EVALUATION OF

YUCCA EXTRACT,

AMINO ACID

AND JERUSALEM ARTICHOKE SUPPLEMENTATION

IN PIG DIETS

A Thesis

Submitted to The Faculty

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by

Andrew Brian Kotchan

In Partial Fulfilment of the

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirements of the degree of

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ABSTRACT

The purpose of this study was to evaluate the effects of yucca extract supplementation, amino acid substitution and Jerusalem artichoke (JA) supplementation on growth performance and manure volatile fatty acids (VFA) in pigs. Jerusalem artichoke (*Helianthus tuberosus*), a relative of the sunflower, is an abundant source of inulin. Inulin can support the growth of certain intestinal bacteria. Deodorase® is an extract from the plant *Yucca shidigera*, and has been shown to bind ammonia and inhibit peptide fermentation. Synthetic lysine, methionine and threonine were used for amino acid substitutions.

The first experiment was a digestibility study using twelve Cotswold pigs randomly assigned to a control, JA or Deodorase® supplemented diet. A 30 % JA diet and a 0.015% Deodorase® diet were evaluated for ileal and total tract digestibilities of energy, crude protein (CP) and neutral detergent fibre (NDF). There were no significant ($p>0.05$) differences observed between the Jerusalem artichoke and control diets for ileal digestibilities of CP and NDF. The ileal digestibility of the energy in the JA diet was approximately 23% ($p<0.05$) less than that in the control diet which may reflect the resistance of fructans to mammalian enzymes. There were no significant differences in total tract NDF digestibilities. Total tract digestibility of energy in the JA diet was similar to that of the control ($p>0.05$). This suggests that most of the fructans which escaped digestion in the small intestine were fermented and absorbed in the colon. Total tract digestibility of crude protein total in the JA diet was 13% ($p<0.05$) less than that of the control. This suggests an increased faecal mass shifting the excretion of blood urea from urine to faeces. Deodorase® did not produce any observable effects on any ileal or total tract digestibilities of energy, CP or NDF.

The aim of the second experiment was to observe the effects of Deodorase® on growth performance and faecal VFA. Faecal samples were tested for VFA as important components of swine odour. The VFA tested included acetic, propionic, isobutyric, butyric, isovaleric and valeric acid. The pigs were fed from 8 to 105 kg live weight and randomly assigned to a control diet or a diet supplemented with 0.012% Deodorase®. There were no significant ($p>0.05$) differences in growth performance, except for an increase in feed efficiency of approximately 4% during the starter phase for animals fed Deodorase ®. There were no significant ($p>0.05$) differences in faecal volatile fatty acids except for a reduction ($p<0.05$) in the butyric acid level with the Deodorase®.

The aim of the third experiment was to determine the effects of amino acid substitution and Deodorase® supplementation on growth performance and faecal volatile fatty acids. The pigs, grown from 60 to 105 kg live weight, were randomly assigned to one of four diets. Diet 1 served as a control with soybean meal as the main protein source. Diet 2 added 0.012% Deodorase® supplementation to this base diet. Diet 3 and 4 substituted amino acid combinations of lysine, threonine and methionine for soybean meal at the levels required to maintain similar levels of these amino acids across all four diets. Diet 4 added Deodorase® supplementation to Diet 3. Average daily gain was significantly ($p<0.05$) higher in those animals treated with Deodorase®, but no differences in feed intake or feed efficiency were observed. No differences ($p<0.05$) in growth were observed with amino acid substitution. Acetic, propionic and butyric acid were significantly ($p<0.05$) lower in those diets supplemented with amino acids, with no differences observed in diets supplemented with Deodorase®. This suggests that lowering crude protein in the diet can reduce volatile fatty

acids in the faeces.

The aim of the fourth experiment was to observe the effects of JA supplementation on growth performance and manure characteristics. This study involved 45 Cotswold pigs. The pigs were on test from 20 kg to 105 kg live weight and fed diets supplemented with JA at levels of 0.0, 2.5 and 5%. Manure (including faeces, urine, waste water and feed) was collected for one week, stored in plastic drums and sampled on day (d) 55, 69, 83 and 111 after collection. A one time collection of fresh faeces was also carried out. Growth was not influenced ($p>0.05$) by JA supplementation. In the fresh faeces, isobutyric and isovaleric acid were significantly ($p<0.05$) lowe. with 2.5% JA supplementation. There were no overall differences ($p>0.05$) in manure VFA levels between treatments except for an increase in acetic acid at 5% JA supplementation. There were no overall differences ($p>0.05$) between sampling days. At d 55, valeric acid was significantly ($p<0.05$) greater at 2.5% JA. At d 69, acetic propionic, isobutyric, isovaleric and valeric acids showed significant ($p<0.05$) increases with JA supplementation. At d 83, acetic, propionic, isobutyric and isovaleric showed significant ($p<0.05$) increases and butyric a decrease, with varying levels of JA supplementation. No differences ($p>0.05$) were observed at d 111. These results suggest that faecal volatile fatty acids can be significantly affected by including JA in the diet, but the effects appear to be variable.

The aim of the fifth experiment, an offshoot of the fourth, was to determine the effects of JA supplementation on nitrogen balance. Eight Cotswold pigs weighing 80 kg were assigned to a control or 5% JA diet. There were no significant ($p>0.05$) differences in nitrogen balance.

