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EFFECT OF FORAGE FIBRE INCLUSION ON INTAKE CAPACITY AND NUTRIENT DIGESTIBILITY OF SOWS

Final degree project

Agricultural engineering

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Resum

La fibra és un component dels aliments que es relaciona habitualment amb la sacietat física de l'estómac, sobretot quan s'ofereix en grans quantitats, com podrien ser el cas d'algunes dietes amb inclusions de farratge ofertes com a ració única totalment barrejada (TMR). L'objectiu d'aquest treball era analitzar l'efecte de diferents inclusions de farratge, les quals s'incrementaven en proporcions iguals, en relació a la ingestió voluntària i la digestibilitat de les racions. Per realitzar l'experiment es van utilitzar 12 truges (Landrace x Large white) destinades ja a sacrifici, de tercer a vuitè part. Les truges es van assignar a gàbies individuals i es van distribuir en 4 grups tenint en compte el pes viu de cadascuna. El disseny experimental va consistir en un Quadrat llatí de 4x4, utilitzant 4 tractaments diferents (proporcions de Farratge :Concentrat; D1, 0:100; D2 15:85; D3 30:70 i D4 45:65, en matèria seca (MS)). Les dietes D2, D3 i D4 van utilitzar-se com a tractaments experimentals, i per això van ser ofertes *ad libitum*; la D1 es va utilitzar com a dieta control a raó de 3kg/dia. La fracció anomenada "farratge" estava formada per ensitjat de blat de moro (55.4% MS), palla picada (33.3% MS) i bagàs de cervesa fresc (11.2% MS). El "concentrat" utilitzat va ser igual en els 4 tractaments, i incloïa un 0.5% de TiO_2 com a marcador indigestible per calcular la digestibilitat. Com s'esperava, es va observar una reducció de la ingestió voluntària associada a l'increment de farratge a la dieta (5.88 vs. 4.25 i 3.26 kg MS/dia; $p<0.05$). Al mateix temps, la concentració d'energia metabolitzable (EM) va baixar considerablement de la D1 a la D4 (3736 vs. 3130 kcal ME/kg MS; $p<0.05$). Les principals conclusions van ser que la ingestió voluntària i la concentració de ME de la dieta es redueixen a mesura que incrementa la inclusió de fibra farratgera, i per tant és possible trobar una inclusió de farratge que permeti una alimentació *ad libitum* mentre que l'animal es capaç de satisfer els requeriments d'energia.

Resumen

La fibra es un componente de los alimentos habitualmente relacionado con la saciedad física del estómago cuando se ofrece en grandes cantidades, como podría ser el caso de la inclusión de forraje ofrecido como ración única totalmente mezclada (TMR). El objetivo de éste trabajo consistió en analizar el efecto de niveles de forraje, a niveles de inclusión crecientes, en relación a la ingestión voluntaria i la digestibilidad de las ración. Para realizar el experimento se utilizaron 12 cerdas de desvieje (Landrace x Large White) de 3 a 8 partos. Las cerdas fueron alojadas en jaulas individuales y se distribuyeron en 4 grupos en base al peso vivo individual. El diseño experimental fue un Cuadrado latín de 4x4, con 4 tratamientos experimentales diferentes (proporciones Forraje:Concentrado, en materia seca (MS; %); D1, 0:100; D2, 15:85; D3, 30:70 y D4 45:55). Las dietas D2, D3 y D4 se utilizaron como tratamientos experimentales, y por este motivo fueron ofrecidas *ad libitum*, mientras que D1 se utilizó como dieta control a razón de 3 kg/día. La fracción forrajera estaba compuesta por ensilado de maíz (55.4% MS), paja picada (33.3% MS) y bagazo de cerveza húmedo (11.2% MS). El concentrado utilizado fue igual para los 4 tratamientos, y contenía TiO_2 al 0.5% como marcador indigestible para calcular las digestibilidades. Como era de esperar, la ingestión voluntaria decreció con el incremento de forraje en la dieta (5.88 vs. 4.25 y 3.26 kg DM/día; $p<0.05$). Al mismo tiempo, la concentración de energía metabolizable (ME) se redujo considerablemente de la D1 a la D4 (3736 vs. 3130 kcal ME/ kg DM; $p<0.05$). Las principales conclusiones fueron que la ingestión voluntaria y la concentración de ME de la dieta se reducen a medida que se incrementa la inclusión de fibra forrajera, y consecuentemente es posible encontrar un nivel de inclusión de forraje que permita una alimentación *ad libitum* satisfaciendo los requerimientos de energía de la cerda.

Abstract

Dietary fibre is a compound of feeds which is related with physical satiety of the gut when provided in huge quantities, for example with forage inclusion, as a total mixed ration (TMR). The aim of the present experiment was to analyse the effect of increasing amounts of forage, offered to culled sows, in relation to the voluntary feed intake and nutrient digestibility of the rations. Twelve culled sows (Landrace x Large white), ranging between 3 and 8 parities, were allocated in individual crates and distributed into 4 groups according to each sow live weight (LW). A 4x4 Latin square experimental arrangement was used to obtain the 4 different dietary treatments (according to Forage: Concentrate, proportions of DM; D1, 0:100; D2, 15:85; D3 30:70 and D4 45:55). Diets D2 to D4 were the experimental diets, and were offered ad libitum, while D1 was used as a control diet offered at 3kg/day. Forage fraction consisted of maize silage (55.4% DM), chopped straw (33.3% DM) and wet brewer's grains (11.2% DM). The concentrate feed was the same for all treatments, and a 0.5% of TiO_2 was included as indigestible marker to calculate nutrient digestibility. As it was expected, voluntary feed intake was reduced according to the forage increase in the diet (5.88 vs 4.25 and 3.26 kg DM/day; $p<0.05$). At the same time, metabolizable energy (ME) concentration of the diets also decreased from D1 to D4 (3736 vs.3130 kcal ME/kg DM; $p<0.05$). The main conclusions were that voluntary intake and ME of the diet decreased when forage inclusion was increased, and therefore it is possible to find an inclusion that enables *ad libitum* feeding while supplying energy requirements.

Keywords: sows, forage, intake, digestibility

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Symbols and acronyms

ADF: acid detergent fibre
ADL: acid detergent lignin
BDG: brewer's dried grains
BG: brewer's grains
CF: crude fibre
CP: crude protein
CS: chopped straw
DC: digestibility coefficient
DC_e: digestibility coefficient of energy
DE: digestible energy
DF: dietary fibre
dDM: digestibility of the dry matter
DM: dry matter
dOM: digestibility of the organic matter
DOM: digestible organic matter
GE: gross energy
HFD: high fibre diets
HP: heat production
LFD: low fibre diets
LW_m: metabolic live weight
ME: metabolizable energy
MS: maize silage
NDF: neutral detergent fibre
NE: net energy
NSP: non-starch polysaccharides
OM: organic matter
SDF: soluble dietary fibre
TDF: total dietary fibre
TMR: total mixed ration
VFA: volatile fatty acids
WBC: water binding capacity

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Introduction

Dietary fibre (DF) is an intrinsic compound of most ingredients used in swine diets. However, differences between ingredients are very large; both because the percentage of DF itself varies considerably, ranging from 10.8% for maize to 81.4 % of DM for sugar beet (Knudsen, 1997), but also because the chemical composition and structure complexity is highly variable. The only feature that the compounds that integrate DF have in common is that they cannot be degraded by mammalian enzymes (Knudsen, 2001).

Swine is currently fed with concentrated feed (mainly a mixture of cereals and cereals by-products plus vegetal protein supplements), and low fibre levels are associated to these diets. However, several decades ago, when pig rearing still was done in a non-industrial way, high fibre ingredients were usually included in pig diets. In now a day's pig industry, high fibre diets (HFD) are used when feed intake has to be restricted, with the goal of achieving more satiety without offering more nutrients than those required. Examples are group-housed gestating sows or heavy swine in the finishing period. In the first case, it is known that *ad libitum* feeding in group-housed sows provides a welfare enhancement (Arey and Edwards, 1998; Ramonet et al., 1998).

Dietary Fibre in swine feeding

The DF is used in animal nutrition to refer to "the sum of non-starch polysaccharides (NSP) and lignin"; so, from a chemical point of view, is mainly a carbohydrate fraction. If we care for a physiological definition, DF consists of "the dietary components resistant to degradation by mammalian enzymes" (Knudsen, 2001). The main components are NSP, mainly hemicellulose, cellulose and pectin, and lignin (which is not a carbohydrate). Those compounds usually are associated to the plant cell wall, while starch and other non-fibre carbohydrates come from the cell content (Mc Donald et al., 2002).

