Reducing Aggression in Group-Housed Gestating Sows through Manipulation of Dietary Water Holding Capacity and Hind-Gut Fermentation Substrates to Control Gut Distension and Blood VFA Levels
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Co-operative Research Centre for High Integrity Australian Pork

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Executive Summary

Daily feed requirements of gestating sows meet nutritional requirements but not satiation which causes feeding motivation to increase. Frustration may be redirected or channeled into replacement behaviours which over time may become stereotypic behaviours, especially in stall housing or aggression, as seen in group-housing. Satiety may be attained by increasing feeding levels, although this is likely to lead to heavier sows with excessive body condition scores, or by increasing the bulk of the diet. Sugarbeet pulp (SBP) has been successful in inducing satiety in gestating sows but currently remains economically unviable in Australia at inclusion levels recommended overseas. Alternative dietary sources which may show similar satiating effects include Guar gum, Opticell® and Magnesium oxide. The aim of this study was to investigate the effects of dietary inclusions, aimed to induce satiety through the manipulation of gut volume and/or volatile fatty acid (VFA) fermentation, on physiological and behavioural measures in sows.

Two experiments were undertaken to investigate the effects of dietary inclusions in isolation and combination. Experiment one, a cross-over study, used fifteen (15) mixed parity sows housed in individual stalls and fed one of five dietary treatments for two week periods, making up one week of diet acclimation and one week of diet study, replicated 5 times, until all sows had received all treatments. Sows were fed twice daily, receiving 60 % (1.5 kg) at 07:00 h and 40 % (1 kg) at 14:00 h. Two techniques, behavioural and physiological, were used to measure the response of sows to dietary treatment. Behavioural parameters were recorded by scan sampling (1 min) and consisted of individual video monitoring during the 5 min before the first feed, 25 min before the second feed and 45 min after completion of the first and second feed. Physiological response was monitored via heart rate and the influence on VFA production by hindgut fermentation through blood glucose measurements. Heart rate measurements were taken every 60 s during the same feeding phases as with behaviour samplings. Blood glucose samplings occurred 15 min prior to feed one and two, then at 0.5, 1, 2, 3, 5 and 7 h after both feeding times. Experiment two consisted of 3 sub-experiments which jointly investigated the effect on mean feed intake in sows when offered 750 g of treatment diet at regular intervals. It also investigated the effect of feeding these ingredients, aimed to induce satiety, in combination with differing inclusion rates of SBP.

There was no significant effect of dietary treatment on behavioural or heart rate measurements. Behavioural data revealed that the proportion of time spent displaying abnormal behaviours increased over time as sows tried to habituate to their stalled environment. As the sows were struggling to adapt, subtle treatment effects may have been masked by abnormal behaviour, typical of that observed in stalls. Physiological data measured by blood glucose sampling showed significant effects of dietary inclusions on blood sugar levels. A delayed postprandial peak in sows fed Guar gum was suggestive of a delayed effect of glucose absorption. Magnesium oxide and SBP are suggested to have had a longer term effect but perhaps from differing modes of action, insulin resistance in the former and VFA production in the latter. The pattern of change in blood glucose levels in sows fed Opticell, suggests the effects of this dietary inclusion occur further down the gastro-intestinal tract.

Experiment two revealed that SBP was the only dietary inclusion that could reduce the voluntary feed intake of the sow, when offered frequent portions of food. Frequent feeding studies have also shown fluctuating intake of the control diet from day 1 to day 2, where sows eat to appetite on day 1, with a result reduction in intake on day 2. This approach could be used to develop a feeding regime at mixing of unfamiliar sows designed to decrease aggressive behaviour through satiation.

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Introduction

Feeding the modern sow during gestation is aimed at providing adequate nutrients and energy for maintenance and the growth of maternal tissues (Meunier-Salaün *et al.,* 2001), generally delivered in one or two daily feeds. Despite diets meeting nutritional requirements, the restricted amount of feed offered to sows results in her not feeling satiated through most of the day (de Leeuw *et al.,* 2005). Diets are often consumed within minutes of being offered and feeding motivation may remain high (de Leeuw, 2008). The inability of sows to exhibit natural foraging behaviour may be channeled as abnormal behaviours (Lawrence and Terlouw, 1993) which overtime can become or create stereotypies in confined sows (Danielsen and Vestergaard, 2001) and accentuate aggression between sows when in group-housing.

It has been shown that two approaches exist to combat these stereotyped behaviours, behavioural satiety and nutritional satiety. By allowing complex feeding behaviours such as foraging to occur through the provision of bedding or other material, stereotyped behaviours can often be prevented (Lawrence and Terluow, 1993). However, satiety is also able to be achieved nutritionally. Many studies have shown that in sows, dietary fibre promotes satiety shortly after a meal (Bergeron *et al.,* 2002) and reduces stereotypic self-directed behaviours (de Leeuw *et al.,* 2008), indicating enhanced satiety. The performance of stereotypies is elicited by food consumption (Robert *et al.,* 2002) and is closely related to the immediate postprandial period (de Leeuw *et al.,* 2008). Providing sows with two daily meals would appear, on face value, to be a way of dealing with hunger, however, it actually stimulates the activity of these behaviours triggered by feeding motivation at each feeding event.

The general effect of fibrous diets on sows is to reduce oral stereotyped behaviour (Meunier-Salaün *et al.,* 2001; de Leeuw *et al.,* 2008) and reduce activity (Bergeron *et al.,* 2000) after the end of a meal. To date, the only real success in inducing satiety has been with incorporating high levels (50 % or more) of sugarbeet pulp in diets (SBP, Meunier-Salaün *et al.*, 2001). Unfortunately this product is unlikely to be an economically viable option in Australia, especially at such high inclusion rates, without a significant increase in local production. The impact of fibre on behaviour is clearly demonstrated, however the next step is to understand the underlying processes which may differ from one source of fibre to another (Muenier-Salaün *et al.,* 2001). There are two mechanisms that are acknowledged as creating the satiety effect. The primary reason seems to be associated with higher water-holding capacity and delayed gastric emptying (Guerin *et al.,* 2001), although interest is being shown in the role of hindgut fermentation of NSP rich diets, with the production of volatile fatty acids (VFAs) from this fermentation having a glucose sparing effect (de Leeuw *et al.,* 2005).