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LIST OF ABBREVIATIONS

CP	Crude Protein
JA	Jerusalem Artichoke
NDF	neutral detergent fibre
VFA	volatile fatty acid(s)
GC	gas chromatography
AA	amino acid(s)
DP	degree of polymerization
FOS	fructooligosaccharide(s)
YE	Yucca extract
EE	Ether extract

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INTRODUCTION

Manitoba's swine industry has grown steadily since the mid 1970's. On farm inventories increased from approximately 600,000 in 1976 to a record 1.9 million by October 1, 1996. In 1996, about 3.1 million hogs were marketed in Manitoba (Manitoba Agriculture, 1997). Manitoba's large land base and the production of large quantities of relatively inexpensive grain have provided the background for this expansion. These cost efficiencies have allowed Manitoba to increase its export of pork to the U.S. and to growing markets in southern Asia. At current levels of production the province can expect to generate approximately a million tonnes of liquid hog manure in per year. The industry is also experiencing a trend toward larger but fewer units and increasing integration with the feed sector (Manitoba Pork, 1994). These larger units are able to take advantage of the economy of scale. However, these increases in size have resulted in increasingly concentrated populations of pigs, along with more concentrated stockpiles of manure.

Current feeding strategies, such has the three-phase feeding system recommended by the National Research Council (1988), have changed because of the breeding of leaner, faster growing pigs which have higher nutritional requirements than their predecessors did. However, specific nutritional requirements, particularly in terms of amino acid balance, are often not well defined or suitably matched to the needs of particular breeds or strains. As a result, although the crude protein and energy supplied is usually adequate to accommodate increased rates of growth, there is great potential for unnecessarily large amounts of excreted waste, particularly nitrogenous compounds.

The increase in both quantity and concentration of manure in a given locality

generates gaseous emissions that affect pig production in four areas: potential negative effects on animal health and performance; health hazards for those working in swine units; pollution and conflicts between residential communities and pig operations. These concerns have been the impetus for research which addresses the problem of swine odour. The objectives of these studies were to determine changes in manure volatile fatty acids and growth performance of pigs as influenced by dietary supplementation of:

1) *Yucca shidigera* extract

2) Amino acid substitution for soybean meal

3) Jerusalem artichoke

in starter-grower-finishing pig diets.

Jerusalem artichoke provides fibre in the form of inulin, which is indigestible by intestinal enzymes (Roberfroid, 1993). Some hind gut bacteria, such as bifidobacteria, are able to hydrolyse inulin and subsequently produce volatile fatty acids (Quemener et al. 1994). Yucca extracts, such as Deodorase®, appear to affect nitrogen metabolism (Mader and Brumm, 1987) and have demonstrated ammonia binding ability both *in vivo* and *in vitro* (Headon et al. 1991). Yucca extracts also surfactant properties which could influence nutrient absorption across cell membranes (Johnston et al. 1982).

The aim of the first experiment was to determine the NDF, energy and CP digestibilities of Jerusalem artichoke and Deodorase ®supplemented diets.

In addition to binding ammonia, yucca extract also appears to be capable of suppressing proteolysis by inhibiting certain bacteria and protozoa (Wallace et al. 1994). These combined abilities suggest a potential effect on the production of such faecal

compounds as volatile fatty acids while concurrently improving growth performance. The aim of the second experiment was to determine the effect of yucca extract (Deodorase®) supplementation on faecal VFA levels and growth performance in pigs.

The majority of offensive volatiles generated in pig manure are products of anaerobic fermentation of waste proteins. Substituting an appropriate combination of amino acids for a conventional protein source such as soybean or supplementing a reduced crude protein diet should support adequate growth while reducing nitrogenous waste (Latimier and Dourmand, 1993). The aim of the third experiment was to determine the effect of amino acid substitution and Deodorase® supplementation on the growth performance of the pigs and the level of faecal VFA.

Some hind gut bacteria, such as bifidobacteria, are able to hydrolyze JA inulin and produce lactic and acetic acid which may lower the pH in the large intestine. This can suppress the growth of putrefactive bacteria and, subsequently, the production some of the volatiles these organisms generate (Modler et al. 1990). The aim of the fourth experiment was to evaluate the effect of JA supplementation on faecal volatile fatty acids and on the VFA profile in manure over time, as well as effects on growth performance of the pigs and the level of faecal VFA.

Encouraging increased numbers of bifidobacteria can potentially displace putrefactive bacteria. Soluble fibres have been shown to increase faecal bulk and faecal nitrogen (Eggum, 1995). The aim of the fifth experiment was to evaluate the effect of JA supplementation on nitrogen content in faecal matter relative to urinary nitrogen.

CHAPTER ONE

LITERATURE REVIEW

Sources of Swine Odour

Odour is a complex phenomenon. More than 150 volatile compounds in swine manure have been identified (Spoelstra, 1980). Examples of these volatile compounds are presented in Table 1. Those volatiles which are most offensive generally originate from the nitrogenous components of feed. The majority of the offensive volatiles are products of anaerobic fermentation of those proteins which reach the hindgut before being absorbed by the pig (Figure 1). A few odour constituents are mammalian in origin, the end products of the pig's metabolism and are excreted in the urine.

Some of the volatiles considered to be responsible for swine odour include volatile fatty acids, phenols, indole, skatole, ammonia and other amines, as well as a variety of sulphur containing compounds (Spoelstra, 1980; Cooper and Cornforth, 1978; Miner 1977; Miner and Hazen, 1969; Yasuhara et al. 1984; Roustan et al. 1977).

Volatile fatty acids (VFA), quantitatively important components of swine odour, are generated from microbial fermentation of both carbohydrate and protein waste. Acetic and propionic acids represent about 60% and 25%, respectively, of the total amount of VFA found in pig waste (Spoelstra, 1980). Butyric acid, isobutyric acid, branched valeric acid and n-valeric acid make up 3 to 10% each of the total VFA (Spoelstra, 1980). Straight chain fatty acids are produced from both plant fibre and protein. Branched chain fatty acids, such as isovaleric, isobutyric and α-methyl butyric acid, are produced from isoleucine, valine and leucine, respectively (Spoelstra, 1980: Allison, 1978).

