Feeding Dry Sows *Ad libitum* with High Fibre Diets

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ABSTRACT : Currently commercial dry sows are housed in individual stalls and subject to restricted feeding. These sows often show stereotypic behaviours which increase their maintenance energy requirement. Group housing is desirable to improve animal welfare and public perception. However, under restricted feeding systems, group-housed dry sows are also aggressive. The feed intake of these sows is variable, depending on their social rank, which results in different milk production and variable piglet performance. These problems can be solved by *ad libitum* feeding systems, but the large capacity of intake by dry sows will not allow this feeding system to be practical as high feeding level during pregnancy can reduce reproduction performance of sows. Current research indicates that feeding high fibre diets to dry sows enables sows to be fed *ad libitum*, but the effect of dietary fibre on feed intake and nutrient utilisation is dependent on the quality of fibre sources. Most research has focused on sugar beet pulp, straw, lucerne meal and by-products, but there is a need to identify and evaluate some widely available and cheap fibre materials and feed grains for developing the best strategy to control nutrient intake of dry sows while feeding *ad libitum*. ***(Asian-Aust. J. Anim. Sci. 2004. Vol 17, No. 2 : 283-300)***

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INTRODUCTION

In conventional pig production systems, dry sows are housed either in stalls or group pens. The body weight of these animals changes with their reproductive cycles with an increase in body weight during gestation and a significant mobilisation of body reserves during lactation. The minimum requirements for feeding sows during gestation are to; 1) meet nutrient requirements by the foetus which develops rapidly during the latter stage of gestation; 2) rebuild body reserves and maximise feed intake for maximum milk production during lactation; 3) minimise the culling rate of sows due to poor reproductive performance and leg problems and 4) ensure high performance of the piglets. In sows, it has been well documented that the effect of energy and protein supply on reproductive performance and longevity is associated with variation in body weight or fat reserves (Dourmad et al., 1994) which can be built only during gestation. However, in high-producing modern multiparous sows, energy supply during gestation is a limiting factor for nitrogen retention and muscle weight gain (Dourmad et al., 1996) and poor nutrition in late pregnancy is the most common cause of low birth weights of the pigs. On the other hand, overfeeding in late pregnancy can cause significant reproductive losses (Williams, 1992), including higher stillbirths, leg problems, reduced feed intake during lactation and potential poor performance of piglets.

To achieve the optimal development of foetuses, growth of the sow to mature size and storage of body reserves for mobilisation during subsequent lactation and the constant maintenance requirements of dry sows, the current feeding recommendations for sows are calculated to allow moderate increases in both liveweight and back fat during gestation and to minimise losses during lactation. The Agricultural Research Council (ARC, 1981) recommended that food levels for pregnant sows are about 1.3 times maintenance. Currently the daily energy intake of dry sows is between 20 and 30 MJ digestible energy (DE) (King, 1990) and can be up to 35.5 MJ DE/day (Dourmad et al., 1996), depending on the liveweight at mating and the net weight gain desired during pregnancy. Based on these recommendations and the use of concentrated diets based on cereals and protein supplements for gestating sows, the feed allowances vary between 2 and 2.5 kg/day, which is approximately 50-60% of *ad libitum* intake (Lawrence et al., 1988a; Mroz and Tarkowski, 1991). This feed restriction is necessary to prevent excess body weight gain and fat deposition during gestation, and the amount of feed offered in gestation is sufficient for good health and performance, but restricted feeding might not fulfil other needs of the sow and result in impaired welfare (Brouns et al., 1995). This review will discuss the problems associated with current restricted feeding practices under different housing systems, and the effect of *ad libitum* feeding of dry sows with high fibre diets on performance and welfare.

WELFARE ISSUES IN STALL-HOUSED OR TETHERED SOWS

Currently commercial dry sows are housed individually in a space of 2 m by 0.6 m. They are either enclosed in this space by a metal cage (stall) or they are restrained by a tether chaining attached to a collar around their neck or girth (tether stall). These pigs cannot turn around and

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Table 1. The incidence of stereotypies shown by tethered sows during pregnancy (Data from Cronin and Wiepkema, 1984)

	Period of pregnancy (days)				
	1-20	31-50	51-70	71-80	81-100
Mean proportion of observation time showing stereotypies	7	41	57	57	42
Number of different stereotypies per sow	1.4	2.3	2.7	3.2	3.6

cannot perform many of the behaviour patterns that pigs perform in less restricted conditions (Broom et al., 1995). Tether stalls are common in Europe, but not used in Australia. For example, in the Netherlands about 20% of pregnant pigs are restricted by tethers, although tethers will be banned by 2005 (Anon, 1999). A common housing system for dry sows in Australia is stalls. About 26% of sows are housed in this system in Australia for most of their reproductive cycles and up to 62% may be in stalls for part of their pregnancy. This system is widely used to control feed intake and reduce aggression (Barnett and Glatz, 2001).

Dry sows in stalls show more stereotyped behaviours which are repetitive actions fixed in form and orientation and serve no obvious purpose, such as bar-biting, drinker-pressing, head-waving, nosing, chain-playing, sham-chewing, and vacuum-chewing (Falk, 1971; Broom and Potter, 1984; Cronin and Wiepkema, 1984; Rushen, 1984a; Vestergaard and Hansen, 1984; Terlouw et al., 1991a). The occurrence of stereotypies in pregnant sows indicates inadequate environmental design or welfare, where animals are under stress (Appleby and Lawrence, 1987). These activities tend to increase in frequency with the time that the animal is confined, and individual sows may change from one stereotypy to another during their period of confinement (Cronin and Wiepkema, 1984; Table 1).

Apart from the confined environment for stall-housed or tethered dry sows, feed restriction is another key factor inducing stereotypic behaviour (Terlouw et al., 1991ab). It is suggested that the low feeding level under current practices does not keep animals satiated for more than 1-2 hours after the meal, leaving the pigs hungry for most of the time (Lawrence et al., 1988ab). The frequency of these stereotypies is related to the level of hunger of the sow (Lawrence and Terlouw, 1993). Falk (1971) reported that intermittent distribution of food to hungry animals may result in the development of various activities such as excessive drinking, air-licking, wood-gnawing, wheel-running or aggressive behaviour. Sows under the restricted feeding system consume their food rapidly and spend more time in a standing position with a greater proportion of their standing time in repetitive behaviour. These sows often drink more water probably because the food lacks bulk and does not provide sufficient stomach distension (Rushen, 1984b; Terlouw and Lawrence, 1993; Brouns and Edwards, 1994). Appleby and Lawrence (1987) also reported a negative correlation between stereotypic behaviour and food allowance, with more activity and repetitive behaviour occurring on food levels below about 2 kg.

The basis for stereotypies under low feeding levels is that the restricted feeding regime elevates the internal hunger state in the long term, reflecting the cumulative difference between animal's perception of its nutritional requirements and its actual intake (Lawrence et al., 1993 cited by Lawrence and Terlouw, 1993). The presentation of feed related cues and the ingestion of feed have positive feedback effects that result in an enhanced tendency to perform feeding responses in the postprandial period. The lack of negative feedback from the meal contributes to the persistence of the positive feedback effects (Hughes and Duncan, 1988). Terlouw and Lawrence (1993) suggested that chewing and rooting of the chain, and drinking, involving swallowing and filling of the stomach with water, could provide relatively appropriate sensory feedback for sows' state of feeding motivation. The trough probably initially had sufficient incentive value because of the smell or the presence of small particles of food, to sustain feeding related behaviour for a short amount of time.