The three dietary inclusions (SBP, Guar gum and Opticell® (agromed Austria GmbH, Kremsmünster, Austria)) investigated in this study are fibrous components thought to have a satiety effect through their high water-holding capacity, resulting in gastric distension and the stimulation of stretch receptors in the stomach (Rainbird, 1986; Ramonet *et al.,* 1999; Kroismayr and Roberts, 2009). The fermentable fibre contained in these products delays the rate of passage of digesta and nutrient absorption and shifts fermentation towards the hindgut. The shift to hindgut fermentation and improved gut health allows the proliferation of beneficial bacteria which produce high levels of VFAs. This VFA production can also impact satiety as it plays a role in stabilising blood glucose and insulin levels (Bo and Pisu, 2008). The fourth dietary inclusion, magnesium oxide, has been suggested to play a role in insulin resistance (Barbagallo *et al.,* 2003). Stabilising insulin levels will in turn stabilise blood glucose levels, as insulin is a facilitator for circulating blood glucose through the bloodstream.

The aim of this study was to evaluate the ability of these various ingredients to induce satiety and thus change the physiological stress and behavioural responses of multiparous sows. The inclusion levels of the various ingredients investigated in this study where held at commercially viable levels and diets were isoenergetic to reduce for the energy dilution effects of fibrous ingredients

Methodology

The first experiment investigated the effect of ingredients aimed to induce satiety in isolation at commercially adoptive inclusion levels. The second group of experiments investigated these ingredients in combination and their effect on intake.

<u>Experiment One</u>

Hypothesis

To induce satiety through manipulation of gut volume and VFA fermentation

Animals and Housing

Fifteen (15) mixed parity sows were recruited (determined non-pregnant by cycling and 25 day pregnancy check) and held in individual stalls (0.65 m x 2.4 m) on concrete floor, within a naturally ventilated dry sow shed with blinds to regulate temperature and wind flow. Fresh water was available *ad libitum* via a nipple drinker.

All animals were cared for according to standard operating procedures at Westbrook Research Facility, and following the Australian Code of Practice. Experimental procedures were approved by the CHM Alliance Animal Ethics Committee (CHM PP 21/12).

Experimental Design

The approach taken to investigate satiety is similar to the approach taken by Robert *et al.* (2002).

The experimental design was a cross-over study, compromised of five (5) blocks with three (3) replicates per block. Diets were offered for two week periods, with one week of diet acclimation and one week of diet study, before progressing to the next treatment. Sows were fed twice daily, receiving 60 % (1.5 kg) at 07:00 h and 40 % (1 kg) at 14:00 h. The individual sow was the replicate for this study and there were 15 replicates for each dietary treatment.

Five treatments (4 diets with inclusions aimed to induce satiety and 1 control diet) were investigated, diets were formulated to be isoenergetic and contain a common level of available lysine (12.8 MJ DE/kg, 0.40 g AvL/MJ DE; Table 1).

Table 1. Dietary formulations and nutrient analyses of treatment diets; Control, Guar gum (Guar), Opticell®, Magnesium oxide (MgO) and Sugarbeet pulp (SBP).

		Control	Guar	Opticell®	MgO	SBP
Ingredients						
Sorghum	(%)	69.6	67.7	63.5	70.0	52.5
Millrun	(%)	17.9	20.0	20.0	17.4	13.7
Treatment inclusion	(%)		0.5	4.0	0.1	20.0
Canola meal	(%)	5.0	5.0	5.0	5.0	9.3
Meat meal	(%)	2.0	2.0	2.0	2.0	2.0
Limestone	(%)	1.00	1.00	1.00	1.00	0.49
Dicalphos	(%)	1.46	1.40	1.40	1.46	1.13
Salt	(%)	0.26	0.26	0.30	0.26	0.20
Choline chloride	(%)	0.06	0.06	0.06	0.06	0.06
Betaine	(%)	0.15	0.15	0.15	0.15	0.15
MHA calcium	(%)	0.01	0.01	0.01	0.01	
Lysine HCl	(%)	0.28	0.27	0.28	0.28	0.16
Bentonite	(%)	2.0	1.3	2.0	2.0	
Biofix/Mycofix plus	(%)	0.1	0.1	0.1	0.1	0.1
BN Breeder Premix	(%)	0.2	0.2	0.2	0.2	0.2
Analysis						
Dry Matter	(%)	88.1	88.0	88.2	88.0	88.0
Moisture	(%)	11.8	11.8	11.7	11.8	11.8
Crude Protein	(%)	12.6	12.8	12.4	12.6	13.6
Crude Fibre	(%)	3.7	4.3	6.2	3.7	6.9
Energy (Digestible)	(MJ/kg)	12.8	12.8	12.9	12.8	12.8
Lysine	(%)	0.64	0.65	0.65	0.65	0.72
Calcium	(%)	1.01	0.99	0.99	1.00	1.00
Phosphorus	(%)	0.78	0.78	0.77	0.78	0.69
Available Pho	(%)	0.47	0.46	0.46	0.46	0.40
Cal:Pho		1.29	1.27	1.30	1.30	1.45
Cal:Av Pho		2.15	2.16	2.17	2.17	2.50
Choline	(mg/kg)	991	1000	1010	989	1002
Fat	(%)	2.99	3.03	2.93	2.99	2.79
Omega-3	(%)	0.11	0.12	0.11	0.11	0.09
Omega-6	(%)	1.12	1.14	1.09	1.12	0.89
Available Lysine	(%)	0.39	0.40	0.40	0.40	0.40
Methionine:Lysine		0.30	0.30	0.30	0.30	0.31
Met+Cys:Lysine		0.66	0.67	0.65	0.66	0.65
Tryptophan:Lysine		0.19	0.19	0.19	0.19	0.19
Threonine:Lysine		0.65	0.65	0.65	0.65	0.69
Isoleucine:Lysine		0.71	0.71	0.69	0.71	0.71

Behavioural parameters

Behavioural recordings consisted of video monitoring and recording of individual sows during five days of the study week. Observations were recorded during the 5 minutes before the first feed, 25 minutes before the second feed and 45 minutes after cessation of the first and second feed. Cessation of feeding was classified as the trough being empty and the sow having stopped eating for a period of 5 minutes. Behaviour and posture, as outlined in Table 2, was recorded by scan sampling at 1 minute intervals upon playback of recorded videos.