Table 1. Manure volatiles that contribute to swine odour

Compound	*Source materials*
Volatile Fatty acids (straight chain).....	*plant fibre and protein*
Acetic	
Propionic	
Butyric	
Valeric	
Volatile Fatty acids (branched chain)	
Isobutyric.....	*valine*
Isovaleric.....	*isoleucine*
Sulphur containing compounds	
Hydrogen sulphide.....	*sulphate, cysteine and cystine*
Methyl mercaptans.....	*methionine*
Indole.....	*tryptophan*
Skatole.....	*tryptophan*
Aromatic Compounds.....	*tyrosine*
Phenol	
P-cresol	
Ammonia.....	*urea*
Amines.....	*amino acids*
Ethylamine	
Methylamine	
Triethylamine	
Trimethylamine	

(Adapted from Spoelstra, 1980)

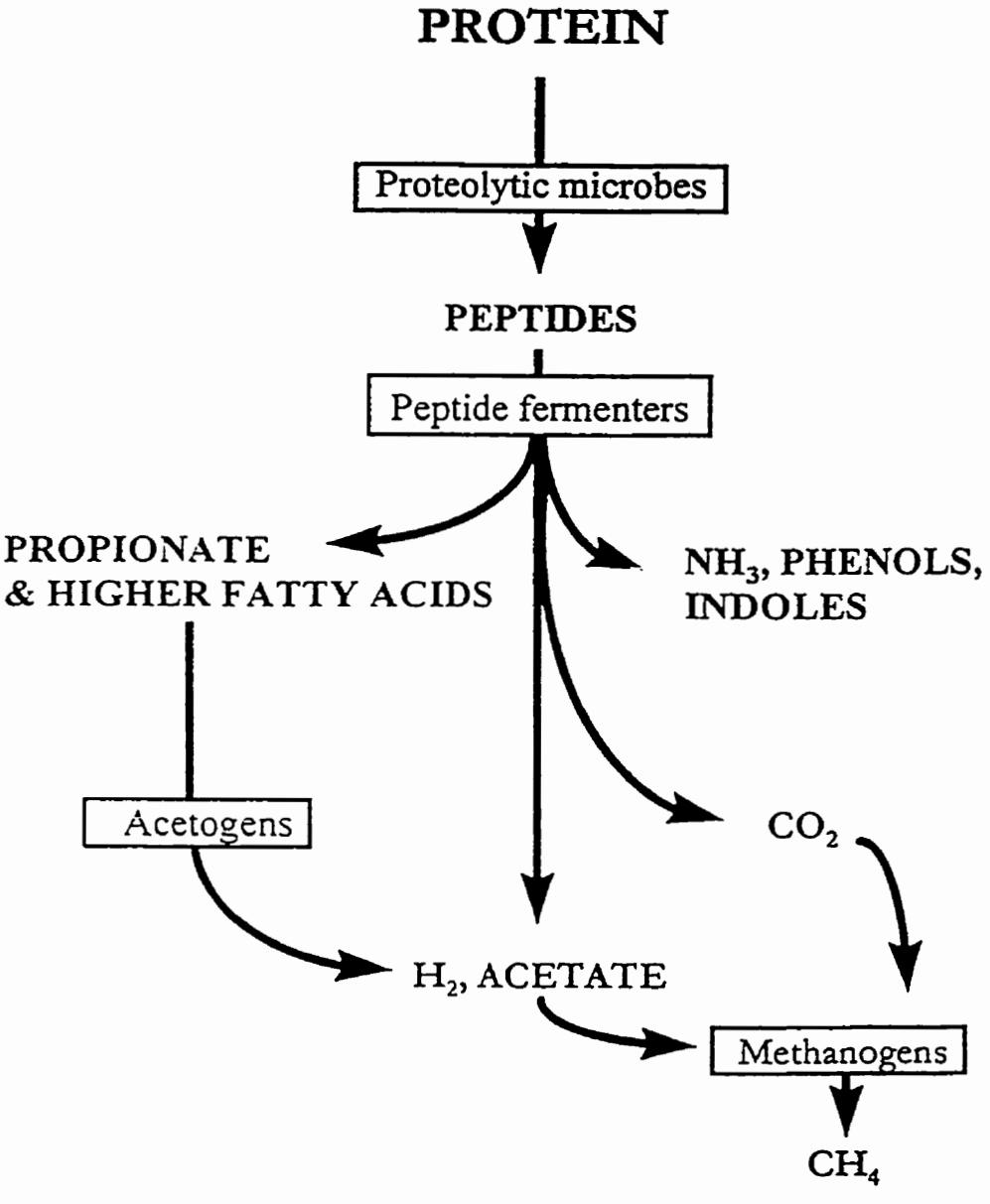

Figure 1. The pathways, products and relevant microbial populations of anaerobic protein formation (Killeen, 1996).

There are numerous sulphur containing compounds such as hydrogen sulphide and methyl mercaptans which have been detected in the head space of pig slurry. These two compounds are quantitatively the most important sulphur containing volatiles. Hydrogen sulphide results mainly from the reduction of sulphate which is contained in urine, in addition to the degradation of cysteine and cystine. Methyl mercaptans are mainly generated from the breakdown of methionine (Spoelstra, 1980).

Aromatic compounds such as phenols and p-cresol are formed as tyrosine is degraded. Phenols may be partially absorbed by the pig and detoxified by conjugation with glucuronic acid (Capel et al. 1974). These conjugates pass into the urine and phenols are subsequently released via glucuronidase which is present in faeces. The derivation of p-cresol from tyrosine involves two key reactions: the transamination of l-tyrosine forming p-hydroxyphenylacetic acid (pHPAA) and the decarboxylation of pHPAA forming p-cresol (Ward et al. 1987). This two-stage process may be a carried out by a single species or two species working in conjunction. Some strains of *Clostridium difficile* (NCIB, 10666 and ATCC9689) are able to produce p-cresol from tyrosine independently. Several other Clostridial species, as well as *Proteus vulgaris* produce pHPAA from tyrosine. A recently isolated Lactobacillus obligate anaerobe (Ward et al. 1987) decarboxylates the pHPAA forming p-cresol.

