 4 |
| Soyabeans full fat | 356 | 189 | 53 | 9 | 480 | 4 | 8 | 3 |
| Sunflower cake expeller | 383 | 71 | 167 | 35[*] | 560 | 6 | 6 | 4 |
| Sunflower meal extracted | 339 | 20 | 192 | 26 | 530 | 6 | 5 | 5 |
| **Animal by-products** | | | | | | | | |
| Blood meal | 878 | 7 | 0 | 0 | 560 | 3 | 5 | 3 |
| Fat (added at mixer) | 0 | 1000 | 0 | 0 | 900 | <–10 | >10 | 0 |

Table 1 (cont.). Feedstuffs and their respective nutritional and pelleting properties (modified after MacMahon and Payne, 1991)

| Raw material | Constituents[†] | | | | Bulk density (kg/m³) | Physical factors [-][††] | | |
|---|---|---|---|---|---|---|---|---|
| | Crude protein (g/kg) | Crude fat (g/kg) | Crude fibre[†††] (g/kg) | Starch[†††] (g/kg) | | Pellet quality | Press capacity | Die wear |
| Animal by-products (cont.) | | | | | | | | |
| Feather meal | 824 | 76 | 0 | 0 | 400 | 4 | 5 | 5 |
| Fish meal | 564 | 116 | 0 | 0 | 640 | 4 | 7 | 5 |
| Meat meal | 569 | 100 | 22 | 0 | 620 | 5 | 7 | 3 |
| Meat and bone meal | 498 | 91 | 16 | 0 | 690 | 4 | 7 | 4 |
| Poultry by-product meal[††††] | 711 | 133 | 27 | 0 | 590 | 3 | 8 | 4 |
| Legumes | | | | | | | | |
| Field beans | 254 | 13 | 73 | 376* | 690 | 7 | 5 | 5 |
| Peas | 206 | 11 | 55 | 410 | 720 | 6 | 5 | 5 |
| Lentils | 229 | 13 | 45 | 422* | 800 | 4 | 4 | 5 |
| Locust beans | 40 | 0 | 71 | 0 | 400 | 4 | 4 | 6 |
| Others | | | | | | | | |
| Brewers grains, dried | 252 | 67 | 126 | 24 | 320 | 3 | 4 | 5 |
| Citrus pulp | 61 | 22 | 118 | 13 | 330 | 7 | 3 | 6 |
| Maize germ meal | 142 | 53 | 69 | 339 | 480 | 5 | 8 | 3 |
| Maize gluten feed | 185 | 38 | 70 | 188 | 540 | 3 | 4 | 6 |
| Maize gluten meal | 607 | 37 | 11 | 156 | 480 | 4 | 5 | 5 |
| Tapioca | 24 | 4 | 43 | 655 | 640 | 5 | 3 | 7 |
| Minerals | 0 | 0 | 0 | 0 | 1000 | 2 | 4 | 10 |
| Beet molasses | 110 | 0 | 0 | 0 | 1230 | 7 | 6 | 0 |
| Rice bran | 129 | 130 | 110 | 200* | 320 | 2 | 3 | 6 |
| Skim milk powder | 349 | 23 | 0 | 0 | 640 | 9 | 2 | 9 |
| Sugar beet pulp (molasses) | n.a. | n.a. | n.a. | n.a. | 240 | 7 | 3 | 5 |
| Lignosulphonate | n.a. | n.a. | n.a. | n.a. | 500 | >10 | >10 | 0 |

[†]Constituent levels derived from the Dutch CVB-table (CVB, 1994).
[††]Figures on a scale of 0 (poor contribution) to 10 (high contribution), based on pellet press operator's experience.
[†††]Crude fibre as component of "Weende analysis"; starch content is given as determined by enzymatic determination (Anonymous, 1974) except were indicated (*), determined by polarimetric method (Anonymous, 1979).
[††††]Poultry by-product meal (chemical data after El Boushy and van der Poel, 1994).

by a number of other ingredients. From their investigation it was concluded that some by-products alter significantly pelleting properties of the feed. The authors concluded that inclusion of about 10 percent cane- or beet molasses in combination with solid by-products reduced the formation of fines and improved specific press capacity. Cotton seed meal gave more durable pellets compared to soybean meal and rapeseed meal (durabilities of 97.2, 94.5 and 91.2% respectively). Specific energy consumption of the pellet press using cotton seed meal (6.5 kWh/t) was higher as compared to soybean meal (5.6 kWh/t).

Table 2. Effect of diet ingredients on specific power consumption and durability of pellets (after Israëlsen *et al.*, 1981)

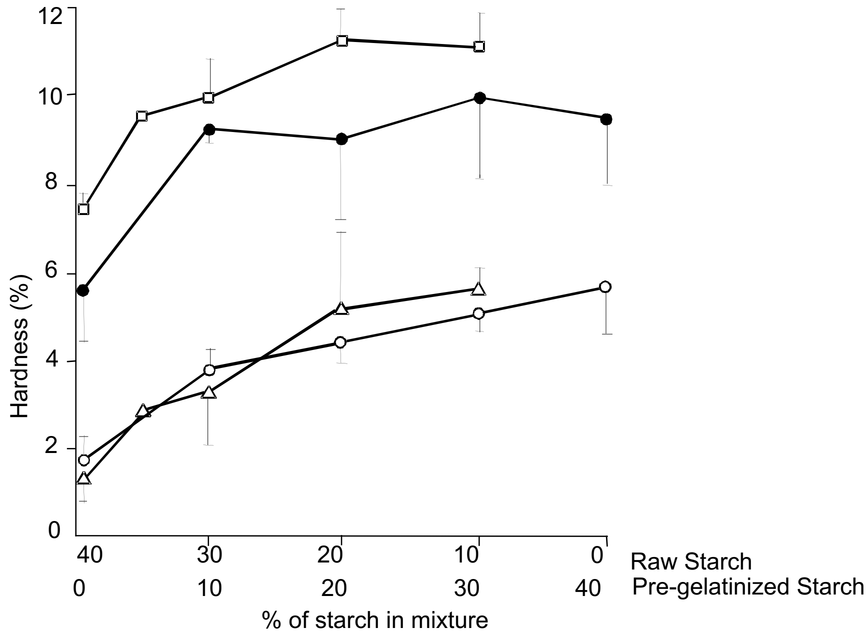
| Diet ingredient | Spec. power consumption (kWh/t) | Durability† (%) |
|---|---|---|
| Control†† | 6.5 | 97.2 |
| Grain substitute††† | | |
| Beet pulp, dried, pelleted | 6.0 | 98.9* |
| Barley malt culms, dried | 4.2* | 98.3* |
| Citrus pulp, dried, pelleted | 4.9* | 97.6 |
| Barley, ground | 7.3 | 97.6 |
| Coconut meal | 7.1 | 97.4 |
| Alfalfa meal, dried | 6.8 | 97.2 |
| Grass, dried, pelleted | 7.6* | 97.2 |
| Wheat bran pellets | 6.9 | 96.9 |
| Palm kernel cake | 8.1 | 96.8 |
| Cotton seed substitute†††† | | |
| Sunflower seed meal | 7.0 | 94.9* |
| Soybean meal | 5.6* | 94.5* |
| Rapeseed meal | 5.8 | 91.2* |