The stereotypies of restrictively fed sows are often associated with the time of feeding and parity. The stereotypies are less frequent in gilts and increase in frequency with parity. Animals show more activities before feeding delivery or after feeding. Hungry animals often show increased activity before a regular feeding time than those fed *ad libitum* (Appleby and Lawrence, 1987). While stereotypic behaviours are not associated with any adverse effect on reproductive performance, they exert a cost in poorer efficiency of feed utilisation and a reduced performance due to the increase in energy requirement for maintenance (Schrama et al., 1996). Apart from the low feeding level, social isolation of pigs housed in individual stalls can lead to behavioural and pathological changes, resulting in reproductive inefficiency (Fraser, 1983; Lawrence et al., 1988b; Hutson, 1991; Edwards, 1998). Tsuma et al. (1996) reported that feed deprivation could elevate maternal plasma cortisol, progesterone and prostaglandin. This can affect embryonic survival because cortisol, when elevated, can be transported into the uterine lumen and influence the uterine environment and alter functions related to embryonic development and attachment.

Due to perceptions of compromised welfare of pigs kept in confined conditions, there has been public concern about the systems for many years. A number of countries (e.g. Sweden, Norway, UK and Switzerland) have banned or intend to ban the use of these housing systems (Edwards, 1998). As a result, group-housing system for pregnant pigs will have to replace stalls and tethers (Broom et al., 1995)

Table 2. Comparison of stall-housed vs group-housed sows in the occurrence of stereotypies

Item	Total frequency
Stall housed (n=81)	
Tongue rolling	22
Bar biting	28
Trough biting	28
Bar licking	14
Vacuum chewing	38
Group-housed (n=71)	
No stereotypy	30
Wall licking	7
Vacuum chewing	7

Source: Derived from Vieuille-Thomas et al. (1995).

even though turn-around stalls may be a satisfactory option for the welfare of sows (Barnett and Taylor, 1995).

GROUP-HOUSING IS DESIRABLE, BUT HAS POTENTIAL PROBLEMS

Indoor group-housing is a common housing system for dry sows. Within this system, pigs are able to turn around and interact socially. Many studies have proven that group-housed sows have less welfare problems than stall-housed sows (Broom et al., 1995; Mason, 1991; Vieuille-Thomas et al., 1995). Sows in a group spend less time on stereotypies such as drinking, rooting or chewing at pen fittings and fewer sows display stereotypic behaviour (Table 2). Differences in animal behaviour and welfare between group and stall housing are more significant for high parity sows (Broom et al., 1995). For example, group-housed dry sows tend to have a decreased morbidity and farrowing time (Vestergaard and Hansen, 1984), spend more time in active behaviours, and have a lower free corticosteriod levels than those in stalls (Barnett et al., 1985).

While group-housing overcomes some of the welfare problems occurring in the stall housed pigs, restricted feeding under this housing system creates a number of concerns. Aggression by pigs occurs during feeding (Ewbank and Meese, 1971) and is strongly related to feeding spaces. Baxter (1986) found that during feeding, 65% of all aggression was initiated by pigs at a trough against an approaching pig, while much of the remainder was between pigs feeding simultaneously. This is not surprising because pigs living in a group generally establish a dominance hierarchy which is maintained by subtle signals and gives high-ranking animals priority of access to resources limited in availability. A dominant animal may chase a subordinate pig away from the feeder (Brouns and Edwards, 1994). Hunter et al. (1988) reported that social hierarchy was positively correlated with feeding order overall, but this was not the case for the latter half of the feeding order, partially due to the disruption of feeder use by non-feeding visits made by early-feeding dominant sows. Older sows have a higher feeding order and social hierarchy than younger sows, and may exclude young sows from the feeder by repeated non-feeding visits. Under commercial situations, competition over access to food is heightened by food restriction, resulting in a variable feed intake among individual pigs (Love et al., 1999). This may contribute to variation in the performance of sows, and the subsequent growth rate of piglets, resulting in significant loss to the pig industry.

The large variation in fitness traits such as growth, survival and reproduction is also associated with increase in competition for food. Brouns and Edwards (1994) reported that sows preferred to feed singly and low-ranking sows had to feed more often at less preferred times together with other sows. Low-ranking sows gained less weight and back fat than high-ranking sows in a restricted feeding regime (Barnett et al., 1999). Sometimes injuries also occur due to aggressive physical interaction between animals although these injuries can be reduced by modifying pen size and design (Barnett and Glatz, 2001) and modifying animals' behaviour (Gonyou, 1986).

Improving welfare and behaviour using straw bedding

Giving pigs access to straw in group-housing has been shown to significantly reduce aggression of sows. The pigs spend more time playing with and eating straw, make fewer visits to the drinkers or feeders. This consequently prevents chain and bar manipulation because straw apparently acts as a foraging substrate (Spoolder et al., 1995), and the dilution of the diet by straw will enhance the gastro-intestinal distension and increase the level of gut fill (Lawrence et al., 1989). However, Lightfoot (1985) found that pigs with access to straw bedding might reduce their water intake and urine production, which might be beneficial for manure handling.

While the behavioural effects of food restriction may be mitigated by satisfying feeding motivation more effectively or by providing sows with a substrate to express their foraging behaviour, Whittaker et al. (1999) reported that pregnant sows in strawed pens received more aggressive interactions and were displaced from the feeding area more frequently than sows in the pens without straw. Sows in straw pens also spent more time standing during the feeding period in comparison with those in no straw pens. The only improvement with the presence of straw in the pen was the reduction in the level of pen component manipulation and non-manipulative oral behaviours. Thus it is clear that neither expensive housing designs which provide sufficient space for pigs plus an allocation for social space nor provision of straw bedding can change the underlying cause of the problem in group-housing systems.

Electronic sow feeder (ESF)

To reduce competition between pigs for feed, computerised feeders are used to provide individual rations for group-housed sows. Most computerised feeders are single-spaced, allowing only one animal to eat at any one time. The design of these feeders differs in the levels of protection offered to the feeding pig. Nielsen et al. (1995) compared three levels of protection (head-guard, full length standard race, enclosed pneumatic race) on the performance and feeding behaviour of pigs. He found that the number of visits to the feeder and rate of food intake were higher and meal size was smaller with feeders equipped with a head-guard than feeders offering full protection. This indicated that pigs using a feeder with low protection might be more disturbed by other pigs during feeding, resulting in a greater forced feeding pattern with smaller meals eaten more rapidly, especially when group size reached 20 (Nielsen and Lawrence, 1993).

Animal behaviour, especially stereotypies under computerised feeding systems, has been studied in comparison with traditional feeding systems. Sows in electronic sow feeding systems are less aggressive and spend less time rooting or chewing at straw or pen fittings than the sows in stalls or small groups, with significant variation between individuals. Sows in electronic sow feeding systems had higher counts of lymphocytes, neutrophils and total white blood cells than those in other housing systems. While there were no differences in reproductive parameters between these housing systems (stall, group and ESF) in the first pregnancy, sows in ESF system gave birth to less live-born piglets than sows in stalls by the end of the second pregnancy (Broom et al., 1995). Sows in electronic feeder systems under restricted feeding had more fights when feeding (Broom et al., 1995).

The effects of group size and feeding frequency have been investigated in computerised systems, but the electronic sow feeding system is not solving the welfare problems of the restricted feeding system. There is little information on the relationship between social hierarchy and the use of the feeder (Hunter et al., 1988). It seems clear that the most effective solution to the problems associated with the current sows' management system is an *ad libitum* feeding system under which the low-ranking sows could achieve comparable intake with higher-ranking animals (Brouns and Edwards, 1994). However, the problems associated with *ad libitum* feeding are; 1) the overfeeding of dry sows can depress the reproductive performance of sows; 2) a high feed wastage; and 3) little scientific evidence for developing recommendations on feeding space for pigs fed *ad libitum*.