Indole and skatole are derived from the catabolism of tryptophan in the faeces. The urine may also be a source of indole by way of the breakdown of indole-3-carboxylic acid (Spoelstra, 1980). Henglemuele and Yokoyama (1990) have isolated a bacterium from caecal contents which produces both skatole and p-cresol. This gram positive rod decarboxylates

indoleacetic acid to produce skatole crystals and decarboxylates pHPAA to form p-cresol.

The release of ammonia originates with ∝-amino groups that are removed during the oxidative degradation of amino acids. If these amino acids are not used by the pig for subsequent synthesis of protein, they are channelled into ammonia which is converted into urea. Urea is released in the urine and ammonia is released by the action of urease (Lehninger et al. 1993). These pathways are outlined in Figure 2. Amines are produced by the bacterial transamination of amino acids or the decarboxylation of amino acids (Miner and Hazen, 1969). Some of those identified in head space of slurry pits include methylamine, ethylamine, trimethylamine and triethylamine (Spoelstra, 1980).

Problems Associated with Swine Emissions

Ammonia is the most common noxious gas found in animal buildings and, though rarely found in lethal conditions, has been shown to influence pig performance and health status (Swine Odour Task Force, North Carolina State University, 1995). For example, pigs exposed to 50 ppm of ammonia versus 5 ppm for short durations (20 min/day on four occasions) gained 8% less, with feed efficiencies reduced by 19% (Cole, 1996). Pigs exposed to ammonia at <5, 50 and 100 ppm and challenged with *Pasturella multocida* exhibited greater incidences of pneumonia symptoms, such as coughing and lung surface consolidation at 50 ppm (Cole, 1996). Increased levels of ammonia have also been associated with Atrophic rhinitis (Robertson et al. 1980). Mallayer et al. (1988) also found that puberty was delayed in female pigs when ammonia levels reached 20 ppm, possibly from an inhibition of pheromone detection. Ammonia is usually absorbed in the upper and lower respiratory passages causing irritation in the nose and throat. Borne on dust, ammonia can enter the

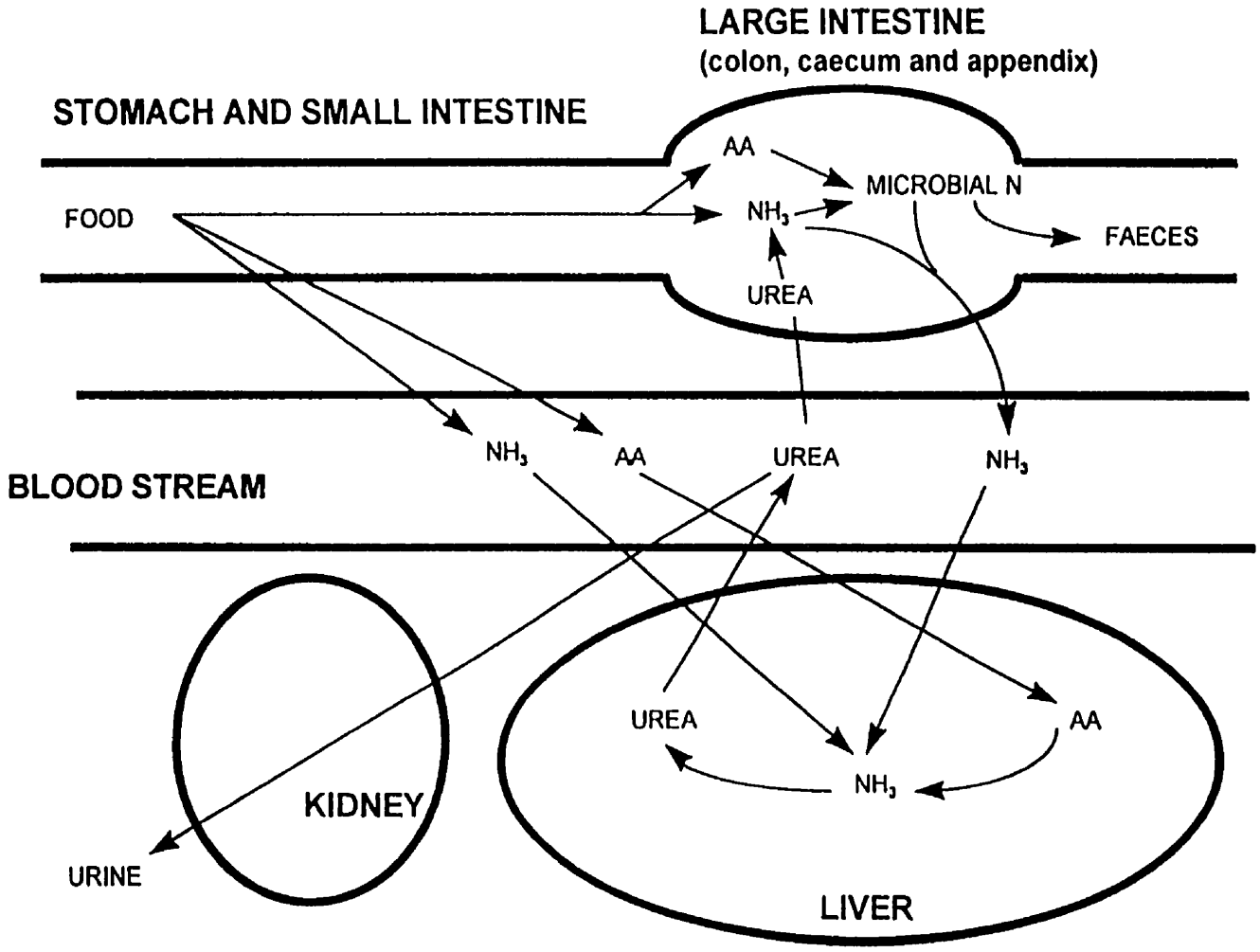

Figure 2. Gut urea cycling (Adapted from Killeen, 1996)

lungs. Ill effects, such as bronchitis, may not be noticed by barn staff immediately, but numerous cases of delayed response have been documented (Bird et al. 1992).