†Durability determined with the Pfost tumbling can.
††Control consisting of 287 g/kg alkali-treated straw pellets, 287 g/kg barley, 287 g/kg cotton seed meal, 40 g/kg fat and 100 g/kg molasses.
†††Grain substitutes replaces barley.
††††Cotton seed substitutes replaces cotton seed meal.
*Significant at $P < 0.05$ different from control.

## Functional properties

Not much research has been conducted on the physico-chemical properties of feedstuff constituents with respect to physical quality of the animal feed. An outstanding example in this respect is the work of Wood (1987), who related degree of starch gelatinization and of protein denaturation towards the durability and hardness of pelleted animal feeds. His results show that there are relationships, but these are too limited to allow quantitative conclusions yet.

To obtain feeds with a certain specified quality standard in terms of hardness and durability, starch needs to be modified by either the feed manufacturing process itself or in a pre-processing step, since native starch in itself does not possess functionality in terms of binding or adhesion to produce durable feed pellets. Wood (1987) showed that the amount of pre-gelatinized starch in feed is related to the physical quality of the feed pellets. Using a design in which native starch was gradually replaced by pre-gelatinized starch (feed model system containing 40% starch), an increase was found in physical quality as determined by Kahl hardness test (Fig. 1) and Holmen durability test. Within the range tested, no optimum was found, indicating that pre-gelatinized starch included in the diets of percentages up to forty percent might still lead to harder (Fig. 1) and more durable pellets (Wood, 1987).




● Cold-conditioned raw protein. Temperature exit conditioner 22°C.
❍ Hot-conditioned raw protein. Temperature exit conditioner 59-73°C.
▵ Hot-conditioned denatured protein. Temperature exit conditioner 59-73°C.
❐ Cold-conditioned denatured protein. Temperature exit conditioner 20-22°C.

Fig. 1. Effects of functional properties of starch and protein on hardness (Kahl device) of pellets after cold and steam conditioning prior to pelleting (Wood, 1987). Two replicates per treatment (means ± 1 SD).

## An example

### Materials and methods

Recent research shows that the state of a raw material component is for a large part responsible for the pellet quality of the manufactured feed (Thomas, 1998). In the remainder of this article, the effect of changes in the state of constituents of raw materials will be discussed in a model feed formulation. Some of the figures presented will be used to give an indication of the economical implication on the cost of pellet quality and energy consumption using least-cost formulation. Although such a methodology has not been evaluated yet, it may serve as a guideline to make use of raw material properties and include these in the least-cost formulation to give an indication of pellet quality.

The following steps were taken:

1. Determining the quality of pellets and energy consumption as a function of the amount of gelatinized starch and dispersible protein. In this case figures were taken from experimental data using a feed formulation study.

2. Prepare two sample formulations, one dairy ration and one pig ration.

3. Estimate the amount of gelatinized starch and dispersible protein present in the raw materials used in the two formulations. Include these as a nutrient in the least cost formulations.

4. Estimate the sensitivity of these nutrients in the least cost formulation and with use of step 1 estimate the spin-off in terms of physical quality and energy consumption.

## Step 1

A feed model system (50% soy-grits/50% tapioca w/w) was used to determine the effect of protein quality and starch degree of gelatinization on the physical quality of manufactured pellets in terms of hardness and durability. In the experiment it was hypothesized that a high amount of dispersible protein and a high amount of gelatinized starch positively affects hardness and durability properties of pelleted feeds. Thirty-six experimental units with varying proportions of gelatinized starch and dispersible protein where formulated. The composition of the four materials [tapioca with native starch, tapioca with gelatinized starch, soy-grits with a high Protein Dispersibility Index (PDI) and soy-grits with a low PDI] is given in Table 3.

Table 3. Chemical composition and some physical characteristics of the used soy and tapioca before blending†

| Component | Tapioca | | Soya | |
|---|---|---|---|---|
| | Native | Pre-processed | PDI-20 | PDI-80 |
| Moisture (g/kg) before blending | 121.2 | 131.0 | 60.3 | 64.3 |
| Crude fiber (g/kg) | 30.5 | 33.8 | 47.1 | 40.9 |
| Crude fat (g/kg) | 5.2 | 3.7 | 11.0 | 8.3 |
| Anorganic matter (g/kg) | 34.4 | 35.0 | 67.8 | 67.6 |
| Crude protein (N*6.25) (g/kg) | 34.6 | 31.6 | 528.8 | 534.8 |
| Starch (g/kg) | 779.9 | 778.3 | 27.3 | 26.8 |
| Protein Dispersibility Index (%) | – | – | 25.9 | 85.1 |
| Degree of gelatinization (%) | 9.4 | 58.8 | – | – |
| Mean particle size ($x_{50}$; µm) | 202 | 334 | 516 | 472 |

†Composition in g/kg dry matter except moisture, which is in g/kg material before blending. Enthalpy values based on, at least, three replicates.