In practice is not easy to quantify the "fibre fraction" of diets and ingredients, since there are several ways to approach the fibre quantification. In this sense Figure 1 (NRC, 2012) shows a clear picture of fibre component and the different ways to be partitioned. Plant cell wall is the main component of dietary fibre, however, resistant starch, which is a component of the cell content, is also considered part of the analytical fraction called total dietary fibre (TDF). Whereas neutral detergent fibre (NDF) and acid detergent fibre (ADF) are clearly defined on their component, crude fibre (CF) is shown to not have a clear composition. Hence it has been replaced by NDF and ADF that give more accurate results. NSP are defined as the sum of plant cell wall components except lignin, which is not a carbohydrate. Finally there is the analytical fraction soluble dietary fibre (SDF) which is the fraction of TDF including resistant starch, β-glucans, pectins and gums.

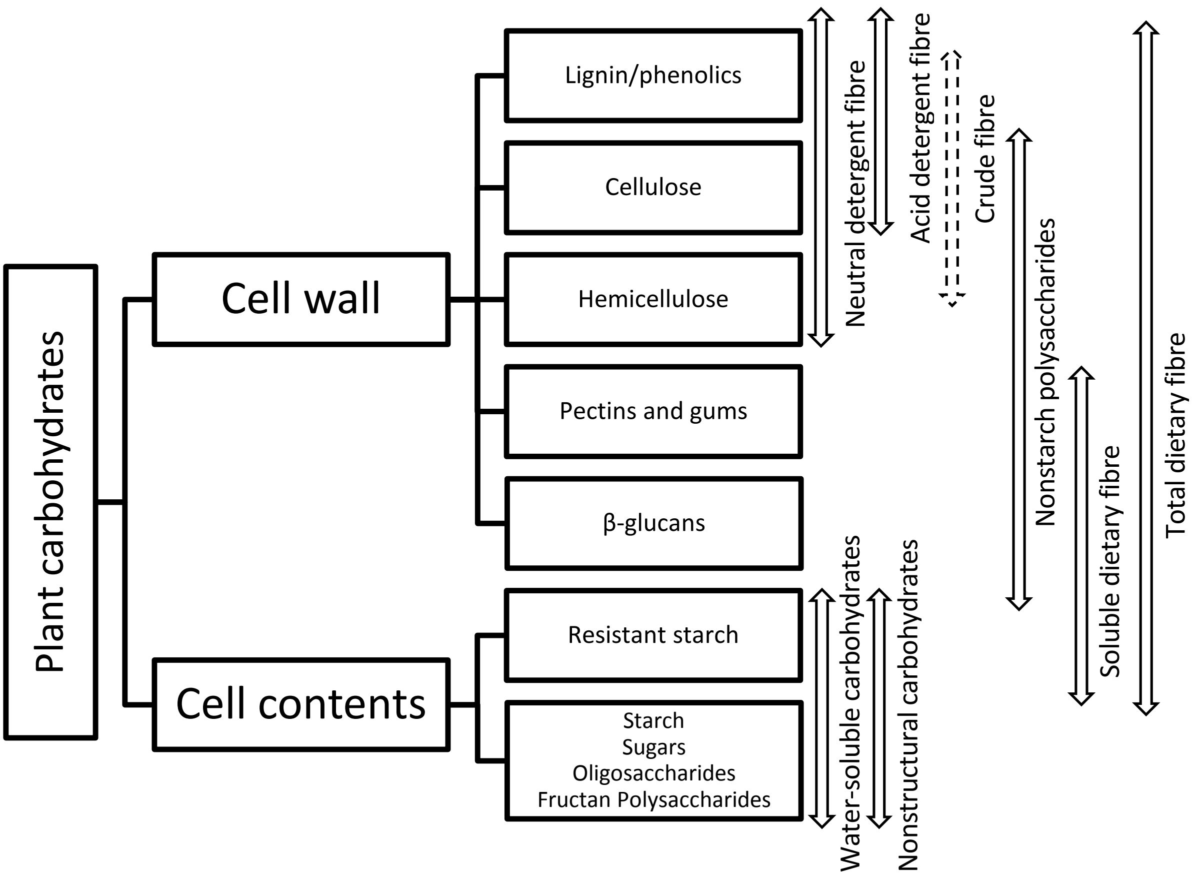

Figure 1-Categories of dietary carbohydrates based on current analytical methods (NRC, 2012)

The DF has an important role in nutrient digestibility, and its composition and digestibility is also the most variable of all the dietary components. The highest DF digestibility coefficients (DC) are obtained with high pectin and/or low lignin, while the lowest are obtained with high levels of cellulose highly lignified. The DC of the fraction called neutral digestive fibre (NDF) range from very low for straw (15%) to considerably high for sugar beet pulp (60,1%) (Noblet and Le Goff, 2001).

The actual implication is that as DF increase, the digestibility of the DM reduces. Considering the different parts of a vegetal cell, the cell content is almost completely digested by mammalian enzymes. Nevertheless cell wall digestibility may vary a lot between diets and ingredients. It depends basically on the degree of lignification of the cell wall structures, which may be expressed in chemical terms as acid detergent lignin (ADL) (Mc Donald et al., 2002) . It is not only that lignin is practically indigestible, but also it decreases digestibility of other compounds to which lignin is bond.

Digestibility of the dietary fibre

Knowing the amount of DF of an ingredient or a diet is not enough to define the nutritive value of this fraction. For this reason, it is necessary to know the proportion that will be digested and used by the animal. The main parameter is called "digestibility" and is expressed as a digestibility coefficient (DC). The DC is defined as the proportion which is not excreted in the faeces, and therefore is absorbed by the animal (Mc Donald et al., 2002).

One of the more relevant conclusions that have been achieved so far is that the capacity of the pig to digest DF is lower compared with other nutrients (mainly fats and protein) and varies with age and live weight of the animal. Experiments proved that adult swine digest better the fibre fraction than young growing pigs, thus they could take advantage of the fibre inclusion in diets and make more feasible this kind of diets (Fernández and Jørgensen, 1986). Noblet and Le Goff, (2001), showed that growing pigs (66 kg LW) and sows (239 kg LW) had DC of DF (DM basis) of 50.2% and 59.6% respectively; this improvement is related to a better digestion of the cellulose fraction by sows.

In general, fibre inclusion reduces DC of almost all components of feed (Noblet and Le Goff, 2001). Partially as a consequence that fibre usually promotes an increase in the rate of passage through the digestive tract (Le Goff and Noblet, 2001) reducing the time for digestion. NSP also influences absorption, metabolism and also the utilisation of other nutrients as glucose, lipids and amino acids. However, it is not clear how it affects minerals utilisation (Grieshop et al., 2001). As a consequence, it reduces digestibility, and also it decreases energy density of the diet. Fernández and Jørgensen, (1986), showed how gross energy (GE) digestibility varies with the % of CF of the diet. With values from 5% to 17% CF in the diet, the digestibility of GE was reduced from 83% to 66%, respectively. Another experiment carried by Chabeauti et al., (1991) showed that DC of GE was reduced from 92%, when no high fibre source were included, to 73.6% when a 22% of wheat straw was included in the diet (DM bases) . The most interesting aspect of this paper is how varies DC with NSP typology, which show that some raw materials as sugar beet pulp or soya bean hulls increase DC, while other ingredients as wheat straw or wheat bran reduce the coefficient.

Dietary fibre and energy

As it has been reported, energy supply per kg of DM is reduced as DF increases in a diet, especially if it has high levels of cellulose and lignin. Energy from DF is provided basically in the hindgut, where is digested and transformed mainly in volatile fatty acids (VFA) such as acetic, propionic and butyric acid, which are absorbed and used as energy sources. When considering DF, not all components are digested in the same proportion and in the same place. Hemicelluloses, and probably pectins, may be degraded partially in the stomach, and a 38% of the total faecal digestibility of it is considered to be digested there, while the remaining 72% is digested in the hindgut. Celluloses however are mainly digested in the hindgut, a 97,8% of the digested fraction (Shi and Noblet, 1993).