Hydrogen sulphide and methane are rarely released in significant amounts on a continuous basis, but when liquid manure is agitated, large amounts of hydrogen sulphide may escape (Bird et al. 1992) and can cause pig death. Animals exposed to sub-lethal doses may be more susceptible to pneumonia and other respiratory diseases. Continuous exposure to hydrogen sulphide can lead to photo phobia, anorexia and nervousness (SOTF, 1995).

It is highly improbable that the dilute levels of noxious gases found outside swine facilities are toxic (SOTF, 1995). However, the rapid expansion of the hog industry in the prairies has created more concern than any other form of livestock production (Duckworth, 1977), with the biggest problem being that of odour. Beyond the immediate nuisance to current residents, concerns have been raised about the potential decline in property values and discouragement of other kinds of economic development, especially in such aesthetically sensitive areas as tourism (SOTF, 1995). Some of the resistance to the construction of new swine units is even coming from other farmers (Duckworth, 1997). Public pressure is likely to move municipal and provincial governments to impose more restrictions and greater regulation future swine operations. This study is an effort to address the issue of swine odour.

Odour Measurement

There are essentially two approaches to odour measurement: analysis of the odorant components and organoleptic assessment (Sweeten, 1995). The former involves both characterization and measurement of concentrations of those specific gases that constitute a particular odour. Organoleptic methods determine the level and character of the odour with

the use of a human panel.

Component Analysis

Various forms of instrumental analysis have been used in attempting to isolate the components of manure odour, as well as determining their relative and absolute concentrations. The use of gas chromatography (GC)and mass spectrometry (MS) has been particularly effective in identifying volatile fractions of swine manure emissions (Yasuhara and Keiichiro, 1983). More recently, a GC system has been developed that permits the human olfactory assessment of separated volatile organic compounds as they are eluted from the GC column (Schiffman, 1995). This research should help provide a more accurate picture of those components chiefly responsible for odour complaints. Other analytical methods include gas chromatography flame ionization detection (GC-FID), steam distillation and high vacuum distillation. The latter method has proven useful in isolating compounds with high water content (Yasuhara and Keiichiro, 1983).

Ammonia and hydrogen sulphide have long been associated with animal wastes (Miner and Hazen, 1969) and there are a variety of well accepted wet chemistry methods for determining their concentrations (Miner 1977). Generally, ammonia is trapped in such acidic absorbing solutions as boric and sulfuric acid. Colorimetric analysis is accomplished with the use of Nessler's agent. Hydrogen sulphide is absorbed with zinc sulphide and its concentration may be determined by a titration or colorimetric procedure.

Detector tubes or Dräger tubes (Drägerwerk ag Lübeck, Germany) can also be used to detect ammonia and sulphide levels (Riskowski, 1991). These tubes are packed with bromo phenol blue and silver cyanide, respectively. A fixed volume of air is drawn through

these tubes. A colour change indicates a reaction with the gas of concern and corresponds to a particular concentration of that gas, typically in parts per million. These tubes are simple to use, but the amount of air passing through must be carefully controlled to avoid potential inaccuracies. Also, if the reaction is slow, the whole length of the tube may be discoloured (White et al. 1974).

Sweeten (1995) outlines a variety of electronic sensors that are being developed, which may make possible the set up of remote, automated monitoring networks. These include piezo-electronic quartz crystal devices, metal-oxide semiconductor capacitors and optical devices.

Piezo-electronic equipment uses crystals that resonate when electrically stimulated. When gas molecules land on the surface of the crystals, their mass causes a decrease in resonant frequency. The subsequent change in the device's resistance corresponds to a particular concentration. The crystals can be altered to respond to specific chemicals. A complex odorant would require multiple senors with overlapping sensitivity. Current research is investigating the use of antibodies and receptor proteins from human sensory cells, attaching these molecules to a crystal surface in an effort to imitate the human system. Electronic noses incorporating a large array of sensors may eventually provide the best blend of accuracy and efficiency. A 32-sensor array has been developed (Schiffman, 1995). However, there is, as yet, poor correlation between known odorant concentration and electronic nose readings at the level of concentration that is generally experienced in a production setting (Bulley, 1996).

Thermal semiconductor sensors are portable odour level indicators. Their main

components include a sampling pump and heated platinum coil which acts as a semiconductor. The presence of gas molecules on the coil increases thermal conductivity and reduces resistance in the device. This equipment has responded consistently to pure 1-butanol (a commonly used reference gas) and ammonia, but erratically to feedlot odour (Watts, 1992)

A similar device, employing silk screen technology, is the thick film semiconductor sensor. It has been used to monitor ammonia levels in swine buildings. However, relative humidity and the presence of other gases have impaired its performance (Berckmans et al. 1992).

Most instruments used for monitoring adherent components are designed to measure the concentration of one specific compound. There is not, as yet, a consensus on which compound(s) provides the best measure of offensiveness. The complex nature of odour confuses this issue. The composite odour may not represent a summation of individual contributions as extensive interactions may be occurring (Miner, 1977). Interestingly, many of the compounds associated with swine house odours are flavour constituents of foods (Hammond et al. 1974). Many of the volatile compounds found in wastes are not always detectable in air because of chemical reactions with the atmosphere (Spoelstra, 1980). This is especially true of reduced sulphur compounds. Also, it is unclear whether or not many of these devices are capable of providing accurate information on odour levels some distance from the source of the complaint. The low concentration of odorous compounds often exceeds the sensitivity existing analytical techniques (Miner, 1977).