Raw materials were obtained from commercial suppliers. 5000 kg of tapioca was obtained from the Cehave, Veghel, The Netherlands and two batches, 2300 kg each, of soy-grits characterised by a high (PDI-80) and low PDI (PDI-20) were obtained from Cargill B.V., Amsterdam, The Netherlands. Half of the tapioca (2500 kg) was pre-processed to gelatinize the starch fraction of the tapioca meal as much as possible. The other half used was used and referred to as the native tapioca. Pre-gelatinized tapioca-starch was obtained by expander processing (AL150, Almex BV, Zutphen, The Netherlands) and subsequent re-milling to approach the mean particle size of the native tapioca. Expander processing and pelleting was done at the Wageningen Feed Processing Center, Wageningen, The Netherlands. Protein quality was determined by the PDI. Differences in the degree of starch gelatinization were determined from the enzymatic amyloglucosidase test (SGDags). The figures on PDI and SGDags were recalculated to grams of dispersible protein and grams of gelatinized starch included in the feed mash before the manufacture of the pellets. For details on the analysis of PDI and SGDags, see Thomas (1998). Physical quality of the pellets was tested by using Holmen durability and Kahl hardness. Specific mechanical energy consumption (SME; kJ/kg) was calculated from the mass-flow and the power consumption of the pellet press. Results were analyzed using response surface methodology using the following model:

$$Y_i = \beta_0 + \beta_1 * GrDispProt + \beta_2 * GrGelStarch + \beta_3 * GrDispProt^2 + \beta_4 * GrGelStarch^2 + \beta_5 * GrDispProt * GrGelStarch + error_i$$

with $Y_i$ the various dependent variables; Kahl hardness (kgf), Holmen durability (% of pellets retained and specific mechanical energy (kJ/kg feed mash), i the number of experimental units: i = 1...36, GrDispProt the amount of dispersible protein in grams per kg feed mash and GrGelStarch the amount of gelatinized starch in grams per kg of feed mash.

Some of the results of the experiment are shown in the contour plots 2, 3, and 4.

The response surface for the Kahl hardness test was convex with respect to PDI and concave with respect to SGDags. Maximum value was 31.9 kgf at 275 g of dispersible protein per kg feed mash and 420 grams of gelatinized starch per kg feed mash. The minimum value was 17.2 kgf, found at 60.8 g dispersible protein per kg of feed mash and 85 g/kg feed mash gelatinized starch (Fig. 2). The quadratic polynomial model does not give an adequate description of the data found in this experiment as determined from the lack of fit test. Higher order terms such as cubic effects seem to be present in the data. It is not clear whether these effects should be associated with the (functional) properties of the raw materials or are related to the test method itself.

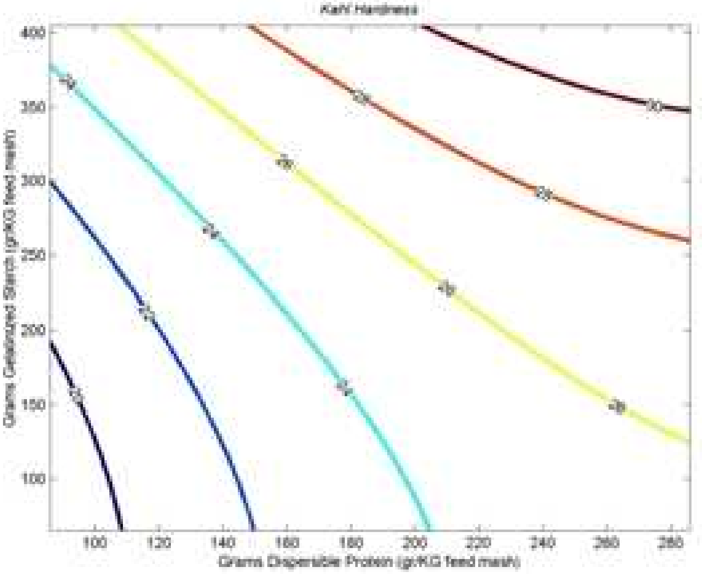



Fig. 2. Kahl hardness as a function of the amount of gelatinized starch (GrGelStarch) and dispersible protein (GrDispProt) present (g/kg).

The equation is given by:

*Kahl hardness = 12.48 + 0.000436526*GrGelStarch + 0.0000368406*GrGelStarch_ + 0.0813489*GrDispProt – 0.000127088*GrDispProt_ + 0.000000670761*GrGelStarch*GrDispProt*

The maximum Holmen durability estimated from the response curve was 96.7% at 190 g of dispersible protein per kg feed mash and 475 g of gelatinized starch per kg feed mash. See Fig. 3.

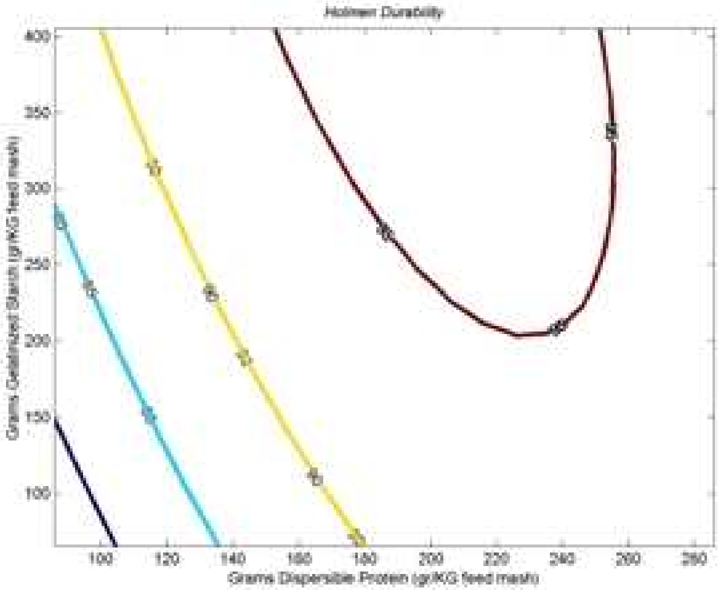



Fig. 3. Holmen durability as a function of degree of gelatinization and of dispersible protein.
The equation is given by:

*Holmen durability (%) = 50.24 + 0.0644603*GrGelStarch – 0.0000328177*GrGelStarch_ + 0.322383*GrDispProt – 0.000626361*GrDispProt_ – 0.000170978*GrGelStarch*GrDispProt*

The highest specific mechanical energy consumption was 66.0 kJ/kg (18.3 kWh/t) and was found at 275 grams of dispersible protein per kg feed mash and 420 grams of gelatinized starch per kg feed mash. The minimum value was 50.6 kJ/kg (14.1 kWh/t) and was found at 130 grams of dispersible protein and per kg feed mash and 475 grams of gelatinized starch per kg feed mash, within the experimental range. See Fig. 4.

