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Serrano X.

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The extrusion-cooking process in animal feeding Nutritional implications

X. SERRANO
AGROTURIA, SA
(VALL COMPANYS GROUP)

SUMMARY - Extrusion-cooking can be described as a process whereby moistened starchy and/or proteinaceous materials are cooked and worked into a viscous, plastic-like dough. This physical treatment combines the heating of food products with the act of extrusion, which could be defined, in a simple way, as the shaping of a material by forcing it through a specially designed opening. In the present work the effect of the extrusion-cooking on the nutritional value of several cereals and full-fat soybeans, used in weaning piglet diets has been discussed. The inclusion of extruded cereals in the experimental diets, had a different effect depending on the ingredient evaluated. So, while the inclusion of extruded wheat or corn had no positive effect on the growth of the animals, the inclusion of extruded barley in the diets led to a better performance parameters during the first 20 days of the experiment. On the other hand, the use of extruded full-fat soybeans improved the performance parameters of the piglets.

Key words: Feed manufacturing, extrusion, nutrients, ingredients, animal performance.

RESUME - *"La procédure d'extrusion-à chaud dans l'alimentation animale. Implications nutritionnelles". L'extrusion à chaud peut être décrite comme un processus par lequel des matières protéiques et/ou amylacées humides sont soumises à une cuisson et transformées en une pâte visqueuse et semblable à du plastique. Ce traitement physique combine la cuisson des produits alimentaires et l'extrusion, ce que l'on pourrait définir en termes simples comme le façonnage d'une matière en la faisant passer au travers d'une grille conçue spécialement à cet effet. Dans le présent article nous avons analysé l'effet de l'extrusion à chaud sur la valeur nutritionnelle de plusieurs céréales et sojas non dégraissés, utilisés pour des régimes de porcins en sevrage. L'incorporation de céréales extrudées dans les régimes expérimentaux présente un effet différent selon l'ingrédient étudié. Tandis que l'incorporation de blé ou de maïs extrudé n'avait pas d'effet positif sur la croissance des animaux, l'inclusion d'orge extrudée dans les régimes menait à de meilleures performances pour les paramètres pendant les premiers vingt jours de l'expérience. Par ailleurs, l'utilisation de soja extrudé non dégraissé a amélioré les performances des porcelets.*

Mots-clés : *Fabrication d'aliments pour bétail, extrusion, substances nutritives, ingrédients, performances animales.*

The principle of extrusion

The verb "to extrude" derives from Latin word *ex* (out) and *trudere* (to thrust), and means to force, as through a small opening. The "Encyclopaedic Dictionary of the Catalan Language" defines this verb, as "to shape a material under pressure by forcing it through a specially designed opening".

The extruder

An extruder is a machine which shapes materials by the process of extrusion. The feed extruders used in our days come from the ones used in the food industry. According to Harper (1979), a food extruder consists of a flighted Archimedes screw which rotates in a tightly fitting cylindrical barrel. Raw ingredients are preground and blended before being placed in the feeding system of the extrusion screw. The action of the flights on the screw push the food products forward and in so doing, work and mix the constituents into a viscous dough-like mass.

As the material moves through the extruder, the pressure within the barrel increases due to a restriction at the discharge of the barrel. The restriction is caused by one or more orifices or shaped openings called a die. Discharge pressures typically varied between 30-60 atm. (Harper, 1979).

Because the flights on the screw of a food extruder are completely full, the food product is subjected to high shear rates as it is conveyed and flows by the action of the screw. These high shear rate areas tend to align long molecules in the food constituents giving rise to cross-linking or restructuring resulting in the extruded foods characteristic texture. The shear environment in the die assembly of the extruder can also have similar effects.

Basically, there are two different kinds of extruders in the feed industry: (i) single-screw extruder; (ii) twin-screw extruder (co-rotating and counter rotating).

Twin-screw extruders have limited use in the production of dry expanded petfoods because of their high relative cost of operation and maintenance. The capital equipment, maintenance and energy costs of a co-rotating twin-screw extruder are about 1.5 times each the cost of a modern single screw extruder (Hauck, 1990). However, twin-screw extruders have the advantage of processing highly viscous or sticky materials due to high fat or water content. Also, due to their more positive conveying mechanism, they offer several advantages over the single-screw counterparts, including better control, faster product changeover (including stop and start) and less dependence on rheological properties permitting more variation in formula and process conditions.