Spoelstra (1980) suggests that odour indicators should (i) be a product of protein or carbohydrate degradation, (ii) be stable under storage, (iii) respond in a representative way

to environmental changes (the concentration correlating with changes in offensiveness that are produced by a particular treatment), (vi) in its formation, reflect the kinetics of waste degradation, and (v) be easy to measure (trace components, such as alcohols, aldehydes and esters, not being acceptable).

Yasuhara et al. (1984) found fatty acids and p-cresol in high concentrations in fresh urine and faeces, rotten urine and faeces and in mixtures of the latter. The concentrations of other compounds such as aromatic carboxylic acids in the urine and indole and skatole in the faeces varied considerably with digestion.

Williams (1984) treated both fresh and stored slurry aerobically over several experiments. Panellists rated samples for offensiveness during treatment and post-treatment storage and these samples were also chemically analysed. Williams (1984) found a correlation between the natural log of biochemical oxygen demand and offensiveness during treatment and in subsequent storage. Correlations between offensive the natural log of VFA, indoles and phenols were observed during post-treatment and at the limits of acceptability during aerobic treatment. Sulphide only correlated with offensiveness during post-treatment storage. Levels of ammonia provided no indication of offensiveness (Table 2).

Spoelstra (1980) judged p-cresol and VFA to be those components best suited to monitor both microbial processes and effectiveness of odour treatments. P-cresol is present in fresh faeces and is produced during storage. Volatile fatty acids are the most abundant volatiles found in waste and are produced from both carbohydrate and protein sources. Both components are strongly related to plant and protein degradation. Changes in the VFA profile need to be considered rather than simply looking at overall increases and decreases in

Table 2. Applicability of chemical characteristics for indicating the offensiveness of slurry odors.

Characteristic[1]	Context[2]	Linear equation equating to offensiveness on a scale from 0 to 5	R^3
BOD_s	AT	$(0.411 \times \ln BOD_s) + 3.16$	0.86
BOD_s	PTS	$(0.544 \times \ln BOD_s) + 2.96$	0.86
TOA	AT	---	---
TOA	PTS	$4.47 \times \log_e [(2.11 \times TOA) \times 1.86] - 2.38$	0.88
TIP	AT	--	---
TIP	PTS	$(0.415 \times \ln TIP) + 4.62$	0.85
VFA	AT	---	---
VFA	PTS	$1.91 \times \log_e [(1.2 \times VFA) \times 0.21] + 3.34$	0.84
Sulphide	AT	---	---

[1] BOD_s = Biochemical oxygen demand, TOA = total organic acids, TIP = total indoles and phenols and VFA = volatile fatty acids.
[2] AT = aerobic treatment and PTS = post-treatment storage
[3] coefficient of linear regression

(Adapted from Williams 1984)

response to treatments. Concurrent olfactory testing is also desirable.

Organoleptic Analysis

Although organoleptic tests are the best indicators of offensiveness and sensitive to very low levels of odour, there are a number of limitations, as noted by Ritter (1989). Rapid saturation of olfactory senses by some compounds may occur. Pungent odours can cause irritation of nerves in nasal systems. There is considerable variation in the sensitivity of individuals to odours. This sensitivity can be affected by many factors including physical health, time of the day, use of perfumes, eating certain foods and smoking.

Riskowski et al. (1991) have outlined some techniques for evaluating odour from swine manure using human panels. These include ranking, rating, dilution and forced choice. Some of these techniques may be combined.

Magnitude estimation ratings may include a) rating of the strength of the odour or b) ranking the odour relative to others. Rating the strength of a particular odour requires the panelist to assign a number to a sample which corresponds to a description of strength on a predetermined scale. Reference samples, with predesignated ratings can assist in this process. Ranking does not assign a specific value to the odour and as such cannot determine the magnitude of difference. Ranking, therefore, is limited to the comparison of manure treatment and management techniques. Additionally, it is recommended that a known odour reducing treatment is included in the comparison in order to validate the results. Dilution techniques can be used in a variety of setting. The number of dilutions required to render an odorous sample undetectable is a measure of the strength of that odour. Forced choice techniques require panellists to choose between two or more air samples or odours and indicate which

is stronger.

Absorption methods lend themselves well to rating or ranking systems. Fabric swatches have been used in the evaluation of livestock odour (Miner and Licht, 1980). Cotton is the medium of choice. The use of wool swatches has been investigated, but this material tended to mask low level odours. For the purposes of comparison, the swatches should be exposed to the odorous air at standardized rates of flow and time periods and subsequently sealed to prevent futher exposure.

Dilution techniques may include dilution of liquid manure samples or dilution of odorous air emitted from such samples or directly from the source and may also include the analysis of ambient odours some distance from the source. Liquid dilution usually requires that analysis be conducted under controlled conditions while vapour dilution techniques can be used in the lab or in the field (Ritter, 1989).

Odour dilution to threshold techniques involve dilution of the odorous sample with odour free air. A threshold value is one which marks the degree of dilution required to bring the odorous sample to a level of concentration that is just detectable. This is distinct from recognition, where the smell is identifiable (Bulley and Phillips, 1980). That level of concentration ranges from 1.5 to 10 times higher than that required for detection (Dravnieks and Jarke, 1980). Sweeten (1995) outlines several ways of obtaining a threshold. A geometric mean of individual panelists' thresholds may be used. The more commonly used threshold level is that at which half of the panelists can detect the odour of the diluted sample and half do not. One can also plot the levels graphically and interpolate an ED_{50} value. A geometric mean may be most desirable when exponential differences between concentrations

are presented (Reddell et al. 1983).