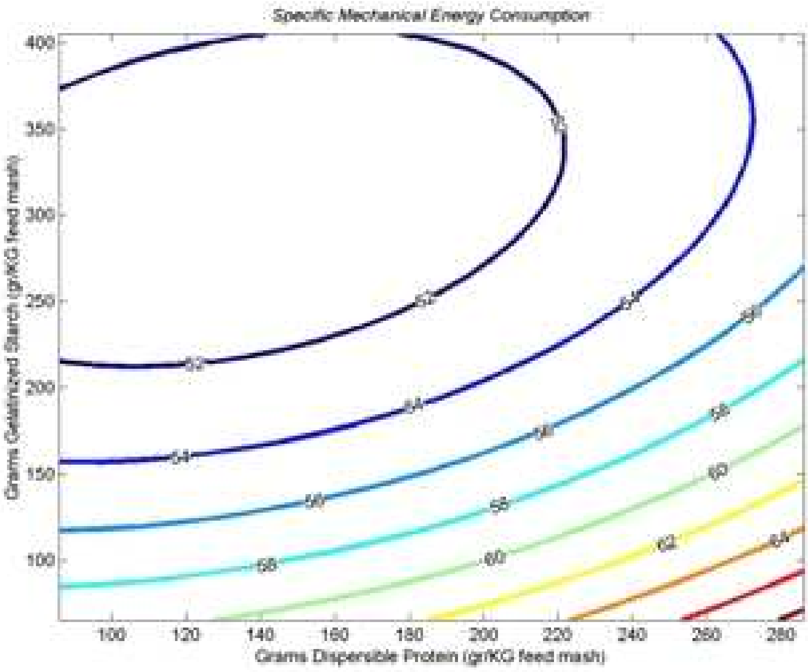



Fig. 4. Specific mechanical energy consumption (SME) (kJ/kg) of the pelletizer as a function of degree of gelatinization and dispersible protein.

The equation is given by:

$$SME = 64.9 - 0.084395*GrGelStarch\_ + 0.000158796*GrGelStarch\_ - 0.0180775*GrDispProt + 0.000190632*GrDispProt\_ - 0.000105217*GrGelStarch*GrDispProt$$

## Step 2

The two feed formulations that were used in the calculation are given below. The raw material (Table 4) and nutrient constraints (Table 5) used represent typical levels as may be found in the Dutch feeding industry.

Using the equations given above, it was tried to analyse which factors would have the highest impact on the costs associated with pellet quality. What follows is a theoretical excercise in which the amount of dispersible protein and gelatinized starch is incorporated as a nutrient in a least cost calculation. Examples are given for a dairy ration (940 VEM/90 DVE) and a pig ration with an energy-content of 1.10 EW (the Dutch feeding system is used throughout). All feed formulations and the sensitivity analysis have been done with use of the least-costing package "Micromix" (Koerhuis Automatisering, The Netherlands).

Table 4. Raw material constraints and linear programming solution for the dairy ration and pig ration used in the calculation

| Raw material | Dairy cattle formulation 940 VEM/90 DVE[†] | | | Pig feed formulation (45-110 kg) 1.10 EW[†] | | |
|---|---|---|---|---|---|---|
| | Amount (%) | Minimum constraint | Maximum constraint | Amount (%) | Minimum constraint | Maximum constraint |
| Maize | 3.32 | 0.00 | 100.00 | 11.12 | 0.00 | 100.00 |
| Maize gluten feed | 40.00 | 0.00 | 40.00 | 0.00 | 0.00 | 0.00 |
| Palm kernel expeller | 20.0 | 0.00 | 20.00 | 5.00 | 0.00 | 5.00 |
| Sunflowe rseed extracted | 0 | 0.00 | 0.00 | 10.00 | 0.00 | 10.00 |
| Soy hulls | 17.91 | 0.00 | 100.00 | 0.00 | n.i.[††] | n.i. |
| Coconut expeller | 7.50 | 0.00 | 7.50 | 0.00 | n.i. | n.i. |
| Soyb.m. 44/45% CP + CF | 2.21 | 0.00 | 100.00 | 23.61 | 0.00 | 100.00 |
| Salt | 0.42 | 0.00 | 100.00 | 0.24 | 0.00 | 100.00 |
| Limestone | 0.73 | 0.00 | 0.00 | 0.12 | 0.00 | 100.00 |
| Magnesium oxide 85% | 0.42 | 0.00 | 100.00 | 0.00 | n.i. | n.i. |
| Molasses (cane) | 6.00 | 6.00 | 8.00 | 5.00 | 0.00 | 0.50 |
| Animal fat | 0.5 | 0.00 | 0.50 | 4.00 | 0.00 | 4.00 |
| Premix 1% | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Phytase 5000 FTU | n.i. | n.i. | n.i. | 0.01 | 0.01 | 0.01 |
| Di-calcium phosphate | n.i. | n.i. | n.i. | 0.01 | 0.00 | 100.00 |
| DL-methionine 99% | n.i. | n.i. | n.i. | 0.02 | 0.00 | 100.00 |
| L-lysine HCl 98.5% | n.i. | n.i. | n.i. | 0.08 | 0.00 | 100.00 |

[†]Dutch energy/protein standard, respectively.
[††]n.i.: not included in recipe for formulation.