Extrusion-cooking process

The extrusion-cooking process combines the effect of heat with the act of extrusion. Heat is added to the feed dough as it passes through the screw by one or more of three mechanisms: (i) viscous dissipation of mechanical energy being added to the shaft of the screw; (ii) heat transfer from steam or electrical heaters surrounding the barrel; (iii) direct injection of steam which is mixed with the dough in the screw.

The temperatures reached by the feed during cooking can be quite high (200 °C) but the residence time at this elevated temperatures is very short (5 to 10 s). For this reason, extrusion-cooking processes are often called HTST (High temperature/Short time) (Harper, 1979). These kind of processes tend to maximize the beneficial effects of heating feeds while minimizing the detrimental effects.

Extrusion-cooking process can be classified as wet or dry, depending on the use or not of water and steam to prepare the product before being extruded. Wet extrusion-cooking often implies the use of a conditioner and always implies the use of a dryer.

There are several different parameters, which are often interrelated, that must be controlled before and during the extrusion-cooking process: (i) particle size of raw ingredient mix; (ii) rate of ingredient mix flow in the extruder; (iii) amount of steam moisture added during the preconditioning; (iv) retention time of the preconditioning; (v) retention time and moisture added in the extruder barrel; (vi) temperature of the mix and the barrel during the extrusion; (vii) geometric configuration of screw segments and interval ribbing of the extruder barrel; (viii) size and shape of the die orifice (s); (ix) retention time, temperature and air velocity in the dryer.

Effects of extrusion-cooking process on the main feed constituents. Nutritional implications

Starch

Starch granules undergo gelatinization and melting by the action of heat and moisture on hydrogen binding among tightly packed polisaccharyde chains in the granule structure. Under conditions of excess water, hydrogen bindings in the less ordered amorphous regions of the granule are disrupted first, allowing water to associate with free hydroxyl-groups. Swelling is the result and further opening of the granule structure to the action occurs. Melting of the crystalline fraction results in complete disappearance of refringence, which is irreversible.

Complete starch gelatinization is generally achieved at temperatures of ≥120°C, % moisture of 20-30 or even at lower moisture levels (10-20%), provided high shear and temperatures are reached during extrusion (Cheftel, 1986).

Holm *et al.* (1985) showed a close relationship between degree of gelatinization of wheat starch suspensions and rate of hydrolysis by amylase *in vitro*, as well as by blood glucose response in rats.

It seems then that both the *in vitro* and *in vivo* digestibility of starch could be enhanced by extrusion and that the degree to which this effect is produced is controlled by the severity of the extrusion process.

Protein

Most protein undergo structural unfolding and/or aggregation when subjected to moist heat or shear. This often leads to insolubilization and to inactivation (when the nature molecules posses a biological activity).

Soybeans and oilseeds or legumes provide a good example of improved protein digestibility and bioavailability of sulphur amino acids through thermal unfolding of the major globulins, and thermal inactivation of trypsin inhibitors and other growth-retarding factors such as lectins.

However, extensive lysine loss can take place when legume or cereal legume blends are extruded under severe conditions of temperature (≥180°C) or shear forces (>100 rpm) at low moisture (≤15%), especially in the presence of reducing sugars (≥3% glucose, fructose, maltose, lactose) (Björck and Asp, 1983). This damage depends on the maillard condensation between ε-NH_2 groups of lysine residues and C=O groups of reducing sugars. It is not fully understood whether the damaging effects at low water contents are due to local temperature increases through intense shear forces, to specific mechanical effects, to an enhancing effect of low moisture on the maillard condensation or to a combination of these effects.

Lipids

The nutritional value of lipids could be affected during extrusion as a result of oxidation, hydrogenation, isomerization or polymerization (Camire *et al.*, 1990).

The autoxidation of essential fatty acids (linoleic, linolenic, arachidonic) renders them unable to prevent the dermatitis and poor growth associated with low intakes of these nutrients. Isomerization of the double bonds from the cis to the trans form also destroys the essential activity of these PUFA. However, the amount of hydrogenation and cis-trans isomerization of fatty acids that takes place during extrusion is too small to be nutritionally significant (Camire *et al.*, 1990).