Ritter (1989) outlines some of the limitations to be contended with in dilution to threshold methods. Differences in results can spring from observers confusing recognition with detection. A change in odour intensity is not a linear function of dilution ratio. There is a range of values for a population of observers and this must be taken into consideration when choosing panelists and/or analyzing results. It is easier to obtain definitive values for pure chemicals as opposed to more complex odorants. Dilution to threshold techniques are more likely to produce a reliable concentration range than a definitive single value.

The method of presenting samples to panelists is also an important factor in dilution to threshold methods. Descending order (from higher to lower concentrations) can quickly result in olfactory fatigue. Reddell et al. (1983) found that a random order of presentation yielded higher matching butanol concentrations than ascending. The occasional high concentration of butanol that could be experienced early on in a random presentation was probably responsible for some degree of olfactory fatigue. Still the panelists favoured this presentation because they felt that the results were more honest and valid.

The Barnebey-Cheney Scentometer (Barneby-Cheney Activated Carbon and Air Purification Equipment Co., Columbus Ohio) is a device which has been used widely in the field (Miner and Licht, 1980). It has been used in a number of U.S. States to check conformity to dilution to threshold regulations (Ritter, 1989). The Scentometer mainly consists of a Plexiglas box, two nose pieces, an activated carbon filter chamber and a series of graduated intake orifices (Sweeten, 1995). Ambient odorous air is drawn in through the intake orifices. The size of intake orifices and the combination employed determine the level of dilution. Air

is sampled through one port and relief air is drawn in through the other port via the activated carbon filter chamber. Portability, durability and ease of use mark the simple design of the Scentometer and it covers the range of dilutions relevant to most agricultural odours (Sweeten, 1995). However this device is not without potential drawbacks (Miner and Licht, 1980). In field use of the Scentometer may quickly limit the sensitivity of the observers. Complete restoration of smell may not occur between observations. Charcoal bed saturation is another concern. As well, the sort of intermittent odours which are common in animal waste situations present additional difficulties. The use of the Scentometer over some period of time may be required to establish a significant data base. Admittedly, this problem exists for any method of ambient air analysis when the air is sampled some distance from the source. In general, on site evaluation presents some problems. These include the transportation of panelists to the site and the potential for psychological bias, especially in an indoor setting.

Dynamic dilution methods supply air samples to the panelist at fixed flow rates. A stream of odorous air is mixed with a stream of odour free air (Miner and Licht, 1980). The source of the odour free air may be compressed breathing air or ambient air that is passed through carbon filters. This air may also be dehumidified to further remove odour carrying capacity. The odour free air is used for relief, as well as dilution, so that olfactory fatigue may be avoided. Air from compressed cylinders is, in practice, not completely odour free (Bundy et al. 1993) and therefore not useful for olfactometry use for samples of very low concentration, emphasizing the importance of carbon filtration. Sampling from livestock facilities requires a dilution ratio of less than 1:1000 (Bundy et al. 1993) and subsequently an extremely low sample flow rate. This can create stability and control problems. To avoid this

a two stage dilution is suggested.

A dynamic olfactometer, incorporating the features mentioned above, also commonly employs a reference gas to help set the threshold (Ritter, 1989), in an effort to eliminate some of the threshold variability that exits between panelists. This method, known as supra threshold referencing, varies the concentration of the reference gas rather than that of the odour. The gas most commonly used is 1-butanol. Butanol is nontoxic, easily obtained, possesses a relatively unique odour and can yield a large range of odour intensities by varying the concentration. The concentration matching the strength of the test odour is an indirect measure of that odour's intensity.

The air that is analyzed in the course of dynamic olfaction may be the ambient air on site or that which is collected from site and transported to the panel. Sweeten (1995) outlines some problems involved in collection and storage and notes some precautionary measures. Some potential problems include the adsorption of odour molecules on the container surface, decreasing odorant concentration and adsorption losses from plastic transfer tubing. As such, it is advisable to use Teflon, Tedlar or Mylar bags for collection, storage and transfer. These materials have low adsorptive characteristics. Mylar is the least adsorptive, but is difficult to heat seal. Bundy et al. (1993) found polyethylene bags to be adequate for collection, noting their low cost, and indicated that odour thresholds should not be affected if the samples are analyzed within 12 hours of collection. The possibility of interaction between odorant components and with the bag is still present. Bags should be spherical in shape for low surface area relative to volume, reducing the opportunity for absorption. Ideally, a new bag should be used for each sample collected and transit and storage times should be kept to a minimum.

Bundy et al. (1993) suggest that Teflon bags can be stored up to 24 hours without significant reduction in concentration.

The method of presentation also needs to be considered. Dynamic olfactometers may have anywhere from one to three sniffing ports. An example of a one port machine is the portable olfactometer (Reddell and McFarland, 1983) developed at Texas University. This olfactometer was designed for in field use. The panelist simply inhales the ambient air and compares this to the diluted butanol mixture via the port or is provided relief air via the same port. Dynamic forced choice olfactometers require the panelists to choose between two or three ports (Schiffman, 1995; Sweeten, 1995). One port, chosen at random, will be supplied with odorous air, presented at varying dilution levels, and the other(s) with clean air. The panelist is required to choose which port contains odour.

Dynamic olfactometry is currently the most widely accepted means of odour measurement (Sweeten, 1995). However, design features and operational guidelines have yet to be standardized. Accordingly, threshold values are variable, which leaves reproducibility and accuracy still in question. Jones et al. (1993) suggest that it is necessary to establish butanol threshold values for each dynamic olfactometer, each panel and each day of testing. It should be noted that standardization of panelists to 1-butanol may not assure standardization to other reference gases or to manure odour (Sweeten, 1995).

Choosing a method for odour measurement depends to some degree upon the task at hand. In general though, the current methods of odorant component monitoring appear to be inadequate for most purposes. The correlation between concentration of specific gases and offensiveness has not been clearly defined. Multi sensor devices have yet to be refined to the

point of practical and reliable use. However, research of odorant components should continue in effort to determine a characteristic profile or fingerprint for the odours in question.