CONTROLLING FEED INTAKE OF DRY SOWS

Factors influencing feed intake of dry sows can be classified into animal, environmental and dietary factors. Animal factors include genetics, parity and body condition; environmental factors include environmental temperature, air quality, stock density, photoperiod and disease and dietary factors include digestible energy content, protein and energy balance, physical characteristics, feeder design and feeding frequency. Some of these factors interact with each other and regulate feed intake through the same mechanism (Graham and Aman, 1991; Revell and Williams, 1993). The detailed mechanism of the physiological control of feed intake in pigs was reviewed by Revell and Williams (1993). It is evident that dietary quality and gut distension have a significant role in facilitating *ad libitum* feeding of dry sows and controlling total nutrient intake.

Diet quality

Diet quality has a large effect on intake. The rate of digestion determines the gut fill and is dependent on the chemical and physical composition of the feed. Feeds with a low digestibility are broken down slowly with delayed access of enzymes to the feed constituents. Therefore the digestibility is related to the rate of digestion, leading to a relationship between digestibility and feed intake. This relationship may be influenced by the properties of dietary fibre through changes in digesta viscosity. It has been proven that in the upper gastrointestinal tract dietary fibre prolongs gastric emptying time and retards the absorption of nutrients (Eastwood, 1992; Frape and Jones, 1995), but these processes are dependent on the physical forms of the fibre, and particularly on viscosity. Isolated viscous fibres tend to slow the gastric emptying rate of liquids and disruptible solids (Eastwood, 1992). It is clear that feeding non starch polysaccharides (NSP) can cause an increase in digesta viscosity in both pigs and poultry and influence the gastrointestinal flora, but these effects on metabolism of nutrients or their absorption in the digestive tract and feed intake of pigs are not clear.

Dietary energy plays an important role in feed intake control. Pigs offered a low energy diet can compensate rapidly to increase their intake to achieve a constant daily energy intake until a point is reached when physical limitation replaces physiological control (Owen and Ridgman, 1968; Zoiopolous, 1978; Pekas, 1983), suggesting the compensation for dietary quality is incomplete (Cole and Chadd, 1989; Revell and Williams, 1993). However, Henman et al. (1999) found no difference in average daily feed intake across an energy density of 12-15.2 MJ/kg, probably due to the narrow energy range in the testing diets. A similar relationship exists between dietary protein and feed intake (Kyriazakis et al., 1987).

Gut distension

Gastro-intestinal distension influences the onset of satiety and the pre-absorptive control of food intake

(Janowitz and Grossman, 1949). In mammals, distension and tension receptors exist in the oesophagus, stomach, duodenum and small intestine. Distension in these areas of the tract increases the activity in the vagus nerve and in the satiety centre of the hypothalamus (McDonald et al., 1988). Meal termination in pigs and other monogastrics results at least in part from gastro-intestinal distension (Houpt, 1982; Gregory et al., 1987). Gyetvai and Bardos (1999) inserted into a separated Thiry-Vella intestinal loop a balloon with different volumes of water (0.05, 0.09, 0.12 and 0.28 ml, respectively) and found a decreased appetitive response after gut distension. Feed intake of pigs was also reduced by gastric injection of saline, due to the increased duodenal pressure and distension (Houpt et al., 1977; Deutsch et al., 1980). Stretch and tension receptors present in the digestion tract probably function as a limiting factor especially when bulky diets are consumed.

FEEDING GROUP-HOUSED OR INSTALLED HOUSED DRY SOWS WITH FIBROUS DIETS *AD LIBITUM*

Pregnant sows have an increased need for nutrients for foetal development. The current feeding practice is to maximise feed intake during lactation, deposit sufficient lean tissue for the development of the mammary (Revell et al., 1995), and prevent animals from hunger under the restricted feeding system. However, the high intake capacity of dry sows limits any attempts to feed a conventional diet at a higher level without concomitant problems of excessive growth and obesity of the sow. Animal nutritionists are required to provide a diet appropriate to the sows' age, weight, behavioural and physiological needs, and to promote a positive state of health and wellbeing (Edwards, 1998). Many attempts have been made to devise practical systems whereby group housed dry sows could be fed *ad libitum*. An ideal system should induce satiety, remove competition and be operational in cheap and simple housing systems. The modification of dietary composition to formulate a bulky diet may be able to achieve the above objective if the dietary components are cheap and widely available, and have less or no negative impact on other nutrient utilisation efficiency, no anti-nutritional effect, a low palatability, no negative effect on animal production and a high water holding capacity. It has been proven that high fibre feeds can meet these requirements.

Feeding high fibre diet improves animal welfare and behaviour

Feeding pregnant sows with high fibre diets had considerable effect on their behaviour. The use of fibrous, bulky foods promotes a feeling of satiation, especially if they have a high water holding capacity. Behavioural studies show that inclusion of sugar-beet pulp (Brouns et al., 1992), wheat bran and cobs (Roberts et al., 1993), straw (Frazer, 1975) or oat hulls (Broom and Potter, 1984) in sow diets increased feeding time, reduced activity and feeding motivation. Pigs on fibrous diets spent more time lying after the meal.

It was also clear that the frequency of stereotypic activities and their duration around meal time decreased when the sows were fed bulky high fibre diets. For example, the supply of loose straw for pigs to explore and chew reduced the incidence of stereotyped activities, especially of the mouth and snout (Lee and Close, 1987), and feeding extra oat hulls resulted in less activity and less bar biting (Broom and Potter, 1984). This reduction in activity can result in a lower energy expenditure and promote a higher rate of nutrient retention and hence rate of body weight gain, if the rate of passage and the heat increment of the feeding are not increased (Broom et al., 1995). However, the magnitude of the reduction in stereotyped behaviours depends on the age of the sows and the length of period of receiving bulky feed. Not all stereotypic behaviour in individual stall systems can be eliminated by the application of bulky feeds. Some controversial results have been reported. For example, Lawrence et al. (1989) found that feeding motivation of boars on chronic nutrient restriction was not reduced by diluting their meal with straw. This motivation will remain potentially open to frustration especially in housing systems such as tether stalls involving physical restraint. This might suggest that the control of feed intake is dependent on adequate major nutrient intake, and feeding motivation cannot be abolished if the diet does not fulfil the metabolic needs of the animals.

Feeding fibrous diets to control feed intake

Feed intake during pregnancy : In general, sows are reluctant to consume a fibrous diet. When high levels of dietary fibre are presented in dry sow diets, sows tend to increase feed intake in an attempt to maintain digestible energy intake. The ability of the sow to maintain digestible energy intake is related to the period of adaptation to the diet and/or physiological age of the animal. This compensation on intake with increasing fibre content in the diet is only effective when the fibre level is low. With high fibre levels in the diet, feed intake is reduced because 1) the diet is unpalatable due to excessive levels or inhibitory substances in the fibre source, 2) the gut capacity becomes limiting and 3) a possible increase in passage rate is counteracted by an increase in bulk content (van Wieren, 2000). Research conducted by Vestergaard (1997) showed that when sows were fed at a similar net energy level to the commercial standard, the feed intake of dry sows over three reproduction cycles was successfully controlled by including 50% sugar beet pulp in the diet. However, there is

Table 3. Mean voluntary intake (during the last 2 weeks of the experimental period) of the diets by gestating sows; change in liveweight during the first week and gain in liveweight and backfat thickness (P2) over the 3 week period (Brouns et al., 1995)

	Diet						SED
	Sugar-beet pulp	Barley straw	Oat husk	Malt culms	Rice bran	Wheat bran	
Voluntary intake							
Feed (kg/day)	2.3	6.4	7.7	6.8	7.6	7.1	0.65***
Dry matter (kg/day)	2.0	5.6	6.7	5.9	6.7	6.1	0.57***
Digestible energy (MJ/day)	24.6	57.0	79.0	70.1	70.8	72.9	11.39***
Change in weight (kg)							
In the first week	3.2	18.5	17.8	18.6	20.6	21.4	3.5***
Overall	2.2	41.8	47.7	46.7	40.8	39.2	6.3***
Overall changes in backfat (mm)	-3.5	0.5	1.3	1.0	2.7	3.2	1.5**

** p<0.01, *** p<0.001.

significant variation among fibre sources on feed intake of dry sows. Zoiopoulos et al. (1983) found that inclusion of oat husks or straw increased voluntary feed intake of sows during pregnancy, and the increase of dry matter and energy intake was more for oat husks than straw. Brouns et al. (1995) compared six diets with a high inclusion level of either unmollased sugar-beet pulp, barley straw, oat husks, malt culms, rice bran or wheat bran. When these diets were fed to dry sows, only sugar beet pulp diet reduced the voluntary feed and energy intake to an acceptable level. Sows on sugar beet pulp diet gained only 2.2 kg weight, while sows receiving other diets gained 39-48 kg (Table 3).