Extrusion-inactivation of lipase and lipoxidase helps protect against oxidation during storage. Higher temperatures reduce the lipase activity and moisture level, thereby decreasing favoring free fatty acids development. However, the expanded porous nature of the extrudate causes the feed to be susceptible to the development of oxidation during storage, even though deterioration due to extrusion may not be immediately apparent.

Dietary fiber

Modifications in particle size, solubility and chemical structure of the various fiber components could occur during extrusion-cooking and cause changes in bacterial degradation in the intestine and in physiological properties.

Extrusion-cooking of white wheat flour (161-171 °C; 15% moisture) was found to cause a redistribution of insoluble to soluble dietary fiber. Thus 50-75% of total fiber were soluble in the extruded flour, depending on process conditions, versus 40% in the raw flour. Relative fiber solubilization was smaller in the case of extruded whole grain wheat flour (Björck *et al.*, 1984).

Up to here, there has been a brief description about the possible effects of the extrusion-cooking process on the main feed constituents. However, it is surely more interesting for us to know how this effects on the nutritive value can be related with a better use of feeds in the animal production systems. It should be considered that a number of difficulties arise when trying to summarize published data on this subject. Firstly, different kind of extruders are used. Secondly, processed conditions are not always well-defined. Thirdly, the processing conditions are interrelated, making it difficult to relate nutrient retention to any one single factor. Caution must also be used when transferring results from one food system to another.

For all these reasons, in the next part of the paper it will be presented several performance results from piglets experimental trials, using different extruded ingredients. All these results are from the experimental work carried out for my doctorate thesis. The tested ingredients were wheat, corn and barley, as common cereals used in piglet diets and full-fat soybeans, a typical protein and energy source. In animal production systems, it seems that weaning diets are the best ones to include extruded ingredients, because of the lack of enzymatic capacity of the animals that are going to consume them. The weaning period is a stressful moment for the animals, and this readily digestible ingredients should help to the transition to the growing period.

In the following Tables 1, 2, 3 and 4 are presented the *in vitro* and *in vivo* results obtained for the tested ingredients. They were included in experimental weaning diets at different levels depending on the specific studied ingredient. Extruded wheat and corn were included in different diets at nearly half of the total composition of them. Extruded barley was used at different levels of inclusion in the diet. Finally, a 16% of extruded full-fat soybeans was used to evaluate their effect in weaning piglet diets.

Table 1. Degree of starch gelatinization and growth performance of weanling pigs fed wheat with or without moist extrusion†

Item	Ground wheat	Extruded wheat	SEM
Degree of gelatinization (%)	11.52	91.30	-
Days 11 to 20			
ADG (g)	179	177	18.0
ADFI (g)	358	369	20.3
G/F	.50	.48	.012
Days 21 to 32			
ADG (g)	287	267	20.0
ADFI (g)	538	537	26.9
G/F††	.53	.49	.012
Days 33 to 41			
ADG (g)	378	331	18.6
ADFI (g)	771	701	32.4
G/F	.49	.47	.008
Days 11 to 41			
ADG (g)	281	258	15.2
ADFI (g)	555	538	25.1
G/F††	.51	.48	.009

†Results of the first ten days are not presented because of the presence of a respiratory process which affected a great number of the animals of the experimental trial
††Wheat product effect P<0.05

Table 2. Degree of starch gelatinization and growth performance of weanlin g pigs fed corn with or without moist extrusion

Item	Ground corn	Extruded corn	SEM
Degree of gelatinization (%)	22.87	89.10	-
Phase 1			
ADG (g)	93	107	8.1
ADFI (g)	217	244	10.9
G/F	.42	.43	.022
Phase 2			
ADG (g)	386	355	19.2
ADFI (g)	608	630	25.8
G/F[†]	.64	.56	.016

[†]Corn product effect P<0.01

Table 3. Degree of starch gelatinization and growth performance of weanling pigs fed graded levels of moist-extruded barley