Table 2. Ethogram used for the recording of behaviour and posture during the periods prior to and post feeding.

Postures	
Standing	Body supported by all four legs
Sitting	Body supported by the forelegs, hind legs are flat on ground
Lying – sternal	Lying with chest and stomach flat on floor, head held up off the floor
Lying – relaxed sternal	Lying with chest and stomach flat on the floor and head lowered to floor
Lying – lateral	Lying on the floor on side with rump, shoulder and head flat on floor
Behaviours	
Eating	Head lowered and directly in feed trough with visible movement of jaw (chewing)
Drinker manipulation	Manipulating the nipple drinker without grasping nipple in mouth
Chewing	Chewing with feed in the mouth, head directly over the feed trough
Licking empty feeder/floor	Head lowered and directly over feed trough or lowered to floor. Tongue clearly visible outside of the mouth with the absence of jaw movement (chewing)
Climbing	Front elevation using forelegs and housing structures for increased height
Nosing	Rubbing object with nose
Sham-chewing	Continuous chewing while no feed or substrate is present in the mouth
Object biting	Biting on object, object between jaws
Aggression	Forceful violent movement of head towards neighbor
Idle	Sow not engaged in any of the following behaviours
Head bobbing	Fast paced continuous movement of head in an up and down direction
Pawing	Striking floor or feeder with forelegs

Time spent engaging in chain and bar related activities, vacuum oral activities and nosing are considered as stereotypies (Rushen, 1984; Cronin, 1985; Terlouw *et al.*, 1991). Drinker manipulation, licking empty feeder/floor, climbing, nosing, sham-chewing, object biting, pawing and head bobbing were classified as abnormal behaviours, which in time may develop into stereotypies.

Physiological parameters

Physiological response was monitored via heart rate, and blood glucose measurements were used to monitor the influence of VFA production by hindgut fermentation. As with behavioural data, heart rate observations were recorded during the 5 minutes before the first feed, 25 minutes before the second feed and 45 minutes after completion of the first and second feed during the five days of study week.The Polar RS400 heart rate monitor (Polar Electro, Kempele, Finland) consists of an electrode belt, sensor/transmitter and a monitor to store information. The frequency of heart rate was recorded every 60 s. The mean, minimum and maximum heart rate values were measured for each of the three feeding phases, pre-feed, during feed and after feed over the 5 day study week.

Blood glucose concentration was measured using an Accu-Chek Performa (Roche Diagnostics Australia, Castle Hill, NSW) via an ear prick from a swabbed site. Measurements were taken on day 3 of diet acclimation week and sampling times occurred 15 minutes prior to feed one and two, then at 0.5, 1, 2, 3, 5 and 7 hours after both feeding times to establish a pattern of blood glucose concentration.

Statistical Analysis

There was incomplete data for 1 of the 15 sows. Despite initial on-farm testing the sow farrowed at a later date and thus data are presented on the 14 sows which had complete behavioural and physiological data.

The observed behavioural parameters were grouped into two categories, postures and abnormal behaviours, and expressed as the mean relative number of 1 min intervals of occurrences. Data were analysed using Univariate General Linear Model (SPSS 16.0) to examine the effects of dietary treatment on time spent displaying abnormal behaviour and postures. Due to the data distribution and in order to meet requirements of normally distributed data, all responses were square-root-transformed. Period, the effect of time, was included as a blocking factor. Tests for fixed effects were performed for treatment and parity.

Physiological parameters, blood glucose and heart rate measurements were analysed using a Generalised Linear Model ANOVA (Genstat v15.0 VSNI Ltd) for repeated measures. Differences in blood glucose concentration (basal level) and stability (variance, sum of absolute differences) were tested; glucose levels within each treatment were compared to basal levels.

Due to the lack of treatment effect, data were pooled to remove feed (am or pm), feeding phases (pre-feed, during feed and after feed) and day (1-5) with no change in response. Differences were determined by least significant difference ($P<0.05$).

Experiment Two

Experiment two consisted of three separate investigations looking at the ingredients identified in experiment 1 in isolation or as combinations.

Experiment 2a – The effect on voluntary feed intake of diets containing ingredients to induce satiety.

The five dietary treatments investigated in experiment 1 were used in this experiment; a control diet, 0.5 % Guar gum, 4 % Opticell®, 0.1 % Magnesium oxide and 20 % Sugarbeet pulp.

Ten mixed parity sows were used in a cross over design that involved 5 blocks of sows with 2 replicates per block. Each block received every diet. The individual sow was the replicate resulting in 10 replicates for each dietary treatment. Frequent feeding was conducted for two consecutive days with one day in between where sows were not on trial and fed 2.5 kg of a standard dry sow diet. The frequent feeding regime consisted of offering 750 g of the allocated diet at 15 min intervals for 12 feeds with a total amount offered of 9 kg. Individual sow intake was recorded and analysed for effects of dietary treatment on voluntary feed intake.

Experiment 2b – Cumulative effects on voluntary feed intake of diets containing 0.1 % Magnesium oxide.

This experiment looked at two levels of Magnesium oxide supplementation, 0 and 0.1%. Previous studies appeared to show a degree of carry-over effect on feed intake from Magnesium oxide inclusion. Diets were randomly allocated to 3 sows per treatment and fed for 5 consecutive days, using the same frequent feeding regime as outlined in experiment 2a. The individual sow was the replicate and diets formulated in experiment one were used. Individual daily voluntary feed intake was recorded and analysed for effects of Magnesium oxide inclusion.