Table 5. Nutrient constraints used in the formulation of the dairy ration and pig feed formulation

| Nutrient | Dairy formulation 940 VEM/90 DVE | | | Pig feed formulation (45-110 kg) 1.10 EW | | |
|---|---|---|---|---|---|---|
| | Amount (g/kg) | Minimum constraint | Maximum constraint | Amount (g/kg) | Minimum constraint | Maximum constraint |

| | | | | | | |
|---|---|---|---|---|---|---|
| C. protein | 153.8 | 140 | 170 | 168.1 | | |
| C. fat | 49.2 | | 50 | 56.2 | | |
| C. fibre | 138.5 | | | 56.8 | | 65 |
| Starch | 110.1 | | | 347.7 | 340 | |
| Sugar | 54.1 | | 100 | | | |
| Ca | 6.0 | 6 | 10 | 5 | 5 | 6.5 |
| P | 5.5 | 4.5 | 6 | 3.6 | | |
| Fermentable org. matter | 522.2 | | | | | |
| Energy value (pigs: kJ) | | | | 97 | 97 | |
| Energy value (cow: VEM) | 940 | 940 | | | | |
| Digest. phosphorus | | | | 1.8 | 1.8 | |
| Int. dig. protein (DVE) | 96.6 | 90 | | | | |
| Int. dig. lysine | 5.22 | | | 7.40 | 7.40 | |
| Int. dig. methionine | 2.12 | | | 2.46 | 2.40 | |
| Int. dig. met + cys | | | | 4.40 | 4.40 | |
| Int. dig. tryptophan | | | | 1.53 | 1.40 | |
| Int. dig. threonine | | | | 4.56 | 4.40 | |
| Na | 3.0 | 3 | 5 | 1.2 | 1.20 | 2.50 |
| Mg | 5.0 | 5 | 8 | | | |
| Cl | | | | 2.87 | 1.50 | |
| K | 12.6 | | 20 | 11.64 | | 12.00 |
| Fatty acid (C 18:2) | | | | 8.00 | 8.00 | 14.00 |

## Step 3

An estimate has been made on the amount of dispersible protein or gelatinized starch that would be ordinarily available in some of the feed raw materials used in the preparation of the animal feeds. Table 6 gives some estimates that were used in the calculation of the examples. Note that depending on processing history, the levels of gelatinized starch or dispersible protein might change.

Table 6. Estimates of the fraction gelatinized starch and dispersible protein in the raw materials used in the formulation of a pig and dairy-ration

| Raw material | Starch-fraction | | Protein-fraction | |
|---|---|---|---|---|
| | Content[†] (g/kg DM) | Fraction gelatinized starch | Content[†] (g/kg DM) | Fraction dispersible protein |
| Maize | 621 | 0.15 | 85 | 0.5 |
| Maize gluten feed | 183 | 0.55 | 185 | 0.25 |
| Palm kernel expeller | 11 | 0.25 | 146 | 0.2 |
| Soy hulls | 66 | 0.15 | 114 | 0.25 |
| Coconut expeller | 14 | 0.25 | 207 | 0.3 |
| Soy 44/45% | 55 | 0 | 425 | 0.2 |
| Sunflower seed extr. | 44 | 0 | 386 | 0.35 |
| Tapioca (starch 65.5%) | 655 | 0.15 | 24 | 0 |
| Maize (gelatinized) | 621 | 0.9 | 85 | 0.1 |
| Wheat (gelatinized) | 586 | 0.9 | 119 | 0.1 |
| Wheat gluten | 30 | 0.25 | 763 | 0.6 |
| Maize gluten | 170 | 0.25 | 595 | 0.6 |

[†]Figures were taken from the Dutch CVB-table (1994).

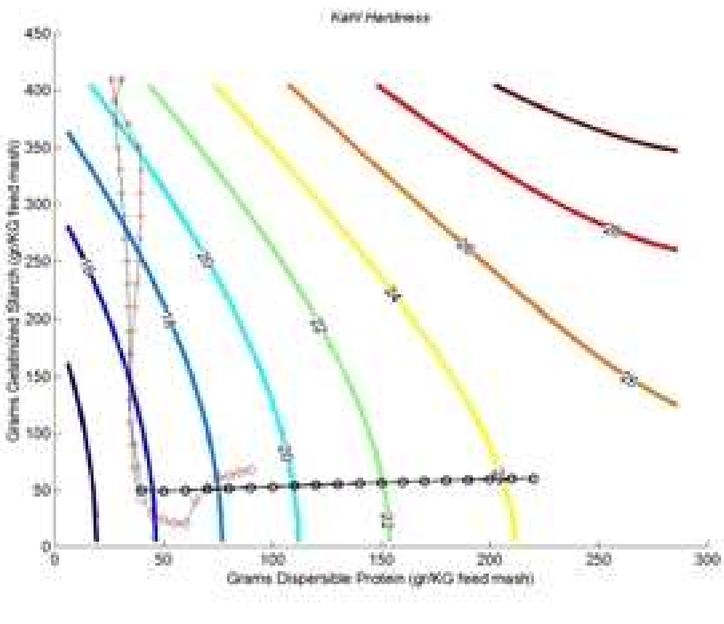
Using the data given in Table 6 and the feed formulations from Tables 4 and 5 it follows that the amount of gelatinized starch in the dairy ration amounts 45.9 g/kg and in the pig ration 49.6 g/kg. The amount of dispersible protein in the dairy ration amounts 37.4 g/kg and in the pig ration 39.8 g/kg after optimization with the least costing package.

## Step 4

A sensitivity analysis is done on the nutrients "gelatinized starch" and "dispersible protein" for the dairy and pig ration. In this sensitivity analysis the price of the ration is calculated as a function of the inclusion level of gelatinized starch or as a function of the amount of dispersible protein.

In Fig. 5 trajectories are plotted on the contour plot of Kahl hardness as a function of the amount of gelatinized starch and dispersible protein. With increasing level of gelatinized starch, it can be calculated what the associated dispersible protein content will be for either the cattle feed (grey colored "+" and "o") or the pig feed (black colored "+" and "o"). In case of the "+", the amount of dispersible protein is calculated when a sensitivity analysis has been conducted on the amount of gelatinized starch. In case of "o" the amount of gelatinized starch is calculated when a sensitivity analysis was done on the amount of dispersible protein. The sensitivity analysis gives the price of the formulation; this price [in Dutch florins (Dfl)/100 kg feed] is given in subsequent plots (Figs 6, 7, 10 and 11). The (calculated) resulting Kahl hardness, Holmen durability and SME are then subsequently plotted in the Figs 8, 9, 12 and 13.