Digestion in the hindgut is done by microorganisms. The VFA are absorbed by simple passive diffusion, and metabolized in the site of absorption and predominantly in the liver (Jørgensen et al., 1997). However the metabolic efficiency is lower than for glucose and other nutrients absorbed in the small intestine. Consequently, the energy supply from VFA is low (Shi and Noblet, 1993). Jørgensen et al., 1997 gave values of efficiency, calculated as the proportion between retained energy and gross energy of 82,1% for VFA infused in the caecum. These low efficiency could be in part due to an enlargement and hypertrophy of the hindgut, which increase the demand of energy of caecum cells. Nevertheless, the effect of DF as a source of energy, is known to be positive to net energy (NE) supply in sows (Noblet and Le Goff, 2001).

In any case, to improve the knowledge associated to digestion and energy value of diets in relation to DF, Le Goff and Noblet, (2001), published equations (Equation 1) to predict the DC_e

(Digestibility coefficients of energy). The equations for sows use NDF as the main variable which affects it, with a negative correlation with DC_e. However, when also ash content is included in the equation, the correlation significantly improves. As expected, DC of organic matter is also negatively affected by NDF and ash content. As mentioned before, DC_e are also different between sows and growing pigs. The higher digestibility for sows compared to growing pigs was partly associated to a higher rate of fibre fermentation associated to more methane energy losses

Equation 1 Digestion coefficient of energy (DC_e) according to Le Goff and Noblet, (2001)

$$DCe = 101{,}6 - 0{,}118 * ash - 0{,}052 * NDF$$

DC_e (%), ash and NDF (g/kg of DM)

As has been shown, DC_e is always reduced when the %DF of the diet is increased, especially the NDF fraction. Consequently, values of digestible energy (DE) of high fibre diets will always be lower compared to diets with low DF. Ramonet et al., 2000 did an experiment to compare two diets, a low fibre diet (LFD) and a high fibre diet (HFD). The diets contained 14.0% and 39.6% NDF on DM basis, and values of gross energy (GE) of 17.74 and 17.78 MJ/kg DM respectively. However, due to a lowest capacity of digestibility, DE was significantly lower in the HFD. The DC_e were 89.7% and 74.0%, and as a consequence DE were 15.9 and 13.2 MJ/kg, respectively.

The lower DE of HFD is linked to a decrease of the DCe, but also ME decreases when DF is increased. Fermentation of fibre in the hindgut produces VFA, H_2, CO_2 and finally CH_4, this last one formed in the process of methanogenesis from H_2 and CO_2 (Bindelle et al., 2008). In fact, methane and urine are the only losses considered going from DE to ME, as:

Equation 2 Metabolizable energy calculation

$$ME = DE - E_{urine} - E_{methane}$$

ME, metabolizable energy; DE, digestible energy and E, energy, all compounds using the same energy units.

Energy losses in urine are similar in LFD and HFD, because differences in urine energy excretion are not related with carbohydrates but mainly with nitrogen or protein intake. However, in some way carbohydrates may affect energy excretion in urine; according to the theory and provided the same N intake, energy lost in urine should decrease when DF increases. Fermentation in the hindgut needs N to carry out the process, and at least partially it is transported as urea from blood. Urea (nitrogen) is not excreted in the urine but in faeces as microbial protein. However, the main change when DF increase in the diet is higher methane yield. In the same experiment, energy lost as methane was 3.8 times higher in the HFD. The values were 0.85% and 3.36% of DE, which together with urinary losses resulted in 15.1 and 11.9 MJ/kg DM, respectively for the LFD and the HFD. As a result, ME/DE ratio is always lower when DF is increased in the diets. It is also shown that the intake of net energy (NE) is much higher in LFD than in HFD diet. This is related to a high ME intake in LFD, but with a lower heat production (HP), vice versa in the HFD. The final result for growing finishing animals will be a decrease in the deposition of fat when a HFD is used (Ramonet et al., 2000).

Voluntary intake

When swine is fed *ad libitum*, feed intake is considered to be controlled mainly by three ways. At the metabolic level, causing start or stop eating, depending on the availability of metabolites, and often regulated by hormones. At the level of the emptiness of the animal, that is the more common way in HFD, when the digestive tract is full enough, gut distension triggers the stop of eating. Lastly, external influences, predominantly the climatic variables (Mc Donald et al., 2002). In commercial production the most important seems to be the metabolic pathway, because climatic conditions are often controlled. However if a high proportion of fibre is included, then both metabolic and distension can be critical.

Considering that in commercial production conditions external influences are the less influential factor, voluntary intake will relate mainly to energy concentration (metabolic factor) and gut distension (emptiness) (Ru and Bao, 2004). The first of the two parameters that is reached, stops feeding motivation. To meet energy requirements, sows tend to eat more of a less energy concentrated food, in order to be able to offset energy intake. This was seen in an experiment carried by Zoiopoulos et al., (1982) ; they fed three diets, a control diet and two experimental diets supplemented with high fibre ingredients. The first was supplemented with 30% wheat straw, and the second with 40% oat husks. Daily DM intake in the control diet was 4.87 kg, whereas when straw was supplemented it increased to 5.80 kg, and when oat husks were supplemented the value was 7.79 kg. The DE concentration (MJ/kg DM) was 14.4, 12.9 and 10.9. Meanwhile DE intake (MJ/day) was 70.1, 60.4 and 85.0 for the control, wheat straw and oat husks diets, respectively. This suggests that in this case energy is not the restriction factor to reduce voluntary intake in wheat straw and oat husks diets, emptiness might be the most important factor.

Gastric emptying causes gut distension, which triggers the effect of tension receptors (Ru and Bao, 2004). These tension receptors don't activate for an increased volume of the digesting food, they are activated by an increased pressure in the stomach (Lepionka et al., 1997). How the different composition of fibre sources affect gastric emptying is an issue that has concerned many researchers. Some of them have attributed this capacity of reducing voluntary intake to an increased swelling and water binding capacity (WBC) (Jørgensen et al., 2010). These features are related in the same research to soluble NSP, which seems to increase these capacities. Swelling is the process in which incoming water spreads macromolecules until they are completely extended, but without being solubilized, and indicates the volume that the material would have for each kg of DM. Whereas WBC refers to the ability of a fibre source to incorporate water within its matrix (Knudsen, 2001).

In humans, it was shown that fibre prolonged gastric emptying time in the upper gastrointestinal tract. The time empting is prolonged depends basically on the physical form of fibre, on its viscosity concretely. The viscosity is a feature of fibre, enhanced mainly by insoluble fibre, and with not a clear effect for soluble fibre (Eastwood, 1992). Bach Knudsen, (2001), after reporting different experiments about DF effect in gastric emptying, found that data between them were contradictory. The only common conclusion was that DF has an influence on gastric emptying, and concluded that these inconsistent results were a consequence of how DF had been included in the diets.

It is necessary to make a difference between commercial feedstuff with high levels of DF and high fibre diets (HFD) to understand how fibre affect feed intake. As it has been explained, swine tend to meet metabolic requirements, and for this reason, when the % of the DF in the diet increases energy concentration decreases. The answer of swine is to reach a larger feed intake, trying to meet the same energy supply. Nevertheless, when we consider HFD, understood as diets which include high fibrous ingredients in large proportions, the role fibre plays on intake is not the same than within values usual in commercial production. Diets with high fibrous ingredients reduce intake, despite having less energy concentration (Ru and Bao, 2004), and it can be related to the diet being unpalatable, due to excessive levels of inhibitory substances in the fibre source; the gut capacity becomes limiting arriving before to the physical satiety; and finally, although there could be a possible increase in the passage rate, which is counteracted by increase in bulk content.

High fibre diets

The use of HFD in swine nutrition is not new. Many researches tried to evaluate these diets mainly for sows during pregnancy (Etienne, 1987), as it is the period when energy requirements are lower. Alfalfa, straw, oat husks, soybean hulls, sugar beet pulp, wheat bran and many others are examples of ingredients used as source of fibre for swine diets. In most cases, high fibre ingredients (sunflower meal, wheat bran, sugar beet pulp…) are included in the concentrate feed prepared as meal or pelleted. This is done to avoid selection between ingredients (Brouns et al., 1995), but there is not significant research in other ways of providing fibre ingredients to swine.

Straw: when added in sow diets, provides a positive supply of ME, however, HP is increased with every MJ of straw added, and energy retention (ER) consequently decreases 0.08 MJ/MJ of straw GE added to the basal diet (Etienne, 1987). Brouns et al., (1995), tested different high fibre diets in gestating sows, one with barley straw. It was included at 357,3 g/Kg as fed basis in a pelleted diet. Results showed an intake of 5.6 kg DM/day and sow, which gave rise to 57 MJ ME intake/day.