Experiment 2c – Voluntary feed intake of sows receiving a 'satiety cocktail' diet containing Guar gum, Opticell® and Magnesium oxide with differing Sugarbeet pulp content.

This experiment investigated 3 levels of Sugarbeet pulp in the presence of 1 % Guar gum, 2 % Opticell® and 0.1 % Magnesium oxide against a control diet containing none of these dietary inclusions. Diets were randomly allocated to 3 sows per treatment and fed for 5 consecutive days, using the same frequent feeding regime as outlined in experiment 2a. The individual sow was the replicate. The three treatment diets were mixed manually on site using a standard mash dry sow diet as the base, and control diet. Additions of Guar gum, Opticell® and Magnesium oxide were made into each of 3 treatment diets. Sugarbeet pulp was then added at three differing inclusion rates 5, 10 and 20 %.Diets were randomly allocated to 3 sows and individual sow intake was recorded and analysed for effects of voluntary feed intake.

Outcomes

Experiment One

The time taken to consume the Sugarbeet pulp diet was significantly longer ($P<0.001$) for both meal times when compared to the mean time taken to consume the remaining diets (Table 3).

Table 3. Mean time taken for meal consumption (minutes) for morning (1.5 kg, 07.00 h) and afternoon (1.0 kg, 14.00 h) feeds over the experimental week for sows receiving control, 0.5 % Guar gum, 4 % Opticell®, 0.1 % Magnesium oxide (MgO) and Sugarbeet pulp (SBP).

	Treatment					
Feed event	Control	Guar	Opticell®	MgO	SBP	*P* value
07.00	11.8^{a}	11.8^{a}	11.1^{a}	10.7^{a}	13.9^{b}	<0.001
14.00	7.2^{a}	7.2^{a}	7.2^{a}	6.7^{a}	9.2^{b}	<0.001

Behavioural Parameters

A generalized linear model revealed that dietary treatment had no significant effect on abnormal behaviour (Table 4); drinker manipulation (P=0.797), licking feeder/floor (P=0.929), sham-chewing (P=0.958), object biting (P=0.427), nosing (P=0.261) and head bobbing (P=0.556). Dietary treatment also had no significant effect on posture; standing (P=0.210), sitting (P=0.920), lying-sternal (P=0.551), lying-relaxed sternal (P=0.752) and lying-lateral (P=0.273). Sows consuming diets containing 20 % Sugarbeet pulp, spent a significantly longer time resting ($P<0.10$) than the control, Guar gum or Opticell treatments.

Given the lack of significant effect of dietary treatment, the effect of period, previously a blocking factor, was analyzed using the same statistical model (Table 5). Period had a significant effect on the abnormal behaviours sham-chewing (P=0.001) and head bobbing (P=0.003). The mean proportion of time (minutes) spent engaged in sham-chewing behaviour showed a significant linear increase (P=0.005) during the first four treatment periods (period 1, 0.334; 2, 0.449; 3, 0.541; 4, 0.549) before decreasing in the final period (5, 0.529). The mean proportion of time (minute) spent engaged in head bobbing behaviour did not follow the same pattern as sham-chewing (period 1, 0.042; 2, 0.111; 3, 0.095; 4, 0.117; 5, 0.098). The effect of period on postures was also analysed and revealed a significant effect on the mean proportion of time (minutes) spent standing (P=0.006) and lying lateral (P=0.001). Further analysis showed a significant linear trend for the mean proportion of time spent standing (period 1, 0.517; 2, 0.567; 3, 0.731; 4, 0.710; 5, 0.628) and an overall negative linear effect for mean proportion of time (minutes) spent lying lateral (period 1, 0.217; 2, 0.206; 3, 0.072; 4, 0.058; 5, 0.019).

Table 4. Log transformed means of total time sows' spent engaged in each abnormal behaviour and posture over the experimental week when fed a control diet or a diet containing 0.5% Guar gum, 4 % Opticell®, 0.1 % Magnesium oxide (MgO) or 20 % Sugarbeet pulp (SBP).

	Treatment						
Activity	**Control**	**Guar**	**Opticell®**	**MgO**	**SBP**	**SEM**	***P* value**
Drinker manipulation	0.266	0.236	0.225	0.242	0.237	0.024	0.797
Licking feeder/floor	0.270	0.294	0.289	0.289	0.285	0.025	0.929
Sham-chewing	0.488	0.477	0.476	0.512	0.498	0.038	0.958
Object biting	0.123	0.103	0.112	0.127	0.118	0.019	0.427
Nosing	0.205	0.186	0.195	0.152	0.202	0.018	0.261
Head bobbing	0.042	0.111	0.095	0.117	0.098	0.014	0.556
Posture							
Standing	0.837	0.803	0.769	0.751	0.762	0.046	0.210
Sitting	0.159	0.150	0.160	0.185	0.203	0.039	0.861
Lying-sternal	0.237	0.209	0.286	0.231	0.268	0.035	0.551
Lying-relaxed sternal	0.326	0.344	0.379	0.401	0.389	0.045	0.752
Lying-lateral	0.137	0.116	0.152	0.039	0.128	0.038	0.273
Lying-total#	**15.1^{x}**	**18.0^{xy}**	**16.0^{xy}**	**18.9^{yz}**	**20.1^{z}**	1.90	0.053

#Bold values expressed as true mean (minutes); xyzMeans in a row not having the same superscript are significantly different (P<0.10); SEM, standard error of the mean.

Table 5. Log transformed means of total time sows' spent engaged in each abnormal behaviour and posture over the experimental week for each experimental period.