Figure 6 gives the price of the cattle ration as a function of the amount of gelatinized starch included. It follows that the price of the feed increases from 22.90 Dfl to 34.35 Dfl at 400 grams of gelatinized starch included. From Fig. 8 it follows that the Kahl hardness and Holmen durability are better at the high inclusion level of gelatinized starch. The SME shows that a minimum amount of SME is needed around 280-300 g/kg starch included. At around 50 g/kg of gelatinized starch included, SME is 60.5 kJ/kg, at 400 g of gelatinized starch included this is 55 kJ/kg. The lowest value is reached at around 300 grams of gelatinized starch included; 52.2 kJ/kg. The energy consumption decreases with (60.5-52.2) 8.3 kJ/kg. Assuming a price of 0.10 Dfl per kWh of electricity, this accounts to a reduction of energy costs (for the pelletizer only) of approximately 0.02 Dfl per 100 kg, a fairly negligible reduction. The price of the feed rises from 22.90 to 30.24 Dfl, a rise of 7.34 Dfl. This indicates that reduction in energy consumption by means of inclusion of different raw materials is not a feasibly option under current manufacturing conditions and energy prices. The increase in pellet quality, however, might decrease the amount of fines generated after pelleting and cooling and may reduce the amount of feed that needs to be reworked (Fig. 8). This may generate an increase in production capacity for the factory.




Grey "+": sensitivity analysis on gelatinized starch for cattle feed.
Black "+": sensitivity analysis on gelatinized starch for pig feed.

Grey "o": sensitivity analysis on dispersible protein for cattle feed.
Black "o": sensitivity analysis on dispersible protein for pig feed.

Fig. 5. Contour plot of Kahl hardness with the trajectory of the combinations gelatinized starch and dispersible protein plotted, as derived from the sensitivity analysis. Trajectories are derived from the sensitivity analysis on the price of the feed formulation (cattle or pig) and give the combination gelatinized starch and associated dispersible protein (or vice versa) for which a price has been calculated.

From Fig. 7 it follows that only a relative small increment in the amount of dispersible protein included gives a tremendous increase in the cost of the feed formulation. At 40 grams of dispersible protein the price of the feed is 22.90 Dfl, this increases to 36.20 Dfl at 90 grams of dispersible protein included. Higher levels of dispersible protein are not possible with the current constraint settings. From Fig. 9 it follows that SME and Kahl hardness remain fairly constant. Holmen durability show a tendency to decrease at inclusion levels lower than 60 grams of dispersible protein, after which it rises again.

It can be concluded that with the dairy formulation used and the estimated fractions of gelatinized starch and dispersible protein in the raw materials, a change in the amount of gelatinized starch has the lowest impact on the costs of the formulation. The amount of dispersible protein that can be included in the ration is constrained: the cost of the formulation rises quickly while pellet quality and energy consumption is only slightly affected in the evaluated range of inclusion levels of dispersible protein.

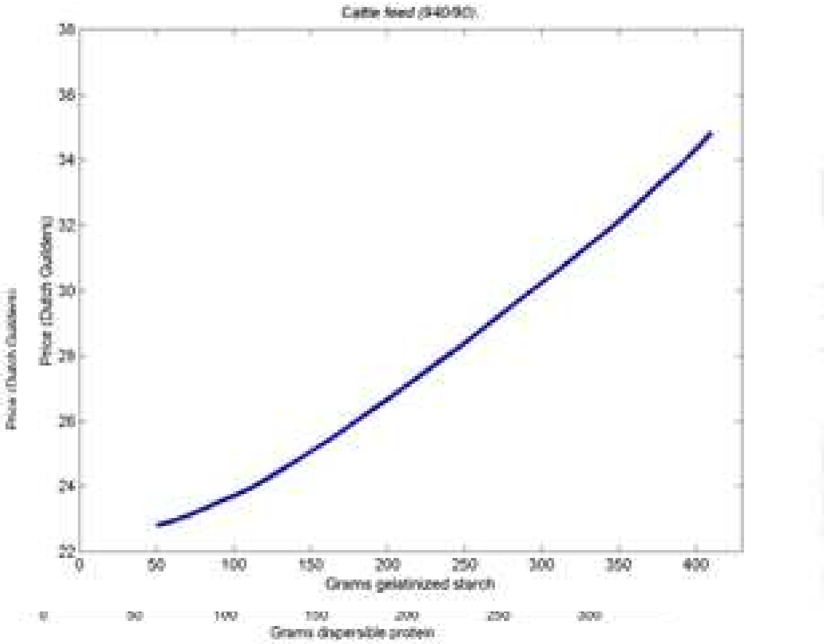



Fig. 6. Price of the cattle feed (Dfl/100 kg) as a function of the amount of gelatinized starch included.

Fig. 7. Price of the cattle feed (Dfl/100 kg) as a function of the amount of dispersible protein starch included.

The price for the pig feed in Fig. 10 rises with increasing levels of gelatinized starch. At an inclusion level of 50 grams of dispersible protein, the price of the feed is 28.74 Dfl which rises to 37.70 Dfl at 400 grams of gelatinized starch included. Kahl hardness increases steadily from 15.6 to 20.7

kgf in the range from 50 to 400 grams of gelatinized starch included. Holmen durability increases from 65 to 78%. The reduction in energy consumption is approximately 5.5 kJ/kg, which gives a reduction in electricity costs of 0.015 Dfl per 100 kg of feed produced (assuming a kWh price of 0.10 Dfl). The price of the feed at 300 g/kg gelatinized starch is 34.68 Dfl. Again, the reduction in energy-costs does not account for the increase in price of the feed. However, pellet quality increases (see Fig. 12), which may reduce the amount of rework to be done. In addition, when certain minimum standards on pellet quality are set, the eventual headroom in pellet quality above this level may be traded in against a higher production capacity of the line. (Generally, pellet quality deteriorates at high throughputs.) Calculations in which these factors are taken into account have not been published yet.