Brewer's grains: it is the most important by-product of the brewing industry, and has high fibre content. As a feed it is used mainly for dairy cattle, but has been tested in some trials for pigs too. It can be provided as wet feed, silage or dried. Amaefule et al., (2006) found that inclusions of 30-40% of Brewer's dried grains (BDG) in growing pigs didn't cause a decrease in weight gain in relation to the control diet; an inclusion rate of 35% had the best performance. Wahlstrom and Libal, (1968) fed also BDG to sows, up to a 20-40% inclusions. They did not found large differences in the productive performance between control, 20% and 40% diets.

Grass silage: this conserved forage, widely used for ruminants, has not been tested in many experiments in swine. It could bring problems mainly for its low palatability. Whittemore and Henderson, (1977), studied the use of grass silage made of young grass (271 g fibre/kg DM) in pigs and barren sows. Pigs refused diets that contained more than 20% DM of silage. Nevertheless, when tested in sows didn't have the same effect. Before starting the trials sows were fed silage alone, and consumed quantities ranging 2-5 kg/day (fresh matter). Considering a 23.5% DM, the intake would be 0.47-1.18 kg silage DM/day.

<u>Maize silage:</u> only one reference has been found reporting maize silage in swine diets. Wecke et al. (1991) cited by Ru and Bao, (2004) found maize cob silage increased feed intake of pregnant sows. Even though, it had positive effects on sow productive performance. Rates of inclusion were not published.

<u>Grass meal:</u> another way to increase DF in the diets is by including grass meal. Vestergaard et al., (1996) cited by Ru and Bao, (2004), found that inclusions from 0 to 30% of grass meal reduced significantly feed intake of dry sows. As a particular case in an experiment alfalfa meal was feed to fattening pigs by Chen et al., (2014); 5, 10 and 20% inclusions were tested, and it was concluded that it reduced productive performance. However, digestibility of DM was only reduced from 88.1 to 81%, still suitable for energy restricted diets.

<u>Sugar beet pulp:</u> is a by-product of the sugar extraction process from sugar beet. It is known that in really decreases feed intake. Brouns et al., (1995) shown that compared to different fibre sources it has a greater capacity to decrease voluntary intake. In the same experiment it was also found that sugar beet pulp had better DC_e than other ingredients.

The amount of fibre sources to be used for swine diets are great, almost any fibre source could be used, and it finally will depend on the availability of where are required. Perhaps, for this reason, it is not suitable to study in detail a particular fibrous ingredient. Therefore, each region should test diets with the available and cheap products, and determine if they are useful for their purposes. Factors involved in making a HFD feasible involve according to Ru and Bao, (2004), "cheap and available ingredients, less or no negative impact on other nutrient digestibility, no anti-nutritional effect, a low palatability, no negative effect on animal production and a high water holding capacity". The main feature that must have any HFD is that causes a decrease in voluntary feed intake. And also there is a need to find a compromise between this intake and the nutrients supply related to it.

Previous work

A previous trial was performed during July-August 2014 (Aymerich et al., 2015). The aim of this preliminary trial was to determine and have a general idea of the effects caused by high fibre inclusion in sow diets, especially on the digestibility of energy. But the main difference between this trial and others cited before is how the fibrous ingredients were included. Rather than preparing a completely homogenised diet, pelleted or mashed, the diet was offered just as a total mixed ration (TMR) in a similar way as it is done for dairy cows.

Five dry-culled group-housed sows (Landrace x Large white), with more than 7 farrowing's, were fed three different diets, two experimental and a control diet. The two experimental diets were composed by two fractions, the first one was a concentrated feed and the second one was called "forage", all mixed as a TMR diet. The first diet (D1) had a 60:40 (Concentrate: Forage) in DM bases. The second diet (D2) had a 40:60 rate. The forage fraction consisted of chopped barley straw (20%), dehydrated alfalfa (20%) and maize silage (60%) as DM basis. Concentrated feed had different features for the two treatments. The one in D1 had a content of 22.5% crude protein (CP) while D2 27.6% PB. These two diets were fed *ad libitum* while the control diet was given at a rate of 3 kg DM/day, and consisted of a mixture 50:50 of the two concentrates used to prepare the other two experimental diets. Titanium dioxide (TiO_2) was included as indigestible marker (1% DM of concentrated feed) to evaluate the digestibility coefficients

The two experimental diets were offered during 3 weeks, the first two were used as adaptation period, whereas during the last week feed intake was measured, faeces were collected and sows weighed the last day. Refusal were also collected, weighed and sampled.

Chemical analysis of the feed and faeces were performed in the lab. Dry matter (DM) and organic matter (OM) were analysed in all samples, while TiO_2 was only analysed in the feedstuff, refusal and faeces. Crude protein (CP), crude fibre (CF), neutral detergent fibre (NDF) and acid detergent fibre (ADF) analysis were taken from concentrates and forage fractions. Table 1 shows the characteristics of all feedstuffs, and also the value obtained when mixing to obtain the experimental diets. As it is obvious, the major changes are seen in the fibre fraction, determined by CF or NDF and ADF fractions. Forage has more than two times NDF and more than three times ADF and CF than the feedstuff. This results in a 35.68 % of NDF and a 19.85% of ADF in the diet with 60% of forage inclusion (D2). This diet is comparable to the barley straw diet in the experiment of Brouns et al.,(1995), which had a 40.48% NDF and 20.64% ADF, but for being pelleted and containing only barley straw, DM content was 87.12%.

Table 1-Chemical analysis of the ingredients and feeds of the preliminary trial

	Feedstuff D1	Feedstuff D2	Forage	D1	D2
Dry matter (DM, %)	87.24	87.79	30.78	64.66	53.58
Organic matter (OM, %DM)	93.83	92.97	86.45	90.88	89.06
Crude protein (CP, %DM)	22.49	27.55	7.12	16.34	15.29
Crude fibre (CF, %DM)	5.32	6.08	20.96	11.58	15.01
Neutral detergent fibre (NDF, %DM)	19.33	21.59	45.08	29.63	35.68
Acid detergent fibre (ADF, %DM)	7.77	9.36	26.84	15.40	19.85

Once all analysis had been performed, titanium dioxide intake was calculated according to the quantity offered in the diet, and the quantity present in the refusal. Subsequently, digestibility of OM was determined for each diet and with it de content of digestible OM (g DOM/kg DM), as it allows calculating the ME value of the diet. The conversion factor used is 4.45 kcal ME/ g DOM.

Table 2 shows how OM digestibility decreases when forage is included, in comparison to control diet. Significant differences are achieved when the inclusions rise from 40% to 60%. Forage OM digestibility was also calculated by difference between experimental diets and control diet. This low digestibility causes at the same time a decrease in the supply of ME energy, which in this experiment was attributed to a low forage digestibility. ME supplied by forage reduced from 2318 kcal/DM kg of forage in D1 to 518 kcal/DM kg of forage in D2.

If we link again with the research done by Brouns et al., (1995), we see that the OM digestibility value for the barley straw diet was higher (61%) in relation to D2 OM digestibility (42,1%). The two diets were fed *ad libitum*, but intake in barley straw diet was 5.6 kg DM/day while in D2 was 2.63 kg DM/day. These differences show that chemical characteristics are not the only factor affecting intake and that many other factors play important roles in intake and digestibility.

Table 2- Digestibility and nutritive value of the rations and the forage, %

DM forage % in the diet	0	40 (D1)	60 (D2)	SE	p-value
Apparent intake (kg FM/y & d)	3	3.92	4.92	-	-
dOM diet (%)	84.3[a]	74.5[a]	42.1[b]	3.29	0.001
dOM forage (%)	-	59.8	14	7.33	0.002
DOM ration (g/kg DM)	774.5[a]	673.1[a]	379.6[b]	29.65	0.001
DOM forage (g/kg DM)	-	520.9	116.3	66.15	0.029
Diet ME (Kcal/kg MS)	3447[a]	2995[a]	1689[b]	131.9	0.001
Forage ME (Kcal/kg MS)	-	2318	518	294.4	0.029

[a,b] Values in the same row with different letter are significantly different ($P<0.05$)

These results achieved suggest that inclusions over 40% represent a huge decrease in digestibility, and make it difficult to supply ME requirements. They also show that when forage inclusion increases, it also increases the variability of OM digestion between individuals. This could be due to an increased flow of the diet through the digestive tract or that the adaptation period for microbial populations with higher fibre rates is longer. Also, it could be due to a greater capacity of some sows to select different ingredients, and to not having the exact ingestion of each sow.