	Period							
Activity	**1**	**2**	**3**	**4**	**5**	**SEM**	***P* value**	**Linear**
Drinker manipulation	0.197	0.220	0.238	0.274	0.277	0.024	0.097	NS
Licking feeder/floor	0.277	0.255	0.284	0.310	0.283	0.025	0.630	NS
Sham-chewing	0.334^{a}	0.499^{b}	0.541^{b}	0.549^{b}	0.529^{b}	0.038	0.001	0.005
Object biting	0.123	0.103	0.112	0.127	0.118	0.019	0.910	NS
Nosing	0.174	0.197	0.200	0.195	0.174	0.018	0.744	NS
Head bobbing	0.042^{a}	0.111^{b}	0.095^{b}	0.117^{b}	0.098^{b}	0.014	0.003	0.053
Posture								
Standing	0.517^{a}	0.567^{a}	0.731^{b}	0.710^{b}	0.628^{ab}	0.046	0.006	0.014
Sitting	0.165	0.184	0.168	0.194	0.146	0.039	0.920	NS
Lying-sternal	0.233	0.267	0.163	0.262	0.306	0.035	0.066	NS
Lying-relaxed sternal	0.496	0.466	0.374	0.290	0.213	0.045	0.752	NS
Lying-lateral	0.217^{a}	0.206^{a}	0.072^{b}	0.058^{b}	0.019^{b}	0.038	0.001	0.001

abMeans in a row not having the same superscript are significantly different (P<0.05); SEM, standard error of the mean.

Physiological Parameters

Blood glucose concentration was monitored after a period of diet acclimation to indicate the effects of the dietary inclusions using an approach similar to Robert *et al.* (2002). Basal blood glucose levels taken 15 minutes prior to the first feeding time (Table 6) showed significant differences between treatments (P=0.05), with basal levels for the Guar gum treatment significantly lower than all other treatments. Analysis of variance by repeated measures and mean response for blood glucose showed reduced and delayed postprandial peaks. Blood samples taken 30 minutes after the offering of the first feed (07:00 h) showed a significant increase in Guar gum and Opticell® treatments compared to Control and SBP treatments. Blood glucose levels taken 1 hour post feeding showed a significant increase when Magnesium oxide was included in the diet (P=0.043). Blood glucose levels measured 7 hours post feeding was significantly lower in the Guar gum, Magnesium oxide and SBP treatments compared with the Control treatments.

Table 6. Mean blood glucose levels (mmol/L) 15 minutes prior to, 30 minutes and 7 hours post first feed (07.00 h) in sows fed a control diet or a diet containing 0.5% Guar gum, 4 % Opticell®, 0.1 % Magnesium oxide (MgO) or 20 % Sugarbeet pulp (SBP).

	Treatment					
Feed event	Control	Guar	Opticell®	MgO	SBP	*P* value
15 mins prior	4.3^{a}	4.0^{b}	4.3^{a}	4.1^{a}	4.1^{a}	0.050
30 mins post	4.1^{c}	4.6^{a}	4.5^{ab}	4.2^{bc}	4.1^{c}	0.011
7 h post	4.6^{a}	4.1^{c}	4.5^{ab}	4.3^{bc}	4.3^{bc}	0.010

^{abc}Means in a row not having the same superscript are significantly different (P<0.05).

Further analysis revealed a significant effect of Period (P<0.001) on mean blood glucose levels 30 minutes after the first feed (Table 7). Glucose levels showed a significant negative linear trend and were significantly higher in Periods 1 and 2 when compared to Period 5. This reduction in the basal blood glucose levels as the experiment progressed is perhaps a direct response of the period effect mentioned earlier within the behavioural data, where period 5 showed a 'leveling out' of abnormal behaviour, with cortisol affecting blood glucose measurements during this initial sampling.

Table 7. Mean blood glucose levels (mmol/L) 30 minutes post first feed (07.00 h) in sows in each of the experimental periods.

	Period						
	1	2	3	4	5	*P* value	Linear
30 mins post	4.7^{a}	4.4^{ab}	4.1^{bc}	4.3^{bc}	3.9^{c}	<0.001	<0.001

^{abc}Means in a row not having the same superscript are significantly different (P<0.05).

Mean blood glucose levels (mmol/L) were observed to drop below basal levels after the first feed event in the control treatment before a sharp rise indicative of a postprandial peak immediately after feeding (Figure 1). When sows received Opticell blood glucose levels dropped to below the basal level two hours after feeding before beginning to rise again. Magnesium oxide and Sugarbeet pulp treatments showed an extended period of increased but stable blood glucose levels after the first feed event compared with the control. Sows fed diets containing Guar gum showed a persistence of higher blood glucose that showed a steady pattern of decline over time, before returning to a higher stable level after the second feed event.

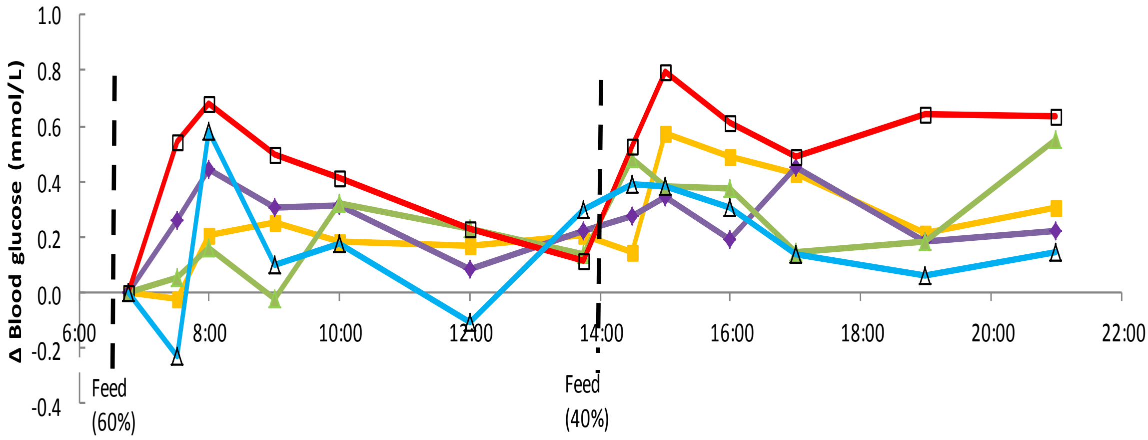

Figure 1. Blood glucose concentration (mmol/L) relative to basal levels in sows fed a control diet (△) or a diet containing 0.5% Guar gum (☐), 4 % Opticell® (▲), 0.1 % Magnesium oxide (♦) or 20 % Sugarbeet pulp (■).