	Ground barley	Extruded barley			SEM
Degree of gelatinization (%)	15.90	91.07			
Item	Inclusion of extruded barley %				
	0	18	36	54	
Days 0 to 10					
ADG (g)	139	161	147	175	13
ADFI (g)	256	283	266	286	20
G/F	.54	.57	.55	.61	.022
Days 11 to 20					
ADG[†] (g)	254	263	302	324	15
ADFI (g)	459	467	514	523	27
G/F[†]	.55	.56	.59	.62	.012
Days 21 to 32					
ADG (g)	413	379	385	427	29
ADFI (g)	703	687	712	752	43
G/F	.59	.55	.54	.57	.012
Days 0 to 32					
ADG (g)	282	280	277	322	19
ADFI (g)	495	501	514	544	30
G/F	.57	.56	.54	.59	.014

[†]Linear increases P<0.01 in ADG and G/F occurred with increasing inclusion of extruded barley

Taking into account the results of the *in vitro* analyses carried out with the studied ingredients, we can observe that moist extrusion-cooking raised the degree of starch gelatinization of the cereals (wheat, corn and barley). On the other hand, there were no difference in urease activity, trypsin inhibitor, nor NSI values between toasted and extruded full-fat soybeans.

The performance results obtained with the ingredients are quite different depending not only on the type of ingredients but also on the special properties and qualities of the specific ingredients. That is why I am going to make a brief discussion for all of them separately.

Table 4. Specific *in vitro* analyses and growth performance of weanling pigs fed full-fat soybeans with or without moist extrusion

Item	Toasted full-fat soybean	Extruded full-fat soybean	SEM
Urease activity (ΔpH)	.15	.09	-
Trypsin inhibitor (TIU/mg)	7.05	3.89	-
NSI (%)	11.10	8.45	-
Days 11 to 20			
ADG (g)	166	189	18.0
ADFI (g)	361	366	20.3
G/F†	.46	.52	.012
Days 21 to 32			
ADG (g)	269	286	20.0
ADFI (g)	532	543	26.9
G/F	.50	.53	.012
Days 33 to 41			
ADG (g)	330	379	18.6
ADFI (g)	728	745	32.4
G/Fb††	.45	.51	.008
Days 11 to 41			
ADG (g)	255	284	15.2
ADFI (g)	543	550	25.1
G/F†	.48	.52	.009

†Full-fat soybean product effect P<0.01
††Full-fat soybean product effect P<0.001

Wheat

There was no relationship between degree of starch gelatinization and performance parameters of the animals. Extruded wheat did not improve growth performance of piglets. Furthermore, it caused a deleterious effect in one period (21 to 32 d) and also when the whole period (11 to 41 d) was considered.

It must be said that there is a lack of information about the use of extruded wheat in piglet diets. Our results are in agreement with those obtained by Lynch and Zoccarato (1992). Unfortunately, these authors did not outlined an explanation of their results. A possible explanation could be the effect of moist extrusion on the protein matrix of wheat grains, increasing their viscosity (Hoseney, 1986). Nevertheless, more specific studies are needed to determine what is really happening when raw wheat is extruded.

Corn

The results are quite similar to those obtained with extruded wheat. However, in phase 1, performance parameters were better, but not statistically significant, for the animals that consumed extruded corn.

Van der Poel *et al.* (1989, 1990), and Richert *et al.* (1992), reported little, if any, improvements using extruded corn in piglet diets. As in our experiment, the best results were obtained in the very early days after weaning the animals.

Barley

The results are completely different of those obtained with the other cereal grains (wheat and corn). There was a good growth performance with extruded barley, until the day 20 of the experiment. The highest the level of inclusion of extruded barley, the best performance parameters achieved.

It should be noted that barley is an ingredient with a lower nutritive value (higher content in fiber), so benefits of extrusion-cooking could be emphasized. Solubility of fiber and, above all, starch gelatinization, could be the possible causes of the improvement.

Full-fat soybeans (FFS)

The use of extruded FFS in piglet diets, has been long studied over the last three decades (Faber and Zimmerman, 1973; Jurgens and Marshall, 1982; Hancock *et al.*, 1990; Enright *et al.*, 1993). In general terms, our results are in agreement with those obtained in former studies.

Besides the inactivation of antinutritive factors (also achieved with a toasting process), extrusion cooking of FFS improves lipid availability due to the shearing effect of the screw on the liposomial structure. This effect enhances the energy value of this ingredient compared with the same ingredient processed under other heat treatments such as toasted or micronized.

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