In conclusion, adult sows have the capacity to digest forages, but when they are included in high proportions, this capacity decreases considerably.

Hypothesis and goals

Forage inclusions of 60% DM were observed to be too high for same production purposes because there was an important decrease in dOM, and also the dispersion of digestibility values between animals increased (Aymerich et al., 2015). For this reason, the aim of the present work was to restrict forage inclusion to a maximum of 45%, just a 5% higher than the D1 in the previous trial.

As a consequence of the previous work mentioned in the introduction, the present research was focused on studying how varies the intake and the digestibility of nutrients when forage is included in a proportion from 0% to 45% DM.

Hypothesis: When forage inclusion in a diet for swine increases, then voluntary intake would decrease, reducing the daily metabolizable energy intake.

Objectives:

Therefore the main objectives of the present work are:

- Describe the evolution of voluntary DM intake of sows when forage is included in increasing proportions.
- Determine the digestibility values of the diets, in relation to forage inclusion, to calculate the energy supply for each specific diet.
- Try to find a forage inclusion level which allows that animals (sows or fattening pigs) which somehow have to be restricted could be fed "ad libitum" in practice.

Materials and methods

Animals and housing

Twelve culled sows (Large White x Landrace) selected at the end of the lactation period were used. The animals came from the same farm were the trial was conducted and parities ranged from 3 to 8. Sows were distributed in four groups of three sows each. Each group was randomly assigned to 4 different dietary treatments following a 4 x 4 Latin square design. Sows were allocated in individual crates to control individual feed intake. Experimental diets were fed *ad libitum* for the entire experimental period except for D1 (100% concentrate diet). D1 was not fed *ad libitum* because it would have led to an excessive and unnecessary fattening of the sows.

The experiment lasted 8 weeks, distributed in 4 periods of 2 weeks each. During a period, the 4 dietary treatments were offered, each to a different group of three sows. Treatments were not repeated in the same group (Table 3). The first 10 days of a period were used as an adaptation period, and from 10^{th} to 14^{th} day, 4 complete days, feed intake was completely monitored by controlling the diet offered and feed refusals at the end of each day. Two samples of faeces were collected per sow, one the 10^{th} day and the other the 14^{th} day, around the same time.

Table 3- Experimental design

	Period 1	**Period 2**	**Period 3**	**Period 4**
Group 1	D1	D2	D3	D4
Group 2	D2	D3	D4	D1
Group 3	D3	D4	D1	D2
Group 4	D4	D1	D2	D3

Diets and feeding

Four dietary treatments were used, one was a control (D1), and the remaining three were experimental. The control diet was a concentrated feed, while the three experimental diets included increasing proportions of forage fraction mixed with the same concentrated feed. The proportions of "forage to concentrated" ranged from 0:100 (D1; control), 15:85 (D2), 30:70 (D3) to 45:65 (D4) in DM basis.

Concentrated feed was based on maize, soybean meal 47% CP, barley and rapeseed meal (Table 4). A 0.5% of titanium dioxide (TiO_2) was included in the concentrated feed as indigestible marker. Table 5 includes the calculated composition of the concentrate feed.

Table 4- Concentrate feed composition (g/kg)

INGREDIENTS (g/kg)	
Maize	549.8
Soybean meal 47% CP	264.5
Barley	110.0
Rapeseed meal 00	60.0
Vitamin-Mineral Premix[1]	8.0
Titanium Dioxide (TiO2)	5.0
L-Threonine	1.0
DL-Methionine	0.9
L-Lysine HCL	0.8

[1] Supplied the following per kg of concentrate feed: 200,000 IU of vitamin A (acetate); 30,000 IU of vitamin D3 (cholecalciferol); 2,000 IU of vitamin D (25-hydroxicholecalciferol); 1,200 IU of vitamin E; 70 mg of vitamin K3; 30 mg of vitamin B1; 100 mg of vitamin B2; 50 mg of vitamin B6; 0.5 mg of vitamin B12; 340 mg of D-pantothenic acid; 527.8 mg of niacin; 4 mg of biotin; 44 mg of folacin; 4000 mg of choline; 7860 mg of betaine; 1600 mg of Fe (ferrous sulphate); 240 mg of Cu (sulphate); 20 mg of Cu (dicopper trihydroxychloride); 1900 mg of Zn (oxide); 50 mg Zn (chelate of glycine); 900 mg of Mn (oxide); 50 of Mn (chelate of glycine); 250 mg of I; 0.3 of Se (organic); 6 mg of Se (sodium selenite); 5,000 OUT Phytase; 0.16 % calcium carbonate

Table 5- Calculated nutrient content of the concentrate feed (g/kg DM)

Calculated nutrient content (g/kg DM)	
Dry Matter	873.0
Organic matter	959.1
Crude protein	199.0
Ether extract	27.5
Crude fibre	37.2
NDF	105.9
Digestible energy (kcal/kg DM)	3807
Metabolizable energy (kcal/kg DM)	3679
Net energy (kcal/kg DM)	2764
Digestible Lysine	9.9
Digestible Metionine	3.8

The forage fraction consisted of maize silage (55.4%), chopped straw (33.3%) and wet brewer's grains (11.2%) in DM basis. Table 6 shows the different content of forage and concentrated feed inclusion for each dietary treatment.

Table 6- Calculated composition of the experimental diets (% of DM)

Ingredients (% DM)	D1	D2	D3	D4
Concentrated feed	100.0	85.0	70.0	55.0
Chopped straw	0.0	5.0	10.0	15.0
Brewer grain	0.0	1.7	3.4	5.1
Maize silage	0.0	8.3	16.6	25.0
% forage fraction (DM)	0	15	30	45

Mixed diets were offered as a total mixed ration (TMR), similar to the "unifeed" fed to dairy cows, and several times a day to make sure "ad libitum" conditions.

Measurements

Sows were weighed at the beginning and at the end of each period. Prior to the start of the trial, sows were fed a restricted concentrate diet. In the first period were weighed on the 8th day to estimate the overweight associated to the gastrointestinal tract filling. Faeces were collected on days 10th and 14th of each period, weighed and subsequently keep frozen (-20ºC) until analysis. At the end of each period, faeces were dried in the lab oven at 65°C until constant weigh was achieved and then were removed. The amount of diet offered to each sow was also weighed three times a week. Refusals collected every day from the 10th to the 14th day were also weighed and the same procedure as with the faeces was conducted.

After drying, all samples were ground to less than 1mm of diameter. Faeces and refusal were analysed for DM and ashes according to AOAC and Horwitz, (1990), and TiO_2 concentration (Short et al., 1996). Forage ingredients, TMR of each diet and concentrated feed were also analysed for DM, ashes, CP (AOAC and Horwitz, 1990), NDF and ADF (Van Soest et al., 1991) to have a complete nutritional value.

Calculations and statistical analysis

The individual daily DM intake was obtained as the DM offered minus the refusal collected each day (DM). Digestibility coefficients were calculated according to Schneider and Flatt, (1975). The concentration of TiO_2 (DM basis) in the whole intake was calculated (Equation 3), Equations 4 and 5 were used to calculate the DM and OM digestibility (%).

Equation 3 – Titanium dioxide concentration in the intake

$$[Ti]_{Intake} = \frac{\left(DM_{offered} * [Ti]_{ration} - DM_{refused} * [Ti]_{refusal}\right)}{\left(DM_{offered} - DM_{refused}\right)}$$

$[Ti]$, titanium dioxide concentration (%) and DM, dry matter (kg)

Equation 4- Dry Matter digestibility

$$\mathrm{d}DM = \left(1 - \frac{[Ti]_{intake}}{[Ti]_{faeces}}\right) * 100$$

dDM, dry matter digestibility (%) and $[Ti]$, titanium dioxide concentration (%).

Equation 5-Organic matter digestibility

$$\mathrm{d}OM = \left(1 - \frac{[Ti]_{intake} * [OM]_{faeces}}{[Ti]_{faeces} * [OM]_{intake}}\right) * 100$$

dOM, organic matter digestibility (%); $[Ti]$, titanium dioxide concentration (%);$[OM]$, organic matter concentration (%).

Equation 6 was used to obtain the content of digestible organic matter (DOM) of each diet (g/kg DM) and the diet ME content (kcal/kg DM) was worked out by multiplying DOM (g/kgDM) for a constant value (4.45 kcalEM/gDOM).