The variation in feed intake may attribute to the lignification of the fibre sources and to chemical variation in the fibre itself. Fibres in pig diets may generally be divided into two physio-chemical groups; soluble fibres which create viscous conditions within the small intestine and can affect digestion and absorption, and insoluble lignified fibres which mainly increase faecal output (Graham and Aman, 1991). While the effect of these two types of fibre on feed digestion by poultry has been examined extensively, knowledge of the relationship between soluble and insoluble fibre and nutrient utilisation and feed intake for pigs is very limited. Potkins et al. (1991) showed that pectin and guar gum with a high content of soluble fibre could reduce blood glucose and insulin response to meals containing digestible carbohydrate, and depress ileal apparent digestibility of nutrients for growing pigs with no effect on overall transit time. While both citrus pulp and sugar-beet pulp have a high content of soluble fibres, the sows fed a diet containing citrus pulp had a higher feed intake than those fed on a diet containing sugar beet pulp. The reasons for this difference between the two types of soluble fibre sources are not clear.

To further evaluate the effect of fibre types on feed intake of sows, Vestergaard (1997) fed gilts and sows with three diets comprising a standard diet; a sugar beet pulp diet and a diet mixed with grass meal, wheat bran and oat hulls. The soluble fibre content was 43, 203 and 30 g/kg, and insoluble fibre content was 133, 243 and 314 g/kg for standard, sugar beet pulp and mixed diets, respectively. Generally, the fibrous diets increased feeding time and reduced rooting time. The weight gain during pregnancy and weight loss at farrowing was significantly higher for pigs fed on fibrous diets. Sugar beet pulp diet reduced aggression and sham chewing and changed the postprandial insulin and glucose profile. However, there was no variation in total number liveborn or total number weaned per litter. Both mean piglet weight and total mean litter weight at birth were negatively influenced by the sugar beet pulp diet. Feed intake was lower for the sugar beet pulp diet than for the mixed grass-wheat bran-oat hull diet (289.7 kg/sow vs. 368.3 kg/sow). While the author suggested that a diet with a high content of soluble fibre and a large capacity to induce satiety may have a negative effect on piglet weight at birth, it should be noted that the sugar beet pulp diet also contained a significantly high level of both soluble and insoluble fibres (203 vs. 243 g/kg). Based on this it is difficult to conclude that the reduction of feed intake and piglet weight at birth is a function of soluble fibre. Thus the effects of fibre types on feed intake of dry sows warrant further research.

Feed intake during lactation : The lactating sow requires 5 to 7 kg of feed daily to maintain body weight and condition while lactating, but such intake is hard to maintain even though the sows are fed *ad libitum*. While a number of factors (e.g. breed, lighting pattern, dietary calcium and phosphorus levels) restrict feed intake during lactation (Lynch, 1989), feeding level and dietary composition at gestation has a strong influence on feed intake during early lactation. Generally, the smaller the amount of food given during pregnancy, the greater is the amount consumed during lactation. However, Miller et al. (2000) reported a positive correlation between food intake in late gestation and food intake in the 3rd week of lactation. He suggested that increasing food intake for the last 2 weeks of gestation can be used to improve sow body condition without risking a drop in lactation food intake, and high feeding level in late gestation could better prepare the digestive system of the sow for high food intakes during lactation.

Increasing diet bulkiness in gestation can increase

Table 4. Mean daily water intake (litre/day)[a] of gestating sows fed a control (1) or bulky high fibre diets (2 and 3) during their first two parities (Roberts et al., 1993)

	Corn and soybean meal (1)	Wheat bran and corn cobs (2)	Oat hulls and oats (3)
First parity	29.1±1.5[c]	9.5±0.3[d]	10.7±0.9[d]
Second parity	37.9±2.5[c]	17.9±1.2[d]	17.7±1.7[d]

[a] Mean values from week 5, 10 and 15 of gestation.
[b] Significant effect of feeding treatment (p=0.0001) and parity (p=0.0003).
[c, d] Means in a row with different letters differ significantly.

lactation food intake through up-regulation of the sow digestive system. For example, 48 gilts were fed high and low fibre diets (15.3 vs. 4.1% fibre) during gestation with a fibre source of oat hulls. Feeding the high fibre diet increased feed intake during the first three weeks of lactation (4.82 vs. 4.45 kg/day), without a significant influence on milk yield, litter size and backfat of sows (Farmer et al., 1996). Matte et al. (1994) compared three diets based on oats and oat hulls, wheat bran and corn cobs or corn and soybean meal and found that sows fed a diet containing oats and oat hulls during gestation consumed approximately 5% more feed during lactation than sows fed on other diets. The research reported by Yan et al. (1995) also showed that sows fed a wheat straw diet *ad libitum* during pregnancy had a higher feed intake during the lactation period than those fed a sugar beet pulp diet (7.1 vs. 5.88 kg). This was probably due to the effect of bulkiness of these diets which could have facilitated the adaptation of the sows to the drastic increase in feed intake required to meet lactation needs. The different responses between gestation diets in feed intake during lactation could be more dependent on the differences in body weight gain and back fat thickness obtained during gestation. This is due to a negative relationship between the body condition of sows at farrowing (especially backfat thickness) and feed intake during lactation, possibly through a mechanism involving lipostatic regulation of long-term feed intake (Dourmad, 1991).

Water intake : There was a significant decrease in water intake by the inclusion of a fibrous material in the gestation diet compared with a conventional concentrated diet. Such a reduction is consistent between fibre sources and is not associated with parity (Table 4). Matte et al. (1994) also reported a decrease in water intake during gestation when feeding a bulky diet. This decrease was still present over the first 3 days of lactation, a period in which low sow water intake may be related to poor performance of pigs (Fraser and Phillips, 1989).

Feeding fibrous diets affects feed utilisation

Dietary fibres are digested to a small extent in the foregut of pigs and pass rapidly through the stomach and small intestine. While a small amount of hemicellulose can be digested, presumably due to enzymic hydrolysis (Kass et al., 1980ab), the presence of fibre in the pig diet influences the digestion and utilisation of other nutrients by pigs (Keys et al., 1970; Bach Knudsen et al., 1995; Jorgensen et al., 1996). The relationships between dietary fibre content and digestibility of nutrients have been well established. In general, with the increase of dietary fibre, there is a linear decline in the digestibility of energy and protein. The decline in digestibility is more significant in the presence of viscous fibres which can result in an increased flow of water past the ileum. A number of fibre-modulated mechanisms are probably involved in the reduction of the rate and extent of absorption in the small intestine. Apparent digestibility will be reduced by an increased ileal flow of digestive enzymes, mucin and sloughed cells owing to the presence of fibre. In addition, components such as bile acids can be bound, particularly by viscous or gelling and lignified fibres. Viscous fibres in particular, may interfere with bulk movement and mixing of digestive enzymes and nutrients in the intestinal lumen, and hinder the hydrolysis of the cell contents by digestive enzymes. Stanogias and Pearce (1985a) also suggested that the depressive effect of increased intakes of neutral detergent fibre (NDF) on the apparent digestibility of dry matter, nitrogen and energy could be the results of one or more of these factors including; 1) faster passage of food through the alimentary tract; 2) increased excretion of metabolic and microbial nitrogen; 3) low availability of nitrogen and other nutrients in fibrous materials; 4) increased excretion of nitrogen and other nutrients bound or physically entrapped in the bulk of the bolus of fibrous digesta. However, it is not clear to what extent such depression is due to a direct decrease in the apparent digestibility of these nutrients or due to an increased excretion in the faeces of microbial and endogenous material.