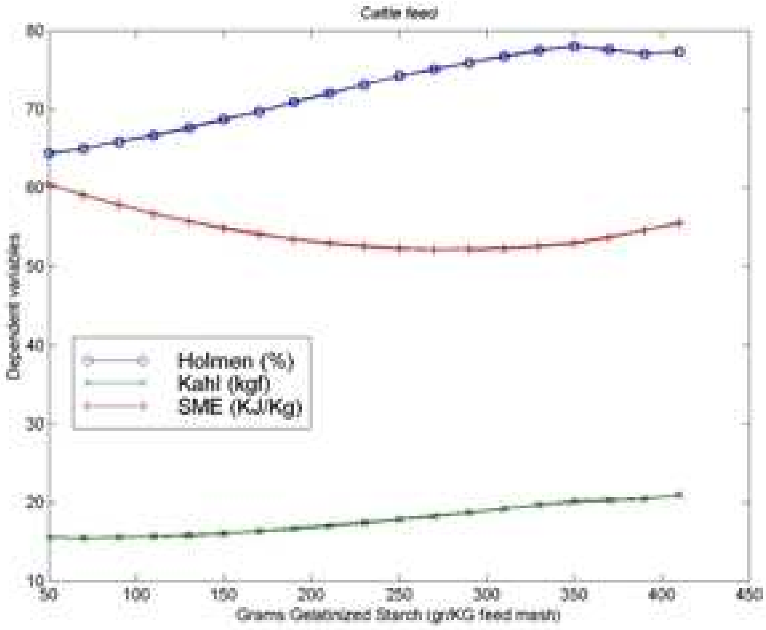



Fig. 8. Kahl pellet hardness (kgf), Holmen durability (%) and specific mechanical energy (kJ/kg) calculated from the combination of gelatinized starch and dispersible protein after the sensitivity analysis for price as a function of gelatinized starch of the cattle feed.

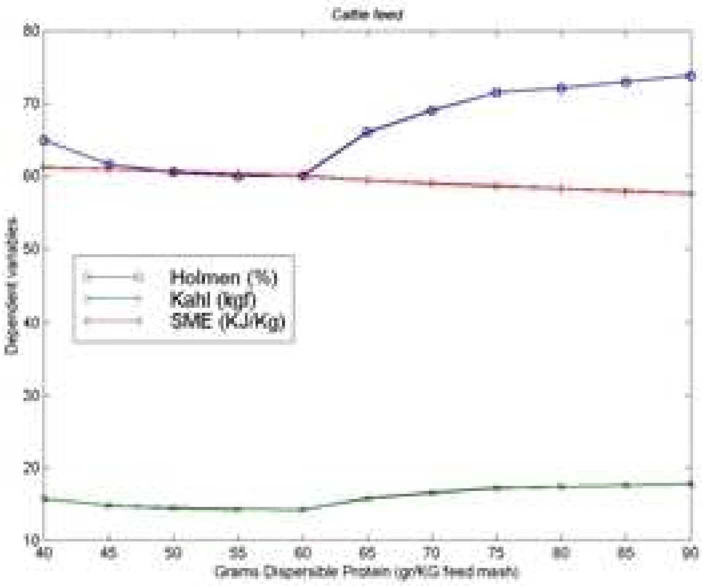


Fig. 9. Kahl pellet hardness (kgf), Holmen durability (%) and specific mechanical energy (kJ/kg) calculated from the combination of gelatinized starch and dispersible protein after the sensitivity analysis for price as a function of the amount of dispersible protein. Notice the difference in inclusion level between Figs 9 and 8.

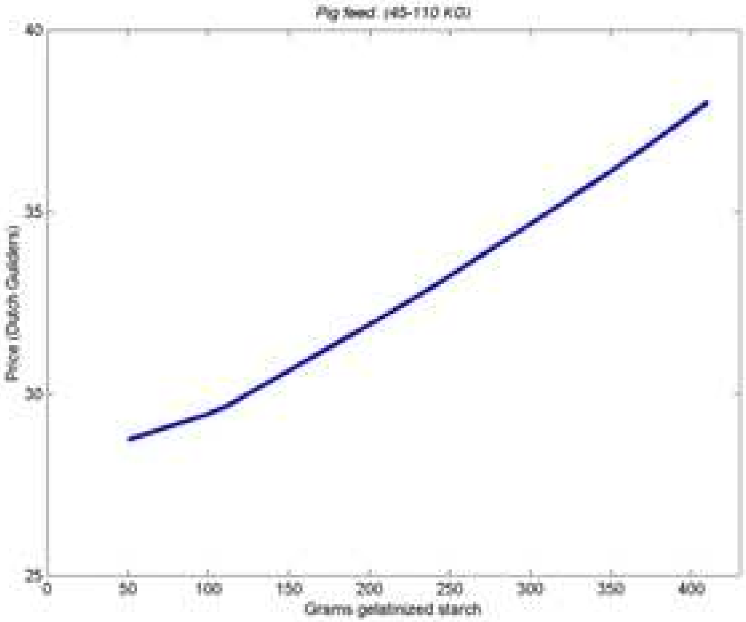



Fig. 10. Sensitivity of the price of a pig ration (Dfl/100 kg) as a function of the amount of gelatinized starch included.

In Fig. 11 the price of the pig feed as a function of the amount of dispersible protein included is given. From the figure it follows that at around 200 grams of dispersible protein included the price of the formulation increases very rapidly. The maximum attainable level of dispersible protein with the current constraints imposed on the formulation is 220 grams per kilogram. From Fig. 13 it can be seen that pellet quality as determined by Holmen durability and Kahl hardness increases and SME is decreasing. However, as can be seen from Fig. 11, the rapid increase in price of the raw materials makes the use of dispersible protein as a means to improve pellet quality and reduce energy consumption uneconomical in this pig feed formulation.

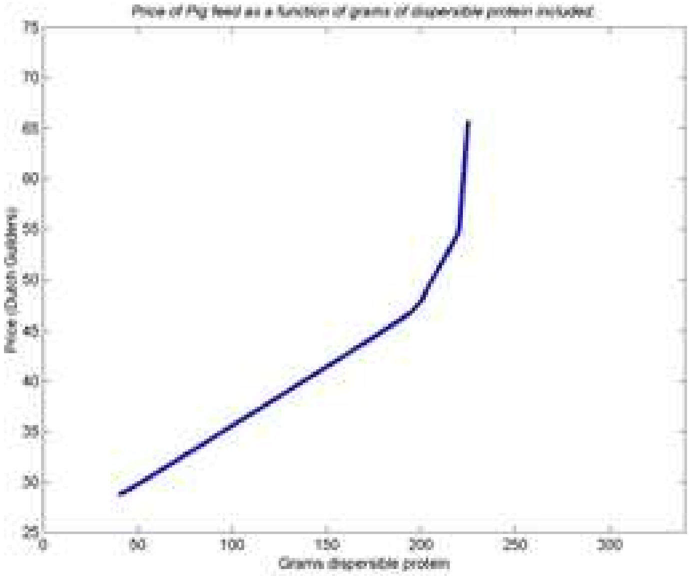



Fig. 11. Sensitivity of the price of a pig ration (Dfl/100 kg) as a function of the amount of dispersible protein included.