Equation 6- Calculation of the digestible organic matter

$$\mathrm{DOM} = \frac{[OM] * dOM}{10}$$

DOM, digestible organic matter (g/kg diet DM); OM, organic matter (%) and dOM, organic matter digestibility (%)

Intake of DM (kg/day), DOM (g/sow and day), EM (kcal/day) were calculated in relation to the live weight (LW) of each sow using the metabolic live weight ($LWm=LW^{0.75}$).

Data was analysed with GLM procedure of the statistical package SAS, taking into account experimental treatment and period as main factors. The alpha level of significance was 0.05.

Results

Diet chemical composition

The analysed nutrient content of feed ingredients is presented in Table 7. The DM content is as high as expected for the concentrated feed (C), and the chopped straw (CS), whereas the ingredients that supplied water to the mixture rations were maize silage (MS) and brewer's grains (BG). All the ingredients supply a similar amount of OM, what makes that the difference between D2 and D4 is almost negligible. The ingredient that has a higher % of CP is the BG. Therefore, CP will be basically supplied by the concentrate feed. The chopped straw has the highest NDF content, followed by brewer's grains, maize silage and finally the concentrated feed. The same order for ADF, but with lower differences between BG and MS was observed. Meanwhile in MS and CS ADF/NDF rate is 0.529 and 0.592, in BG is only 0.374. D3 and D4 have more than two times ADF than the control diet (D1).

Table 7- Chemical analysis of the diets and the ingredients

Ingredient/Diet	C/D1	*MS*	*BG*	*CS*	D2	D3	D4
Dry Matter (DM, %)	87.4	*28.3*	*23.9*	*90.7*	72.6	61.4	53.1
Organic Matter (OM, %)	95.6	*94.4*	*95.7*	*91.4*	95.3	95.2	95.0
Crude Protein (CP, % DM)	19.7	*8.2*	*29.8*	*5.9*	18.2	16.9	14.7
Neutral Detergent Fibre (NDF, % DM)	12.3	*31.9*	*51.5*	*73.9*	16.5	23.5	27.6
Acid Detergent Fibre (ADF, % DM)	5.4	*16.9*	*19.2*	*43.7*	7.9	11.4	13.1

C, concentrate feed, MS, maize silage, BG, brewer's grains and CS, chopped straw.

Voluntary DM intake

Results (Table 8) clearly show that when forage increases, voluntary DM intake decreases. When comparing the two diets with higher forage inclusion with D2 (5.88 DM kg/day), that is the diet with a higher voluntary intake, it was observed a reduction of 27.7% and 44.6% for D3 and D4, respectively. Higher feed intake was observed for D2 than for D3 and D4 (5.88 vs. 4.25 and 3.26 kg DM/day and sow; $P<0.05$). When DM intake is presented on LW_m basis, similar results are achieved. In this case, D2 has a daily intake of 91.52 g/kg LW_m while D3 and D4 have drops of

30.1% and 46.8%, respectively. This values, which include LW_m can be considered more reliable, because clear differences among sows.

Table 8- Voluntary feed intake of the diets fed *ad libitum*

% forage inclusion (DM)	15(D2)	30(D3)	45(D4)	SEM	p-value		
% forage inclusion (DM)					Treat (t)	Period (p)	t x p
Intake (DM kg /sow and day)	5.88[a]	4.25[b]	3.26[b]	0.35	<0.001	0.743	0.491
Intake (DM g /kg LWm sow and day)	91.52[a]	63.97[b]	48.68[b]	5.43	<0.001	0.732	0.483

[a,b] Values in the same row with different letter are significantly different (P<0.05)

Faecal DM content

The percentage of DM in faeces was calculated to determine the effect of forage inclusion in sow diet (table 9). Higher DM content was observed for D1 (31.59%), which consisted only of a concentrated feed, than for D2, D3 and D4, respectively which had an approximate DM of 20%. This means that the weight of excreted faeces for the same DM intake would be higher in diets with forage inclusion than in the control diet, suggesting a higher gut fill. No differences were observed between collecting dates.

Table 9- Dry matter of the faeces in the different treatments (%)

	D1	D2	D3	D4	SEM	p-value		
						Treat (t)	Period (p)	t x p
DM faeces 10^{th} day (%)	31.59[a]	20.48[b]	19.61[b]	19.55[b]	1.27	<0.001	0.267	0.781
DM faeces 14^{th} day (%)	32.16[a]	21.03[b]	19.22[b]	18.61[b]	1.20	<0.001	0.249	0.595

DM, dry matter.

[a,b] Values in the same row with different letter are significantly different (P<0.05)

Digestibility coefficients, energy content and intake

As expected, the DM digestibility (dDM) of the diet was reduced when forage proportion was increased in the diet (Table 10). The fall of dDM was from 85.0% in the control diet to a 78.9% in the D2, the one with less forage (15% DM). However, this fall was not completely linear, because when another 15% more forage is included (D3) the fall is only of 1.7%. Finally, although D4 had a

15% more forage than D3, there was a decrease of 5.8%. Therefore, forage inclusion has a great impact on dDM, but a completely linear response, as could be expected due to a linear increase of forage, was not shown. The OM digestibility (dOM) of the diet showed a similar performance to dDM, but higher values were observed in dOM, usually within a range of 2-3%.

If we have a look to the digestibility of the forage obtained “by difference”, it has a different performance than the TMR digestibility. Forage digestibility was higher when was included at 30% (58.8% dDM / 60.8% dOM) while with less or more forage dDM was reduced. However, only D2 digestibility of forage is significantly lower for both DM and OM (44.1% and 48.2% respectively). In addition, it was observed that the digestibility of the forage fraction was significantly different between some periods when was calculated for OM. Regarding dDM there was only found a tendency to be differences between periods.

Table 10- Dry matter and organic matter digestibility’s of the rations and of the forage (%)

	D1	D2	D3	D4	SEM	p-value		
						Treat (t)	Period (p)	t x p
dDM ration (%)	85.0[a]	78.9[b]	77.2[b]	71.4[c]	0.66	<0.001	0.353	0.189
dDM forage (%)	-	44.1[b]	58.8[a]	54.7[a]	2.00	<0.001	0.061	0.092
dOM ration (%)	87.8[a]	81.9[b]	79.7[b]	74.1[c]	0.66	<0.001	0.159	0.243
dOM forage (%)	-	48.2[b]	60.8[a]	57.3[a]	2.10	<0.001	0.022	0.076

dDM, digestibility of the dry matter, dOM, digestibility of the organic matter.

[a,b,c] Values in the same row with different letter are significantly different (P<0.05)

Table 11 shows the energy of the concentrate feed and of the three experimental diets when calculating its digestible organic matter (DOM) content. Again, DOM was analysed for the TMR’s and the forage. The DOM (g/kg DM) was reduced when forage increased, mainly because dOM also decreased, because OM content of the diets was almost similar. Forage DOM showed also the same performance than forage dOM, with higher value for D3, although not significantly different than D4. Once applied the proportion of ME supply for each gram of DOM (1 g DOM =4.45 kcal ME), the ME of the diets and of the forage were obtained. As expected, the higher energy value was the concentrate feed with 3736 kcal/kg DM, not so far from the theoretical 3679 kcal/kg DM for what this diet was formulated. ME decreased with every increase of forage, but no significant differences were observed between D2 and D3 (3474 and 3375 kcal/ kg DM). The diet with higher fibre inclusion (D4) supplied 3130 kcal/kg DM. Again, as with digestibility values, when forage was considered, ME concentration of the forage was higher in D3 and D4 than in D2 (2534 and 2390 vs. 1985 kcal ME/kg foraged; P<0.05). The lower ME supply was observed for forage in the diet with lower inclusion, showing a EM value of 1985 kcal/kg DM of forage.

Table 11- Nutritive and energetic value of the rations and of the forage

% forage inclusion (DM)	0 (D1)	15 (D2)	30 (D3)	45 (D4)	SEM	p-value		
						Treat (t)	Period (p)	t x p
DOM ration (g/kg DM)	840[a]	781[b]	759[b]	703[c]	6.25	<0.001	0.153	0.247
DOM Forage (g/kg DM)	-	446[b]	569[a]	537[a]	19.94	<0.001	0.022	0.077
ME ration (kcal/kg DM)	3736[a]	3474[b]	3375[b]	3130[c]	27.80	<0.001	0.154	0.247
ME forage (kcal/kg DM)	-	1985[b]	2534[a]	2390[a]	88.73	<0.001	0.022	0.077

DOM, digestible organic matter; ME, metabolizable energy.