Some experiments also demonstrated that the addition of fibrous feeds in the pregnant sow diets increased the digestion coefficients of nutrients between early and late pregnancy. This effect is related to the adaptation of the large intestine microflora of the pigs to the diet and not to the effect of pregnancy per se (Zoiopoulos, 1984). An increase in the digestibility of NDF by growing pigs with increasing dietary fibre content was also reported by King and Taverner (1975). These results further demonstrate that the effect of dietary fibre on nutrient digestion is dependent upon the fibre sources, the structure of polysaccharides (e. g. the degree of branching of arabinoxylans) (Bach Knudsen et al., 1995) and the feeding intake. Keys et al. (1970) reported that increasing the crude fibre level of swine diets resulted in a lower digestibility of crude fibre when these diets were fed *ad libitum*. When intake was reduced to maintenance levels digestibility of the crude fibre in the high and low fibre diets was equal.

Fibre and hind gut fermentation : The effects of dietary fibre in the colon can be summarised in terms of 1) susceptibility to bacterial fermentation, 2) ability to increase bacterial mass, 3) ability to increase bacterial saccharolytic enzyme activities, and 4) water holding capacity of the fibre residue after fermentation (Eastwood, 1992). Once the fibres pass through small intestine to the large intestine, about 59-77% of fibre is fermented in the hind-gut, depending on the fibre level in the diet, and is accompanied by absorption of water and minerals, especially sodium (Jorgensen et al., 1985).

The degradation of fibre in the hindgut produces various gases (H_2, CO_2, CH_4, NH_3), lactic acid, short chain fatty acids and microbial cells as the main products. Of these end-products, only the organic acids are absorbed from the gut lumen and utilised by the host (Kass et al., 1980b), but they most likely have a lower metabolic efficiency than glucose absorbed from the small intestine. The crude protein or amino acids entering the hindgut are partly decomposed and converted into ammonia and probably amines, which may be absorbed, but they are mainly excreted with the urine (Just, 1982). The organic acids can provide a substantial amount of energy, but such contribution to overall energy metabolism for pigs is poorly quantified. However, based on calculations from the production of organic acids, fermentation could provide about 5-30% of the maintenance requirements of growing pigs (Friend et al., 1964; Farrell and Johnson, 1970; Pond, 1989; Graham and Aman, 1991; van Wieren, 2000), with a significant difference between feed sources (van Wieren, 2000). Kass et al. (1980b) reported that volatile fatty acids produced in the large intestine can provide up to 6.9, 11.3, 12.5 and 12.0% of energy required for maintenance in 48 kg pigs, respectively, when fed 0, 20, 40 and 60% lucerne meal in the diets. Van Wierem (2000) concluded that the energy contribution of neutral detergent fibre (NDF) digested can amount to proportionately 0.26 of the metabolisable energy (ME) intake. Pigs can maintain weight on an all grass diet if the NDF of the grass diet does not exceed 550 g/kg. Assuming that basal diet digestibility is not changed by adding fibrous feeds, the digestible energy content is 0.134 MJDE/kg dry matter (DM) for straw (Muller and Kirchgessner, 1983 cited by Etienne, 1987); 7.89 MJDE/kgDM for corn cobs (Etienne and Henry, 1973 cited by Etienne, 1987); 3.03 MJDE/kg DM for tall wheatgrass (Pollmann et al., 1979).

Although the fermentation of fibre material in the hindgut contributes to the energy requirement of pigs, the reduction in the energy utilisation by pigs is significant. Pollmann et al. (1979) reported a decrease of the ME to DE ratio after the inclusion of bulky feeds in sow diets. This ratio was 90.1% for a diet with 97% sun-cured lucerne or 92% with 66% tall wheatgrass hay, but was up to 96.8% for the control diet based on corn and soybean meal. The reason for such depression is the high methane production due to microbial activity in the hindgut and the high urinary energy excretion which may be related to an increased hippuric acid excretion. In addition, feeding high fibre diets to pigs causes an increased heat production associated with additional energy costs of ingestion and digestion. However, some studies revealed that energy losses through methane and urine were not affected by the quantity of straw in the diet (Muller and Kirchgessner, 1983a cited by Etienne, 1987), probably due to the suppression of certain bacteria by feeding high fibre diets, associated with a decrease in gastric pH, a change in transit time and faecal dry matter and variations in both bile secretion and volatile fatty acid production (Lawrence, 1972).

Fibre and digesta transit : The length of time digesta remains in the alimentary tract of the animals, where it is exposed to digestive enzymes and microbial degradation, largely influences the extent to which feed is digested. The retention time of digesta in the caecum and the large intestine is of particular importance for pigs as these organs are the only sites where the digestion of dietary fibre can occur. It has been well understood that the rate of passage of digesta is related to physical characteristics of the feed such as particle size of the feed, water absorption and retention capacity, bulk of feed and body weight of the pigs (Stanogias and Pearce, 1985a). It is believed that the fibrous part of the diet travels very fast in the stomach and small intestine with limited digestion in these organs (Kass et al., 1980a). For example, Holzgraefe et al. (1985) showed that corn-lucerne and orchardgrass hay-fed sows had a faster rate of digesta passage and shorter caecal retention time than pigs on corn-soybean meal diet. Cherbut and Ruckebusch (1985) included indigestible particles at 10% dry matter of the diet for pigs, and found that mean retention time was decreased from 129 h to 94.2 h, entirely due to the mechanical properties of polyethylene particles which cannot be fermented and have no water -holding capacity. However, the turnover time of digesta has no influence on total volatile fatty acid (VFA) concentration in the caecum-colon, but is positively correlated with total amount of VFA and negatively correlated with cell wall digestibility (Kass et al., 1980b). It appears that the impact of the increased passage rate of digesta by feeding high fibre diet on digestion and fermentation is dependent on the fibre sources used in the feed. For instance, Stanogias and Pearce (1985a) found that the high apparent digestibility of nutrients in a diet containing soyabean hulls and lupin hulls was associated with the extended time that digesta remained in the alimentary tract of the pigs, but this was not the case for the diet containing oat hulls.