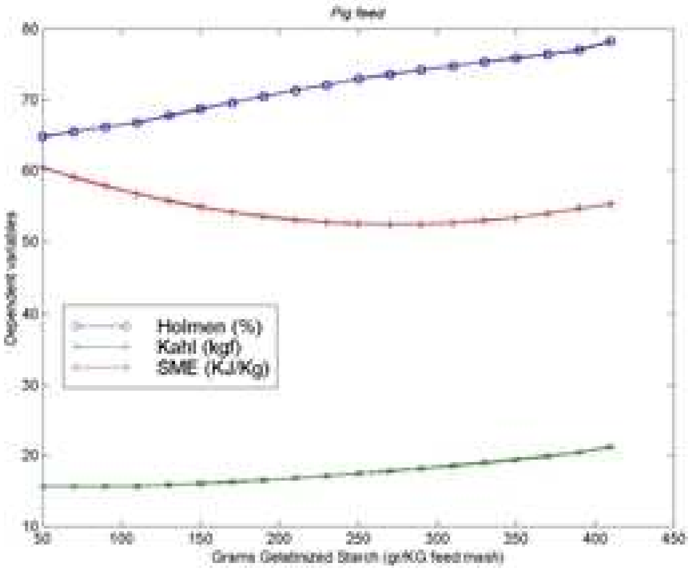



Fig. 12. Kahl pellet hardness (kgf), Holmen durability (%) and specific mechanical energy (kJ/kg) calculated from the combination of gelatinized starch and dispersible protein after the sensitivity analysis for gelatinized starch on the pig feed.

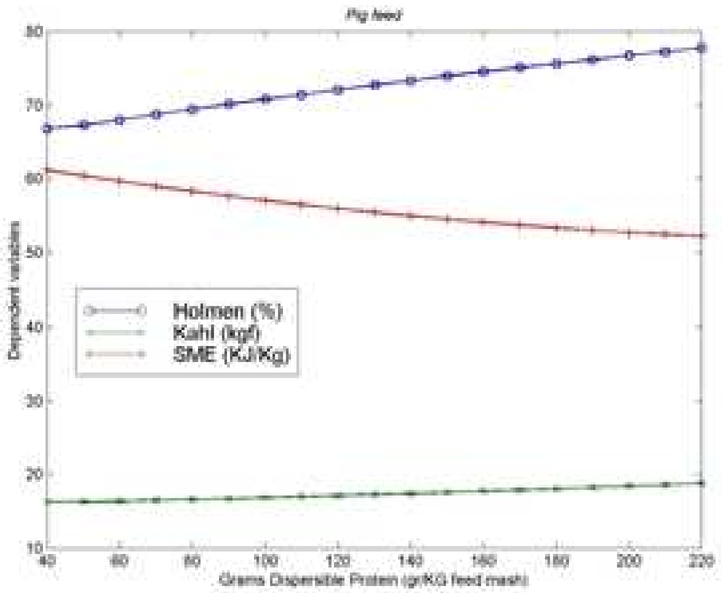



Fig. 13. Kahl pellet hardness (kgf), Holmen durability (%) and specific mechanical energy (kJ/kg) calculated from the combination of gelatinized starch and dispersible protein after the sensitivity analysis for on dispersible protein on the pig feed. Notice the difference in scale (x-axis) between Figs 13 and 12.

## Discussion

From the results of the experiment with the feed model system it was concluded that the state in which protein and starch appear, rather than the incorporation level of a specific raw material determines the physical quality of a pellet. Only few investigations have been done in which these differences in state of the raw material components have been tested.

In the case of the example discussed in the paper, estimates were given of the amount of gelatinized starch and dispersible protein present in the raw materials. However, differences in processing origin may change the state of the components that possess functional properties. This –in turn– affects the pelleting abilities of the raw materials in a feed formulation. Currently there are no quick measurements available that can determine the state of a raw material component. Application of Differential Scanning Calorimetry (DSC) might prove to become a feasible technique for such quick analysis (see a.o. Thomas, 1998).

Amongst the state of starch and protein, other factors influence the physical quality of pelleted feeds or agglomerates in general. Factors which have not been used here, but in future applications should be included, are for instance particle size, particle size distribution and free fat-content. In both the cattle and the pig feed formulation, for the sake of the example, the same equations have been used for pellet quality and specific mechanical energy. However, in the cattle formulation a half percent of animal fat is used in the pig formulation 4.0 percent is used. The factor fat-content, however, has not been evaluated in the feed model experiment, yet added fat has a profound effect on the physical pellet quality.

The strength of certain agglomerates is determined for a large part by three factors; the type of bond that is established between two or more particles, the void-volume or porosity of an agglomerate and the rheological properties of the particles themselves. An overview on the various aspects related to agglomeration has been described by Pietsch (1991). In future applications these effects and how they emerge from the processing conditions during the manufacture of pelleted animal feed should be included. The equations used in the calculation of the physical quality and the specific mechanical energy consumption have been derived from a feed model experiment (Thomas, 1998). Hence, they are not representative for ordinary day-to-day formulation of animal feeds. However, the use of state determinants such as "amount of gelatinized starch" and "dispersible protein" has a higher predictive capability in comparison with ranking of raw materials on the basis of experience past. It may also account for differences found in pelletability of a raw material due to differences in processing history.

From the calculations in this paper it follows that inclusion of gelatinized starch is more cost-efficient than the use of dispersible protein. However, in the case presented above, the reduction in energy consumption did not account for the increase in price of the feed. Pellet quality increases both with inclusion of gelatinized starch or dispersible protein. It is therefore depending on the economical value put on product quality whether or not the increase in raw material costs is justified by notions as better feed quality and good appearance.

The use of the state of raw materials or components and thereby its functionality, provides additional information that can be used to increase the predictability of the physical quality of the pellet.

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