A generalized linear model revealed that there was no significant effect of dietary treatment or period on heart rate measurements during both feeding periods over the study week (Table 8).

Table 8. Mean, minimum and maximum heart rate (mean (SE), bpm) during both feed events over the 5 day study week in sows fed a control diet or a diet containing 0.5% Guar gum, 4 % Opticell®, 0.1 % Magnesium oxide (MgO) or 20 % Sugarbeet pulp (SBP) and in each experimental period.

	Mean	Minimum	Maximum
Treatment			
Control	64.1 (6.1)	48.6 (5.3)	89.6 (8.3)
Guar gum	64.9 (6.1)	52.1 (5.3)	89.7 (8.3)
Opticell®	76.9 (6.7)	60.1 (5.7)	104.8 (9.0)
MgO	73.9 (6.1)	57.8 (5.3)	102.3 (8.3)
SBP	65.0 (6.4)	49.0 (5.5)	90.6 (8.6)
P value	0.483	0.468	0.551
Period			
1	76.2 (6.1)	60.9 (5.3)	103.7 (8.3)
2	70.8 (6.1)	56.5 (5.3)	95.0 (8.3)
3	72.7 (6.1)	56.0 (5.3)	102.7 (8.3)
4	68.6 (6.1)	52.5 (5.3)	94.7 (8.3)
5	56.5 (7.0)	41.8 (6.0)	81.0 (9.5)
P value	0.307	0.197	0.402

Experiment Two

Experiment 2a – The effect on voluntary feed intake of diets containing ingredients to induce satiety.

The inclusion of Sugarbeet pulp in the diet significantly reduced the mean voluntary feed intake of sows (*P*<0.001), when compared with all other treatments (Figure 2.).

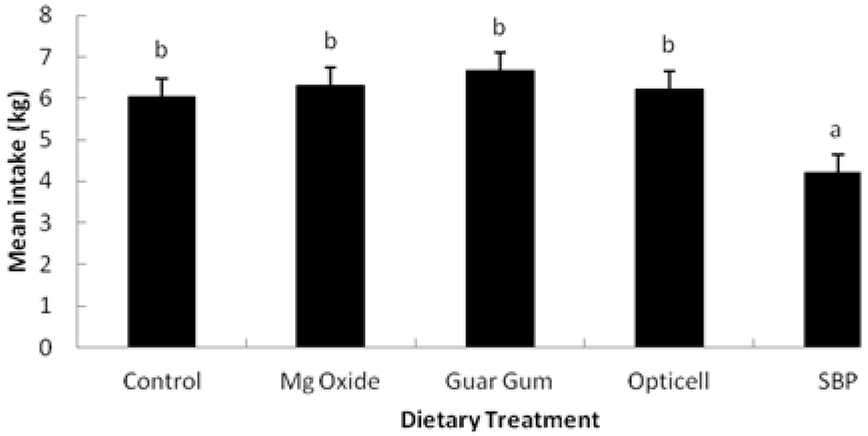

Figure 2. Mean voluntary feed intake (kg/d) of sows offered a frequent feeding regime fed a control diet or a diet containing 0.5% Guar gum, 4 % Opticell®, 0.1 % Magnesium oxide (MgO) or 20 % Sugarbeet pulp (SBP).

Experiment 2b – Cumulative effects on voluntary feed intake of diets containing 0.1 % Magnesium oxide.

There were no significant effects on the voluntary feed intake of sows when fed a control diet or a diet containing 0.1 % Magnesium oxide (Figure 3.).

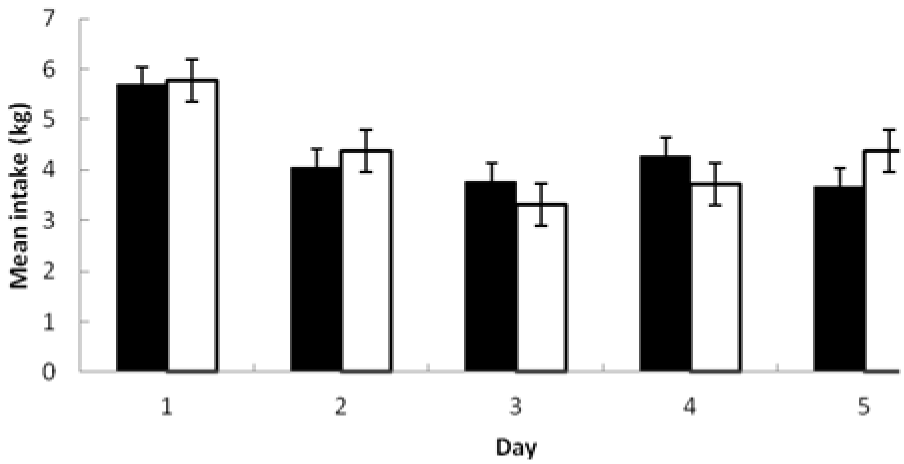

Figure 3. Mean voluntary feed intake (kg/d) of sows fed a control diet (■) or a diet containing 0.1 % Magnesium oxide (□) when offered a frequent feeding regime over 5 consecutive days.

Experiment 2c – Voluntary feed intake of sows receiving a 'satiety cocktail' diet containing Guar gum, Opticell® and Magnesium oxide with differing Sugarbeet pulp content.

There was no significant effect on mean voluntary feed intake of sows when fed a 'satiety cocktail' diet containing differing levels of Sugarbeet pulp.