In summary, the effect of fibrous feeds in the sow diet on nutrient utilisation efficiency is largely dependent on the

Table 5. Apparent digestibility coefficients for dry matter (DM), organic matter (OM), crude protein (CP), neutral and acid detergent fibre (NDF, ADF) and gross energy (GE) of the diets with gestating sows (Brouns et al., 1995)

	Diet						SED
	Sugar-beet pulp	Barley straw	Oat husk	Malt culms	Rice bran	Wheat bran	
DM	0.73	0.58	0.65	0.74	0.57	0.65	0.016***
OM	0.82	0.61	0.67	0.77	0.62	0.71	0.017***
CP	0.57	0.69	0.79	0.77	0.67	0.77	0.020***
NDF	0.84	0.33	0.35	0.51	0.40	0.51	0.026***
ADF	0.80	0.26	0.29	0.37	0.13	0.26	0.033***
GE	0.77	0.58	0.65	0.74	0.61	0.69	0.048***

*** p<0.001.

Table 6. Effect of dietary fibre on final body weight, gutfill and weight and length of the digestive tract in growing pigs (mean values for four pigs) (Derived from Jorgensen et al., 1996)

	Low fibre diet (5.9% DM)	High fibre diet (26.8% DM)
Body weight (BW) (kg)	122	129
Gutfill (g/kg BW)	29[a]	82[b]
Empty body weight (EBW) (kg)	118	119
GI tract weight (g/kg EBW)		
Stomach	5.74[a]	7.27[b]
Small intestine	15.57	16.23
Caecum	1.64[a]	2.83[b]
Colon	8.70[a]	17.23[b]
Total	31.65[a]	43.56[b]
GI length (m/kg EBW)		
Small intestine	0.151	0.157
Large intestine	0.047[a]	0.061

GI, Gastrointestinal; Gutfill, content of the digestive tract; [a b] mean values within a row with different letters were significantly different between the two treatments (p<0.05).

physical form and the chemical composition of the fibre material. For natural fibre sources, the digestibility coefficient of fibre per se by pigs can vary from 0.205 to 0.665 (Baird et al., 1989). Stanogias and Pearce (1985a) also reported a large range of 0.181 to 0.840 for the mean apparent digestibility coefficient of NDF from natural fibres. This variation may be related to the extent of lignification, mineralisation, crystallinity, size of the cellulose chain or particle size of the fibre or both (Cowling and Brown 1969) and the balance of nutrients because all these factors determine the extent and rate of fermentation of fibre by pigs. Any variation in these chemical and physical characteristics will result in variable responses in the digestion of fibres. For example, Brouns et al. (1995) and Le Goff et al. (2002) found that the apparent digestibility of the fibre fraction of the sugar beet pulp diet was considerably higher due to the nature of the fibre fraction sugar-beet pulp (Table 5). The fibre fraction of sugar beet pulp consists of highly fermentable polysaccharides, while the fibre fractions of other diets contains more secondary cell wall material which is generally less degradable due to a high lignification. Low (1990) reported that insoluble types of dietary fibre such as cellulose and wheat bran did not have significant effect on the rate of passage, digestion and absorption in stomach and small intestine, probably due to the complicated interactions between the total diet and the fibre type.

Feeding fibrous diets stimulates gut development

Early research showed adaptive increase in intestinal absorption by chickens during the dietary stresses of high bulk diet and intermittent starvation is associated with an increase in mucosal enzyme activity (Michael and Hodges, 1973). Chickens fed a restricted diet had slightly shorter and thinner villi, with an increased activity of alkaline phosphatase, leucine naphthylamidase, acid phosphatase, 〈-glucuronidase, non-specific esterase and succinic dehydrogenase in the absorptive cells. When these restricted fed birds were changed to *ad libitum* feeding they had better growth than those fed normally (Michael and Hodges, 1973). Feeding guar gum to rats increased the small intestine length, mucosal mass and crypt-cell proliferation, but reduced the activities of some mucosal enzymes. However, the addition of cellulose had the opposite effect (Johnson et al., 1984). This indicates that materials defined as dietary fibre may differ markedly in their physiological effects.

Based on the above findings, if pigs could become adapted to a type of digestion that increases their ability to utilise energy from dietary fibre, it would appear that parts of the digestive tract would be enlarged by increases in length or weight or both (Kass et al., 1980a; Stanogias and Pearce, 1985b). These changes in size and weight of gastrointestinal organs are believed to reflect a hypertrophy of particular tissues of the organ in response to the increased amount of work performed by these organs in drying, mixing, shaping, moving and expelling large amounts of undigested dietary residues. With increasing levels of fibrous materials in the sow diet, there is an increase in weight and length of the gastrointestinal organs (Stanogias and Pearce, 1985b; Pekas and Wray, 1991; Jorgensen et al., 1996; Table 6) especially for the caecum. Such an increase may be due to a number of factors such as prolonged caecal residence of the fibre, increased bacterial mass, or increased bacterial end products (Eastwood, 1988). It should be noted that these changes in both size and

Table 7. Effect of oat hulls added to the basal diet on the reproductive performance of pregnant sows (Mroz et al., 1986)

Basal diet (kg/day)	2.15	2.15	2.15	2.15		
Oat hull (kg/day)	-	0.24	0.92	2.15		
No. animals per treatment	11	8	8	8		
Reproductive performance					SED	P[A]
Net gestation gain (kg)	26.5	38.2	40.3	49.6	3.12	**
No. piglet born alive	9.45	11.50	12.40	11.50	0.99	ns
Litter weight at birth (kg)	14.7	18.1	18.7	20.9	1.29	*
Milk fat content (g/kg)	64.8	75.0	74.5	72.22	9.2	ns

[A] P denotes level of significance. ns, $p>0.05$, * $p<0.05$, ** $p<0.01$.

Table 8. Pectin and fibre content of orange and grapefruit by products (% of fresh weight) (Braddock and Graumlich, 1981)

Fruit material	Pectin	Cellulose	Hemicellulose
Orange			
Juice sac	4.8	3.5	1.7
Peel	3.7	3.8	1.8
Grapefruit			
Juice sac	4.9	1.8	1.5
Peel	4.8	1.4	2.6

weight of gastric intestine have an impact on energy metabolism as visceral organs have a high rate of energy expenditure relative to their size (Pekas and Wray, 1991**)**. However, the magnitude of the effect of fibrous diet on the development of intestinal development is dependent on the type of fibre. For example, Stanogias and Pearce (1985b) found that the increase of gastrointestinal tract size is more significant in the pigs given lupin hulls and lucerne stems than those fed other fibre sources (wheat bran, maize cobs, pea hulls). Cunningham et al. (1961) and Gargallo and Zimmerman (1980) reported no significant changes in organs of the gastrointestinal tract of pigs given diets containing increased levels of lucerne, wheat bran, cellulose or sunflower hulls. The differences in these results cannot be adequately explained, but may be associated with the genotype of pigs used, individual variation among pigs in the ability to utilise fibre and the difference in fibre sources.

Feeding fibrous diets improves reproduction

In general, the use of bulky diets diluted with fibrous feedstuffs has beneficial effects on body condition and some traits of the reproductive performance of sows. The number of pigs weaned and/or pig birth weights tended to increase when the gestation diets contained roughages such as maize silage, chopped hay, or chopped straw (Carter et al., 1987; Plagge, 1989; Everts, 1991), oat hulls (Mroz et al., 1986; Table 8), sunflower hulls (Carter et al., 1987), perennial peanuts (Lopez et al., 1988) or sida meal (Mroz and Tarkowski, 1991). The growth of the litter was increased by approximately 20% during the second parity when a bulky diet based on wheat bran and corn cobs was fed during the first and second parities, probably due to the beneficial effect of this diet on the sows' well-being reported in these animals (Matte et al., 1994). Mroz et al. (1986) found that when oat hulls were added to the ration for pregnant sows, the fat content of both the colostrum and milk was increased (Table 7), which had a beneficial effect on the growth and survival of piglets in the immediate post-natal period, especially when piglet mortality is high. The high fat content of milk may result from a higher rate of volatile fatty acid production, especially acetate which can be directly incorporated into milk fat (Lee and Close, 1987). Pollmann et al. (1980) also reported that the longevity of sows as determined by the proportion of animals which could be kept on the same diet during three pregnancies, was higher when they received 2.36 kg day sun-cured lucerne than with 1.95 kg/day of a corn-soybean diet. Litter size at farrowing and number of piglets born alive or dead were generally not affected by the addition of fibrous feeds to sow diets although early experiments have shown an increased prolificacy for brood sows which received diets containing lucerne due to a higher ovulation rate (Teague, 1955).