[a,b,c] Values in the same row with different letter are significantly different (P<0.05)

Once the DOM and ME of the rations and forage was obtained, voluntary feed intake was used to know the total amount of energy consumed by each sow and treatments (only for those which were fed *ad libitum*). Table 12 shows the calculations for both DOM and ME intake per day and per kg LWm for the TMR. The ME intake was decreased for every higher level of fibre inclusion; the higher intake was in D2, 20.38 Mcal/day, and the lower in D4, 10.16 Mcal/day. If we calculate forage ME intake as a proportion of the total ME intake, it would be 8.4% for D2, 22.2% for D3 and 34.1% for D4. This suggests that low forages rates supply low energy, whereas when forage is increased its usefulness as a source of energy is really considerable.

Finally, ME intake in LWm bases, shows again a decrease in the intake, the highest in D2 (313.5 kcal/kg LWm), but in this case there are not significant differences between D3 and D4 (215.8 and 153.7 kcal/kg LWm, respectively).

Table 12-Nutritive and energy intake of the diets (%)

% forage inclusion (DM)	15 (D2)	30 (D3)	45 (D4)	SEM	p-value		
					Treat (t)	Period (p)	t x p
DOM intake (g/sow and day)	4580[a]	3210[b]	2283[c]	256.33	<0.001	0.841	0.521
DOM (g/kg LWm and day)	70.43[a]	48.52[b]	34.53[b]	4.02	<0.001	0.927	0.636
ME intake(Mcal/sow and day)	20.38[a]	14.28[b]	10.16[c]	1140.66	<0.001	0.841	0.521
ME (kcal/kg LWm and day)	313.5[a]	215.8[b]	153.7[b]	17.86	<0.001	0.928	0.634

DOM, digestible organic matter, ME, metabolizable energy.

[a,b,c] Values in the same row with different letter are significantly different (P<0.05).

Discussion

The use of high fibre diets to reach physical satiety in swine and reduce voluntary feed intake, is an idea quite extended. However no consensus has been achieved in relation to which level and type of fibre source has to be used (Ru and Bao, 2004). While sugar beet pulp has been shown as the most suitable ingredient to promote satiety and reduce voluntary intake, the fibre fraction shouldn't be composed of only one ingredient, and consequently be completely dependent on it. It should have specific features which can be reached using different fibre sources. Perhaps, it would be important to define those ingredients more than by the chemical features, by their physical properties. Considering traditional fibre determinations exposed in the introduction, the diets used in the present experiment had similar features than those used in other experiments. However, in most of these experiments emptiness was not reached in such an important way. This suggests that perhaps not only the chemical characteristics of fibre influence voluntary intake. Therefore, other properties as particle size could have a higher impact.

Definitely, the reduction of voluntary intake might not be dependent on a specific ingredient; it should be achieved in any part of the world with the area specific resources. In this way, deciding to use forage as a fibre source resides in this idea of using ingredients available in different part of the world, non-specifically expensive. Nevertheless, there is no doubt that the ideal fibre source would be one which doesn't compete with other animals for its use.

Effect of forage inclusion on voluntary DM intake

In the present experiment voluntary intake was reduced with forage inclusion in the diet, as it was expected. Although many authors have described the capacity of high fibre diets to reduce intake, research about diets with forage inclusion for swine has not been found. Similarities could be seen with Zoiopoulos et al.,(1982) that reported the effect of including 30% of ground straw to the control diet. DM intake was of 5.80 kg/day while in D3 of the present trial (30% forage inclusion, DM) was 4.25 kg/day. These differences can be related to the physical treatments of straw. While with the highest intakes it was grounded, in D3 was chopped. The effect of particle size could be attributed, although further research should be done.

This reduction of the voluntary intake is considerable and can be therefore useful to achieve the goal of giving a diet with a forage inclusion that enables an *ad libitum* intake while supplies the energy requirements. Figure 2 shows how feed intake decreases with the increase of forage proportion in the diet. To have a better knowledge of the response of voluntary intake to forage inclusion, data from the preliminary work was included. Only the intake of the second diet was used (60% forage inclusion). Meanwhile intake in D2 (15% forage) is between 5-8 kg DM/day, in D4 is between 2-4 kg DM/day. These huge differences between individuals in intake could suppose more heterogeneity within a group of the same characteristics.

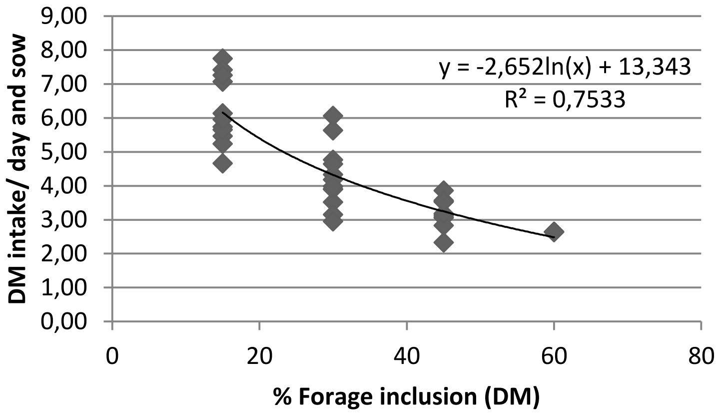

Figure 2- Effect of forage increase on voluntary intake of culled sows

Digestibility

Results of digestibility, both for DM and OM, link with Noblet and Le Goff,(2001) proposal that digestibility was reduced for any nutrient when fibre concentration in the diet is increased. Brouns et al., (1995) used experimental diets containing different fibrous ingredients, as barley straw, sugar beet pulp, oat husks or malt culms, which had a lower ADF/NDF than the ratios used in the present diets. The diets containing oats husk (36.9 % DM) showed almost 2 more percentage points of ADF than D4 (14.96 vs. 13.08% DM), and dOM of 67%, while in D4 dOM was74%. Meanwhile if we compare it to malt culms diet (45.5%DM), which had a similar amount of NDF to D4 (27.89 vs 27.60% DM), dOM is higher with malt culms (77%) than D4, but the values are closest. However, malt culms had lower ADF content (9.71%). This is explained by the equations proposed by Le Goff and Noblet, (2001), where NDF was considered the main factor in reducing digestibility of energy, together with ashes. Nevertheless, even with similar NDF concentrations, dOM can be different, and probably due to dissimilar ADF concentrations. Therefore, when high fibre diets are used, in addition to NDF, ADF could be introduced in the equations of digestibility.

Chabeauti et al., (1991) analysed digestibility of a diet with wheat straw included at 22.13% DM, and the other basic ingredients were wheat, maize starch and soybean protein. Digestibility of gross energy was 73.6% while the control diet was 92%. However, wheat straw diet only had 18.8% NDF and 10.3% ADF, as DM basis. As a consequence, we can state that digestibility not only depends on NDF and ADF contents, there might also be other factors which influence it. One could be the passage rate through the tract, which is a factor that seems to decrease digestibility when the passage is faster.

One result that may seem surprising is the digestibility of the forage obtained by difference with the digestibility of D1. It would be expected to have a greater digestibility of the forage in D2, which decreased in D3 and D4. However, results show a lower digestibility of the forage fraction in D2 (44.1%) than in the others (58.8 and 54.7 respectively). The reasons that may cause these unexpected differences could be: that the reliability of the digestibility coefficients obtained "by difference" is lower with low levels of forage/fibre inclusion; that D3 and D4 had a longer adaptation period to the forage fibre diets, compared to D2, as the treatments in the Latin square were not randomly assigned and followed always the same pattern; and finally that perhaps a high rate of passage through the digestive tract in D2, related to a higher intake, can have reduced the digestibility of the ration. The last reason is linked with the first, showing that when forage is included in low rates and the diet is fed *ad libitum* it can cause a high drop in digestibility of the forage.

Energy intake affected by forage

The use of the constant 4.45 kcal/g to convert DOM to ME may be used especially for low fat content in the diets, and consequently the energy provided comes mainly from carbohydrates and protein. Both are considered to have similar value of energy, provided that a proportion of protein energy absorbed is excreted in the urine as urea. Since OM is the result of the sum of carbohydrates, protein and fats, it is possible to give and approximate value of energy to each g of DOM (Schneider and Flatt, 1975).