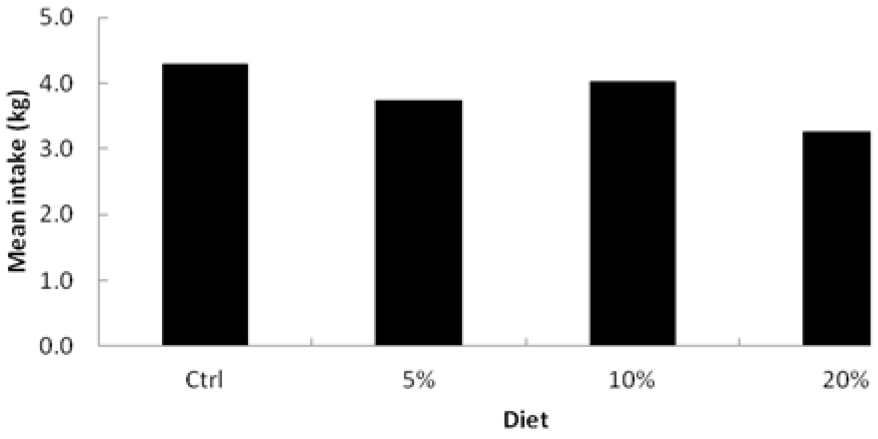

Figure 4. Mean voluntary feed intake (kg/d) of sows fed a control diet or diets containing 1 % Guar gum, 2 % Opticell® and 0.1 % Magnesium oxide and differing levels of Sugarbeet pulp (5, 10 or 20 %).

Further analysis of voluntary feed intake revealed a significant effect (P=0.007) of feeding day with the control diet having a significantly higher feed intake on day 1 compared with other treatments (Figure 5.). There was a significant linear increase (p=0.011) in feed intake on day 1 with all diets. This increase on Day 1 appeared to result in a decreased voluntary feed intake on the following day.

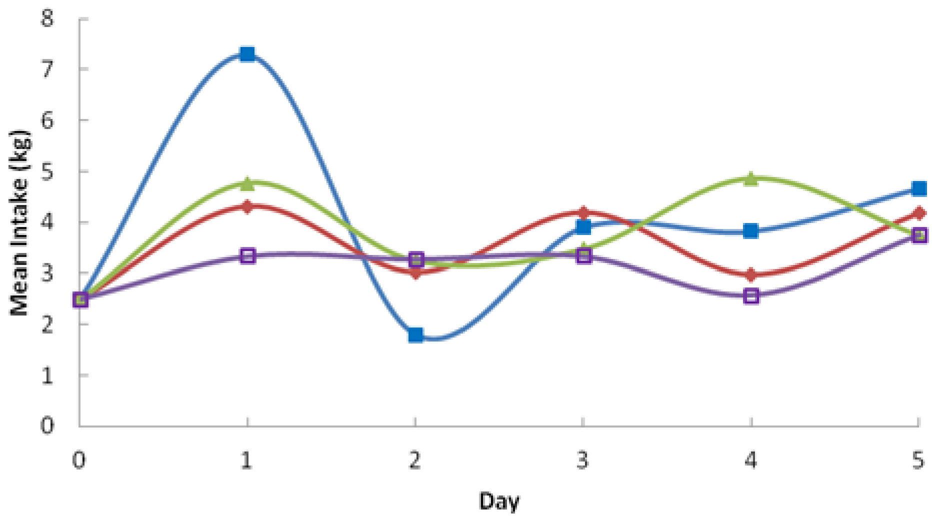

Figure 5. Daily voluntary feed intake (kg) of sows fed a control diet (■)or diets containing 1 % Guar gum, 2 % Opticell® and 0.1 % Magnesium oxide and Sugarbeet pulp at 5 (♦), 10 (▲), or 20 (□) % inclusion rates.

Discussion

A delayed postprandial rise in glucose may be indicative of a number of potential mechanisms. Dietary inclusions may show a possible prolonged effect on glucose availability from the diet, the delay may be due to delayed nutrient absorption or as a result of the production of VFA in the distal region of the large intestine. All treatments appeared to have some level of modification of blood glucose concentrations. Magnesium oxide reduced the peak but extended the time of increased blood glucose concentrations, suggestive of its reported insulin resistance mechanisms. Sugarbeet pulp appears to act at both ends of the tract with a delayed glucose release/absorption and acting as a potential substrate for VFA production. Opticell® would appear to be of benefit in maintaining satiety in the sow some time after feeding with varied responses in the period around feeding, but an increase in blood glucose levels in the latter stages of the observation period. Sows fed Guar gum showed an increased blood glucose level 30 minutes after the first feed (07.00 h) with an extended period of raised blood glucose which declined gradually over time. This changed pattern may be attributed to slower digestion or absorption (Hagander *et al.*, 1984) although the theory of delayed gastric emptying has not yet been supported (Holt *et al.*, 1979). Basal blood glucose levels in this study were lower than those in other studies, which may be attributable to different methods of analysis, however, relative movements would still be valid. The method used in this present study may have been affected by the stress response and in particular, circulating cortisol levels, as shown by the period effect previously identified.

It has been observed that fibrous diets decrease oral stereotyped behaviour after the end of a meal and increase the time spent lying (Bergeron *et al.*, 2000; Fraser, 1975; Robert *et al.*, 1993; Brouns *et al.*, 1994) which is likely to be a sign that satiety is being achieved (Robert *et al.*, 1993). The inclusion rate of dietary ingredients used to induce satiation on stereotypic behaviour in this study, showed a lack of effect immediately after a meal. This is in accordance with previous research (Terlouw *et al.*, 1993), where restrained sows developed stereotypies which were only enhanced in the post-feeding period by the addition of an extra meal. The addition of a second feeding time increased the time spent displaying abnormal behaviours and remained relatively high, increasing with time. Although not significant in this study, after pooling all means for lying postures the mean time spent lying for each dietary treatment was highest in sows consuming Sugarbeet pulp, which is consistent with previous research (Brouns *et al.*, 1994).