The effect of bulky diets on reproductive performances of sows previously reported in the literature are variable. For example, Danielson and Noonan (1975) showed that sows ingesting diets containing 96.75% lucerne hay during their first three pregnancies performed well, but another experiment with straw instead of lucerne would not be feasible. In most experiments, the comparisons were made between conventional and bulky diets that were not balanced to provide the same total daily amount of major nutrients (protein, amino acid and minerals). A lack of knowledge of the availability of nutrients in fibrous feedstuffs can also result in imprecise formulation, consequently variable reproduction performance. This indicates that to properly evaluate the effect of bulky diets on reproductive performance of sows, it is critical to feed sows diets that are different enough in bulkiness and formulated to provide the same total daily amount of major nutrients. Another reason for the variable responses in reproduction performance when feeding fibrous diet is that most experiments were run for a short period of time, with a limited number of animals. For instance, many of the effects reported by Matte et al. (1994), particularly on body condition of sows and growth of the piglets, were observed during the second parity. Apart from the potential higher capacity to digest or utilise the nutrient in the bulky diets by second parity sows, it is more likely that the energy requirements for maintenance of sows during the second parity are lowered, probably due to the reduction of stereotypic behaviour when fed a bulky diet (Lee and Close, 1987; Robert et al., 1993). Noblet et al. (1989) suggested that such a change in behaviour can represent a reduction of at least 10% in the energy used for maintenance, which is sufficient to produce an increase of body weight gain of 15-20 kg (ARC, 1981), as observed between sows fed on wheat bran-corn cobs diet and on corn-soybean diet by Matte et al. (1994).

POTENTIAL DIET COMPONENTS FOR CONTROL OF FEED INTAKE IN SOWS

A number of fibrous materials have been evaluated for feeding dry sows to reduce hunger and improve welfare. These include sugar-beet pulp, distiller's products, wheat bran, oat bran and husks, guar gum, citrus pulp, solka floc and some roughages. While most research has focused on the by-products or roughages, some feed grains, especially grain legumes may have potential for the control of feed intake of pigs.

Lupinus albus has about 45% crude fibre in hulls and 1.3% in kernel. Its thin seed coat and softer seed make it possible to process into protein and dietary fibre fractions. There is a poor acceptance of albus lupins by pigs and a lowered growth rate if included at above 15%. *L. albus* contains some anti-nutritive factors such as alkaloids, tannins, saponins, oligosaccharides, but generally these are of no practical concern. However, van Barneveld (1997) showed that growing pigs fed diets containing 20% whole seed or kernel of *L. albus* had a significant lower feed intake than controls (1.68 *vs* 1.88 kg dry matter/day). The impact of feeding *L. albus* to dry sows has not been examined.

Vicia sativa (Vetch) : There are many types of vetch and some of these are very toxic even at levels as low as 0.5% of the mixed feed for growing pigs. Among these, Languedoc and Blanchefleur may be suitable for use in pig feeds as a source of energy and protein even though they contain a number of anti-nutritional factors such as β-cyanoalanine compounds and potentially toxic non-protein amino acids. An experiment with growing pigs showed that the inclusion of Vicia sativa cv Blanchefleur in the diets of pigs of 25-100 kg body weight decreased feed intake with increasing inclusion level. No neurotoxic effects were evident and no L-B-cyanoalanine or its derivatives were detected in muscle tissues, suggesting factors in vetch other than these compounds were responsible for the observed decrease in feed intake and growth (van Barneveld et al., 1997). This might indicate that the inclusion of vetch in sow's diets may help control feed intake, but its high energy content could be a limiting factor for its practical application.

Sugar beet pulp has been tested extensively in UK, The Netherlands and Denmark. When it is included in the diet to provide the same amount of digestible energy as a conventional diet, dry sows can be fed *ad libitum*, without significant influence on litter birth and weaning weight, maternal weight gain in pregnancy, total number of piglets born (Edwards et al., 1991; Kay et al., 1991; Glasgow et al., 1996) and feed intake of sows during lactation (Whittaker et al., 1996). The large amount of energy derived from fermentation had no detrimental effects on reproductive performance (Edwards et al., 1991). The lower feed intake of dry sows on sugar beet pulp relative to other fibre sources (oat husks, rice bran, citrus pulp or wheat bran) was also reported by Brouns et al. (1991) and Offredo et al. (1994). It appears that gastric distension is the major factor in regulating intake when feeding a diet containing sugar beet pulp (Brouns et al., 1997). However, feeding sugar beet pulp reduced the mean weight of piglet at birth and consequently the total litter weight at birth.

Three distillery products, malt draff, maize curne gold and wheat supergrains were evaluated by Edwards et al. (1992) for use as a fibrous feed for dry sows. Voluntary food intake of dry sows were 7.6, 10.7 and 5.7 kg fresh weight per day for malt draff, maize curne gold and wheat supergrains, respectively. Sows offered maize curne gold became obese while those offered malt draff and wheat supergrains required additional barley to prevent loss of body condition.

The role of wheat bran as a fibrous material for dry sow diets has not been clearly defined. Brouns et al. (1991) compared wheat bran, straw, oat husks, malt culms, rice bran and sugar-beet pulp at an inclusion level of 350-670 g/kg, and found that all these fibre sources failed to prevent excessive intake and liveweight change except for sugar-beet pulp. The inclusion of wheat bran in the pig diet reduced the apparent digestibility of organic matter, neutral detergent fibre, acid detergent fibre and gross energy for sows (Brouns et al., 1991).

Oat bran has a high content of soluble dietary fibre in the form of 〈-glucan. Oat non-starch polysaccharide (NSP) is a readily available energy source for the microflora in the large intestine. Pigs fed oat bran diet showed faecal bulking caused by an increased excretion of protein and fat, presumably of bacterial origin (Bach Knudsen et al., 1993). Oat husk is very rich in lignin and insoluble NSP in the form of cellulose and arabinoxylose. Vestergaard and Danielsen (1998) reported that feeding dry sows with diets containing oaten hulls, wheat bran and grass meal at 600 g/kg did not affect piglet performance, the mean number of piglets born, live born, and weaned. However, the mixture of oat hulls, wheat bran and grass meal is not as effective as sugar-beet pulp in reducing aggression and sham chewing of dry sows.

Citrus pulp and grape mark have high levels of pectin which is soluble and cannot be attacked by enzymes of the digestive tract. Pectin, cellulose, and hemicellulose, with only trace amounts of lignin, are the predominant components of dietary fibre from most fruit including citrus (Baker, 1994; Table 8). Although the levels of pectin in whole or section of citrus can be influenced by variety, growing region and weather, pectin is concentrated in peel, membranes and juice sacs which make these fractions unpalatable due to the excessive levels of bitter and astringent compounds such as naringin and limonin (Baker, 1994).

Little pectin can be digested in the stomach and small intestine. However, pectin can be largely fermented by bacteria in the hindgut with products of short chain fatty acids, primarily acetate, propionate and butyrate. These short chain fatty acids can be utilised by bacteria or absorbed by the intestinal mucosa (Baker, 1994). Studies showed that citrus pectin increased gastric viscosity and reduced the rate of gastric emptying of digesta, without affecting dry matter, total glucose and total nitrogen emptying of growing pigs (Rainbird and Low, 1986a; 1986b). Offredo et al. (1994) fed citrus pulp to gilts at a level of 500 g/kg and found an intake of 3.3 kg/day, relatively higher than the intake of sugar-beet pulp diet (2.9 kg/day). The digestibility of NDF was lower for citrus pulp diet than for sugar-beet diets. However, the use of citrus pulp and grape marks may be limited by its regional and seasonal availability and the cost of drying.