The ME content (kcal/kg) of the experimental diets showed a decrease with forage inclusion in the diet, but high energy content is still associated to these diets. This high energy has to be considered to come in a large extent from the concentrate feed. Control diet offered by Zoiopoulos et al., (1982) had 3444 DE kcal/ kg DM, while the diet with +30% straw had 2491 kcal DE/kg DM. Therefore, in that experiment energy concentration was highly reduced when straw was included. This led to a reduction in daily energy intake from 16.77 to 14.45 Mcal DE/day. Consequently, it was achieved the goal of supplying less energy while achieving emptiness. Comparing it with the present experiment, ME intake was reduced to 10.16 Mcal ME/day in D4. Considering a ME/DE ratio of 0.91 in HFD (Ramonet et al., 2000), DE intake of D4 would be of 11.16 Mcal DE/day. Therefore, a higher voluntary intake reduction and energy supply was achieved in the present trial. By contrast, Brouns et al., (1995) only found both the capacity of regulating voluntary intake and energy supply with sugar beet pulp inclusion, with a voluntary intake of 2kg/day and 5885 kcal DE/day at inclusions of 65% DM. Barley straw in this same experiment was included at 35.7%, but didn’t have a great effect on voluntary intake (5.6 kg DM/day). However, energy supply was 13.63 Mcal DE/day, suggesting that one more time, energy concentration of diets which include straw is considerably reduced.

Results show that increasing the level of forage inclusion promotes a decrease in voluntary intake and also a reduction of the ME content (kcal ME/kg DM) of the different rations. These results can really provide information to formulate diets to find a balance between voluntary intake and energy supply of the diet. By this way, it will be possible to formulate diets which fed *ad libitum* can control energy intake of swine.

Figure 3 show how varies the voluntary intake of ME in relation to LW_m. It includes data of the present experiment and the preliminary experiment to widen the range of forage inclusion. To avoid the deviation caused by the use of concentrate feed with different ME concentrations, Equation 7 was defined. It enables the calculation of ME voluntary intake considering the differences of ME concentration in the feeds. The ME of the concentrate feed (ME_c) was considered 2875 kcal/kg, which is the energy concentration of gestation diets according to Blas et al., (2013). Therefore, this graphic is a representation of the energy intake for each sow and day, when offered a TMR of forage *ad libitum*. It can be useful to predict the forage inclusion to meet ME intake in accordance to the LWm of the swine fed, as long as it has the same ingredients and are mixed in the same proportions.

Equation 7 - Calculation of the ME intake with the same concentrate

$$ME(kcal/LWm) = \frac{(ME_C * \%\,C + ME_F * \%\,F) * Intake}{LWm}$$

ME_c, metabolizable energy of the concentrate feed (kcal/kg DM); % C, proportion of concentrate feed (DM); ME_F, metabolizable energy of the forage (kcal/kg DM) for each forage inclusion; %F, proportion of forage (DM); Intake (kg DM/day) and LWm, Live weight metabolic $=LW^{0.75}$.

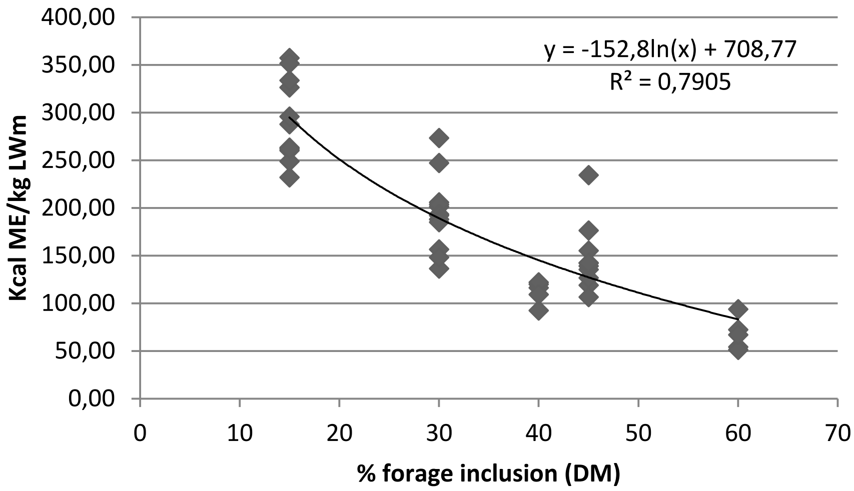

Figure 3- ME intake in relation to forage inclusion in the diet

Forage diets for swine

Figure 3 and its corresponding regression equation have seemed appropriate to try to formulate forage diets for two situations of swine production in which they could be really useful. The first case is gestating sows, which have restricted diets, mainly to avoid difficulties during farrowing. The second is heavy swine (Parma pigs or Iberian pigs) in the finishing period to make cold meat, ham and other products, in which feed intake is restricted to control fat deposition as would happen in an *ad libitum* diet using a commercial feedstuff. However, it would have to be taken into account the genetics used and its capacity to deposit fat rather than lean meat.

GESTATING SOWS

According to de Blas et al., (2013), energy requirements for sows during gestation differ mainly whether being gilts or sows. If we consider LW of a multiparous sow to be 250 kg, the total energy requirement, including maintenance, gestation, and udder, if no energy is expended for thermoregulation, is 7834 kcal ME/sow and day. This equals 124.6 kcal ME/LWm. The procedure proposed consists in using Equation 8 (from regression equation of Figure 3) to calculate the proportion of forage that can be included in the diet, to provide the amount of energy required by a sow. Therefore, the results of forage obtained will be suitable only for diets made with concentrate feed of 2875 kcal ME/kg and the same forage used in the present experiment. Results obtained suggest a forage-concentrate proportion of 45:55 and an average intake expected of 3.25 kg DM/day, corresponding to D4. To increase forage proportion in diets for multiparous sows, energy content of the concentrate feed could be increased, with a consequential voluntary intake reduction, and probably by this way reduce the cost/day and sow would be decreased.

Equation 8 - ME intake per LW_m in relation to forage inclusion in the

$$\%Forage = e^{\left(\frac{ME/LWm - 708{,}8}{-152.8}\right)}$$

ME/LW_m (kcal ME/ $kg^{0.75}$)

HEAVY SWINE IN THE FINISHING PERIOD

The potential use of forage diets for heavy pigs is during the last months of fattening, going from 110 to 130 or more kg, when they are slaughtered. As has been commented before, this could be really useful in breeds that have the capacity to deposit huge quantities of fat during this final period. Although it has not been reported exactly which would be the energy requirements of this swine, energy calculation will be done considering a 20% less energy requirements. An example can be done considering energy requirements of barrows with a LW of about 120 kg, which according to Blas et al., (2013) have 4163 kcal ME/day requirements including maintenance and growing. If energy requirements are reduced a 20%, energy intake of a day should be 3330 kcal ME/day. Therefore, considering the average weight of 120 kg, 91.9 kcal ME/kg LW_m. Using again Equation 8, which considers the use of a 2875 kcal ME/kg concentrate feed, an inclusion of forage of 56.7% is obtained. However, further research should be done to know also how voluntary intake changes considering the LW of the animals. This would be suitable for both heavy swine and gestating gilts.

Conclusions

It is concluded that:

1- Neither gestating nor lactating culled sows do eat forage concentrate mixed diets offered as TMR. The DM intake varies among 91.5 and 48.7 g/kg LW_m depending on the proportion of forage in the diet.
2- DM and OM digestibility of the diet was consistently reduced with the increase of the forage proportion in the diet. This reduction was not linear; the diet OM digestibility drops from 81.9 to 74.1% when the DM proportion of forage in the diet increases from 15 to 45%.
3- Including forage in the sow's diet increases the amount of excreted faeces, not only because the DM digestibility decreases, but also due to the higher moisture content of the mixed diets faeces compared to the control concentrate diet (67.8 vs 80.0% of water for control and 30% forage diets, respectively).
4- Daily ME intake was also reduced as the proportion of forage in the diet increased. Daily intake was reduced from 313.5 to 153.7 Kcal EM/LWm when the proportion of forage increases from 15 to 45% in DM bases.

Implications

The present study provides a formula (Equation 8) to calculate the forage inclusion proportion, as a percentage of dry matter, which should be suitable for feeding multiparous gestating sows "ad libitum". The equation shows that, using a concentrate feed of 2875 kcal ME/kg and the same forage as in the present experiment, gestating multiparous sows should be fed with 45% of forage, in DM basis. It is necessary to take into consideration that this level of inclusion in only suitable with the specific forage mix used in this trial.

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