Investigations into stereotypies of tethered sows performed by Rushen (1984), described the stereotyped behaviours as either being of short-duration bouts of rubbing, head waving and bar-biting during feed delivery or long-duration bouts of highly stereotyped sequences of rubbing and drinking after feeding. The behavior observed in this study agrees with these assumptions in that abnormal behaviour displayed prior to feeding consisted of short repetitive movements such as bar-biting and head bobbing followed by long sequences of almost idiosyncratic behaviour after feeding, highly consistent of sham-chewing. Results show that the mean time spent engaged in sham-chewing over the ten week observation period of the study inclined from period 1 through to period 4 before leveling off in period 5. Although not significant, the majority of abnormal behaviours consistently demonstrated this pattern of incline followed by a decline in period 5. This suggests that initially the sows were struggling to adapt or habituate to their housing with abnormal behaviours leveling off by week 10 as they begin to use redirected behaviour as a means of coping.

The use of a frequent feeding regime is an effective tool to analyse the response in voluntary feed intake of sows when fed differing dietary treatments. It was shown that the inclusion of Sugarbeet pulp into the diet at a rate of 20% in isolation and combination reduces individual intake on the day offered. It was also demonstrated that when sows were offered *ad libitum* access to a standard dry sow diet, voluntary feed intake was very high on day 1, but was reduced on the subsequent day. These results reveal the benefits of Sugarbeet pulp in reducing feed intake by mechanisms associated with inducing satiety when added at a 20% inclusion rate. The finding of high fluctuations in voluntary feed intake of a standard dry-sow diet from day 1 to day 2 may be useful in developing a feeding regime designed to decrease aggressive behaviour through satiation when mixing unfamiliar sows.

Application of Research

It has been hypothesized that bulky fibres increase satiety and thereby decrease stereotypic behaviours immediately following a meal (de Leeuw *et al.*, 2008) in a confined environment and decrease aggression in group-housed sows (Danielsen, 2001). The inclusion of SBP within gestating sow diets has shown significant effects on behaviour (Meunier-Salaun *et al.*, 2001). In the present study, stereotypic behaviour remained unchanged by the inclusion of ingredients for satiation at commercially adoptive levels. It has been suggested that adding a large quantity of fibre in diets for pregnant sows decreases stereotypies (Bergeron *et al.*, 2000) however at the commercial feeding level of 2.5kg/day used in this study, no effects were measured behaviourally. A delayed postprandial peak in sows fed Guar gum was suggestive of a delayed effect of glucose absorption. Magnesium oxide and SBP are suggested to have had a longer term effect but perhaps from differing modes of action, insulin resistance in the former and VFA production in the latter. The pattern of change in blood glucose levels in sows fed Opticell®, suggests the effects of this dietary inclusion occur further down the gastro-intestinal tract. The identification of a readily available and affordable feed ingredient that can elicit a similar response to SBP will go a significant way to minimize aggression in group housed sows. The methodology employed to assess the ability of a wide range of alternative products to influence animal physiology and behaviour was sound but requires utilization in a previously adapted environment by sows. Further research is required to determine the effectiveness of these selected alternative products in an adapted environment to determine the most effective means of commercial exploitation.

Conclusion

Studies on the reduced stereotyped behaviour and feeding motivation in sows fed fibrous diets linked to physiological stress indicators are still limited and have somewhat divergent results (Meunier-Salaun *et al.*, 2001). The lack of effect of diets, even at the inclusion levels used, on feeding motivation measured behaviourally was unexpected given their positive effects in literature. It was thought that by inducing abnormal behaviours with a stalled environment, dietary treatments aimed to induce satiety may positively affect the development of stereotypic behavior over time. The response of the sow's behaviour is typical of that when housed in stalls and as a consequence the effect of the intensive housing on abnormal behaviours was too great. The effects of the environment or housing in this study appeared to be too strong and tended to override any possible effects on the behaviour of sows that were offered dietary manipulations to induce satiety. The most consistent behavioural response from this Project was that SBP appeared to have a positive effect on satiety, as inclusion of 20% SBP in a diet increased meal time and reduced voluntary feed intake to no more than 4 kg/day. Physiologically, results of the blood glucose sampling suggest that all four dietary inclusions used may play a role in stabilizing blood glucose levels. This warrants further investigation of economically viable inclusion levels used in this study, in a more stable housing environment.

Limitations/Risks

Stereotypic behaviour may be an expression of high levels of motivation for feed or forage (Lawrence and Terlouw, 1993) and previous studies suggest that a feeding level of 2.5kg/day is a restricted amount and perhaps therefore facilitating the development of stereotypies. The inability of the sows to cope with their stalled housing and low feeding level further enhanced the need to re-direct their frustration into abnormal behaviours. The housing environment in this study was too challenging for the sows to display any behavioural changes which may have been elicited through the inclusion of possible dietary satiation. A better model for studying satiety and behavioural responses to these dietary ingredients may have been sows housed in groups which were exposed to longer term studies.

Recommendations

As a result of the outcomes in this study the following recommendations have been made:

- Sows housed in stalls may not be an ideal model to study behavioural responses to dietary manipulations to induce satiety because:
  - Aggression may be better assessed under group housing systems.
  - Sows are only likely to be housed commercially in stalls for short periods in the future.

- As an alternative, future experiments examining dietary manipulations to improve satiety and reduce aggression may be held in group housing systems with free access stalls to prevent the high levels of stereotypic behaviour displayed in stalled housing.

- In view of the positive effects of SBP on reducing voluntary feed intake, increasing meal time and an apparent improvement in satiety, the use of SBP in diets should be further investigated for short term critical times, particularly when sows are mixed into groups.

- Monitoring glucose levels after feeding provides some insight into the mode of action of dietary supplementation and manipulations that are designed to inmprove satiety.

- The use of heart rate as a measure of physiological response of sows to their environment, may not be a good measure in an uncontrolled environment. It may be more useful in a controlled room or chamber without noise or activity interference as heart rate is a sensitive measure.

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