Straws : The utilisation efficiency of roughage is considerably higher in sows than in growing pigs (Vestergaard et al., 1996). A long-term experiment conducted by Everts (1991) showed that the addition of chopped straw, maize silage or fibre in the dry sow diets did not improve the reproductive performance. However, sows on high fibre diets had the highest body weight and a higher number of litters per year. Yan et al. (1995) evaluated wheat straw for dry sow feed and found that inclusion of 260 g/kg NSP in the sow diet from wheat straw did not affect digestibility of nitrogen and the reproductive performance of sows. The low apparent digestibility of NSP in wheat straw, together with the high faecal bulk and reduced faecal dry matter from wheat straw diets may render wheat straw particularly suitable for reducing constipation and acting as a low-energy bulking agent in pregnant sow diets.

Soyabean hulls are a by-product obtained during dehulling of soya beans. With a crude fibre content of 35%, fibres in soybean hulls, such as cellulose and hemicellulose, are more digestible than those from other feedstuffs as observed in growing pigs (Kornegay, 1978; Stanogias and Pearce, 1985a; Ewing, 1997). With soybean hulls, Kornegay (1978) observed a 0.76% decrease in crude protein digestion with each 1% acid detergent fibre increase in food, but energy digestion was unaffected with over 15% soybean hulls in the diet. However, the digestibility of cell walls and cellulose tended to increase as dietary levels of soybean hulls increase (Kornegay, 1978). Ewing (1997) suggested that the inclusion level of soybean hulls in the sow diet can be up to 10%, but whether this level will be enough to control feed intake of dry sows is not clear.

Maize cobs have not been extensively evaluated as a dry sow feed. However, Wecke et al. (1991) reported that feeding maize cob silages increased feed intake of pregnant sows, stabilised or improved liveweight gain during pregnancy, fertility, litter weight, number of weaned piglets and liveweight gain of piglets during the sucking period. Mortality and diarrhoea was decreased and energy utilisation was increased, compared with a commercial diet without silage.

Lucerne meal is a good protein and fibre source, with vitamin, mineral and amino acid profiles higher than corn (Ensminger and Olentine, 1978). It has been proven that feeding lucerne meal to sows can improve sow reproductive performance and reduce feed costs (Peo, 1975). The inclusion of lucerne meal in the diet can reduce the digestibility of dry matter, fibre, nitrogen and energy in the diet, increase the weight of the empty gastrointestinal tract and the rate of passage of digesta which is responsible for the reduction of nutrient utilisation efficiency (Muller and Kirchgessner, 1985b cited by Etienne, 1987; Kass et al., 1980a). However, an experiment with growing pigs showed that the daily feed intake was unaffected by the level of alfalfa meal in the diet (Pond et al., 1981). It is expected that lucerne meal is too nutritious as a fibre source for dry sows. Smits et al. (2001) reported that gilts and sows offered *ad libitum* diets containing lucerne meal, mill-mix, and rice pollard had a greater increase in live weight than control animals with a higher feed cost, although the authors did not report the actual diet composition and daily feed intake.

Grass meal is rich in insoluble fibre. Its nutritive value is dependent on the maturity stage. Ewing (1997) recommended an inclusion level of 2.5% in the sow diet. When dry sows were fed diets containing 0, 10, 20 and 30% grass meal, the intake was reduced significantly with 30% grass meal in the diet (Vestergaard et al., 1996).

Wood cellulose (Solka floc) has not been assessed as a dry sow diet. The research using growing pigs showed that the inclusion of 11 or 20% in a wheat-soybean meal based diet did not affect the rate of gastric emptying. Pigs have less capacity to ferment NSPs from solka-floc (Low et al., 1985; Longland et al., 1993). Farrell and Johnson (1970) fed 4 growing pigs with diets containing 8 or 26% cellulose (solka-floc) and found that the digestibility of cellulose, though variable, was higher for the diet with 8% cellulose. Pigs on the 26% cellulose diet had larger amounts of digesta in the caecum, and lower caecal retention times, than pigs on the 8% cellulose diet. The caecum played only a small role in the breakdown of feed substances. Two experiments were conducted by Owen and Ridgman (1967, 1968) who fed pigs between 29 and 118 kg liveweight diets that were diluted with varying amounts of sawdust. The animals were able to increase their voluntary feed intake as the proportion of sawdust in the diet increased, but this compensation was not immediate. The increase in voluntary feed intake was not sufficient to maintain energy intake.

FACTORS RESTRICTING THE OPTIONS AVAILABLE FOR NUTRITIONISTS TO DEVELOP A CHEAP DIET FOR *AD LIBITUM* FEEDING OF DRY SOWS

Lack of understanding of the characteristics of feed resources that relate to reduction of feed intake of dry sows

From the above review, it is clear that the response of sows to different fibrous sources varies. The control of feed intake using fibrous feeds is a “hit and miss” situation. For example, most researchers in UK, The Netherlands and Denmark achieved control to a certain degree with sugar-beet pulp, but failed to control feed intake with other fibrous materials. No researchers have examined the chemical or physical characteristics of fibrous materials responsible for the control of feed intake of sows although some assumed that water holding capacity is the key factor. More importantly, no one explored the variability of intake between individual sows caused by different fibre resources. This should be one of the key parameters for selecting fibre materials for feeding dry sows *ad libitum* because variability in feed intake of sows caused by different fibre materials will influence individual sow performance, contributing to variable growth rates of their progenies.

Lack of data on nutritive value, especially digestible energy content, of fibrous materials for dry sows

To develop a cost effective diet for *ad libitum* feeding dry sows, it is essential to have data on the nutritive value of feed ingredients, including fibrous resources. There is substantial information on the nutritive value of fibrous feed for growing pigs, but very limited data for dry sows. It is believed that dry sows digest fibrous materials better than growing pigs due to their large capacity for fermentation in the hindgut, a longer time available for adaptation to the diet and a slower digestive transit. The by-products produced in the hindgut can contribute to the energy requirement for dry sows, but not much for growing pigs. Based on this, the largest difference in digestibility between sows and growing pigs is expected in feedstuffs of low digestibility like cereal by-products and most roughages. From a practical point of view, at least two sets of nutritive values should be attributed to most ingredients used in pig feeds, especially fibrous feeds, for both growing pigs and sows. Due to the limited data on digestible energy content in feed ingredients for sows, Noblet and Goff (2001) proposed to establish equations for estimating DE values at this stage from DE in young growing pigs. The following equation was obtained based on their unpublished data,

$$\text{DE in sow} = 3.91 + 0.777 \times \text{DE in growing pigs}$$

However, this equation is not applicable to all ingredients, especially fibrous materials because of the difference in the capability of utilizing energy from dietary fibre between sows and growing pigs. This suggests a need to determine the net energy and protein contribution by fibrous materials to dry sows.

Lack of knowledge of the availability and continuity of supply of local fibrous feed resources

As mentioned in the previous section, the researchers in Europe are focusing on typical fibre resources (e.g. sugar beet pulp) available in their region. However, the availability of these fibrous ingredients is limiting or seasonal in other countries such as Australia. Due to animal welfare concerns on restricted feeding and the stall-housing system, more sows will be housed in groups and fed ad libitum. To prepare for the change in dry sow feeding strategy, it is crucial to understand the availability and continuity of supply of feed resources in a particular country.

Feed delivery and waste disposal in the current housing systems

Fibrous feeds are bulky and the feeders currently used for dry sows may not necessarily suit *ad libitum* feeding. More importantly, feeding fibrous diets can decrease water consumption, and hence urine volume, and increase the output of faeces with a higher dry matter content. This may become a problem in systems involved in the disposal of liquid slurry. Feeding dietary fibre would also increase particle size of faeces (Lee and Close, 1987) and requires more power for mixing the slurry to ensure that all the particles are in suspension before application onto land. In addition, the pumps and pipes could be easily blocked, increasing the maintenance cost of the system. These practical problems and the potential solutions should be studied so that feeding a high fibre diet is practical.

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