Presently, an organoleptic approach is best suited for addressing nuisance complaints, setting community standards and for comparing methods of manure treatment or waste management.

Absorption media techniques provide the benefits of simplicity and low cost. The use of swatches appears well suited to comparison studies with respect to odour strength and offensiveness. However some questions remain with regards to standardization of collection, use in field conditions, where concentrations of odorants may be low, and reliability and reproducibility.

The Scentometer is simple, portable and durable and covers the range of dilutions relevant to most agricultural settings. However, its accuracy is questionable.

Dynamic referencing olfactometry is the generally the most complex, the most costly and least portable method of odour measurement. However, it is also that most likely to yield reproducible and reliable data and is to date the most widely accepted technique. It primary advantage is the control over such features as airflow and the use of a reference gas help to reduce some of the variability associated with panel assessment. As well, it can be adapted for use in both in the field (at varying distance from the odour source) and in the laboratory.

Manipulating the Diet to Affect Manure Characteristics

The feeding strategies that may be adopted to address swine odour generally fall under one of two categories. First, the environment in the large intestine may be altered in an effort

to reduce the production of obnoxious volatiles. This can be achieved by limiting the waste substrate that is available to the putrefactive flora or by encouraging the growth of desirable flora, subsequently inhibiting the growth of putrefactive bacteria. The second strategy involves feeding inert material that absorbs the volatiles that are produced. The use of absorbent material is best used in combination with other approaches, as the amounts required to produce significant effects can significantly impinge on feed efficiency.

Nitrogen efficiency

Microbial activity may be modified by reducing the amount of material that is available to bacteria in the hind gut. In odour control, the emphasis is focussed on nitrogen as it is the breakdown of nitrogenous material that appears to produce most of the offensive volatiles. Of the total nitrogen consumed by growing finishing pigs, approximately 20% is excreted in faeces and 50% in urine (Jacob, 1995). Accordingly, making nitrogen in feedstuffs more available to pig and less available to its hindgut flora should result in the production of fewer odorants. This may be achieved by increasing digestibility with the use of enzymes, using an increased amount of synthetic amino acid supplementation as substitution for conventional protein sources and with greater use of phase feeding (Jongbloed and Lenis, 1992; Hartog, 1993; Jacob, 1995). Phase feeding involves frequently adjusting the dietary composition, in areas such as protein quantity and amino acid balance, in order to meet the animal's changing nutritional needs as related to growth and other physiological changes. Typical corn-soybean meal-based diets usually supply an excess of amino acids and a number of amino acids, such as cystine, methionine, threonine and tryptophan, are now commercially available (Easter et al. 1993). The use of a beta-adrenergic agonist may facilitate more efficient nitrogen use by

partitioning nitrogen toward increased skeletal muscle accretion and possibly lowering nitrogen excreted in the waste (Easter et al. 1993).

Gatel (1993) suggests that diets should be formulated on a digestible protein basis rather than on a crude protein basis. Efforts to provide adequate protein can lead to an overall excess of nitrogen if a significant fraction of this protein is not easily digestible. Liebert (1993) contends that efficient nitrogen utilization is more dependent on amino acid balance and level of protein intake than protein digestibility. Improving nitrogen efficiency in feeding requires a greater knowledge of amino acid digestibility and requirements at every stage and type of production (Jongbloed and Lenis, 1992) and should include formulating diets to meet the needs of specific genotypes.

Recent research has shown that crude protein content in the diet can be significantly reduced with no detriment to pig growth performance. Tuitoek et al. (1997) found that dietary crude protein could be reduced from 16.6 to 13% in growing pigs and from 14.2 to 12.8% in finishing pigs with no effects on pig performance, providing that there was adequate amino acid supplementation. Bolduan et al. (1992) found that weaner pigs were able to tolerate 20% lower crude protein in their diets when lysine, threonine and tryptophan are supplemented in accordance with need. The combination of crystalline amino acid supplementation and dietary protein should match the apparent ileal digestible amino acid ratios in an assumed ideal protein (Tuitoek et al. 1997). An ideal protein is that which provides a complex of available amino acids which perfectly meet the pig's metabolic requirements for maintenance and growth.

Even relatively small decreases in dietary protein may result in substantially reduced

nitrogen output in the faeces and urine. Jacob (1995) suggests that a 1% decrease in total protein along with lysine and methionine supplementation can result in a decrease in nitrogen excreted by as much 8.5% and that nitrogen excretion may be lowered by as much as 20% if a 2% decrease in total protein nitrogen is accompanied with even further amino acid supplementation that included threonine and tryptophan. Jacob (1995) also indicated that the use of multi phase feeding, altering protein content weekly, can effect a 10% decrease in nitrogen output for Large White boars and 20% decrease in nitrogen output for Large White barrows. In addition to reducing nitrogen output, multi-phase feeding should result in greater feed efficiency than conventional feeding strategies. Since changes in diet are more frequent in multi-phase feeding, the pig is less likely to receive an excess of nutrients.

Latimier and Dourmad (1993) investigated the effects of crude protein (CP) reduction combined with amino acid supplementation in the diets of grower and finisher pigs. The first group was fed diets containing 17.8 and 17.1% CP (for growers and finishers, respectively), the second group was fed 17.8 and 15.4% and the third, 16.2 and 13.5%. All diet sets were supplemented with synthetic lysine in order to maintain an 8.5 and 7.5 g of lysine per kg of feed in the diet, for the grower and finisher diets respectively. They found that growth rate and feed conversions were similar. Dressing percentage decreased in response to protein content decrease, but muscle percentage at slaughter was unaffected. The decrease in dressing percentage was attributed greater development of organs. The nitrogen content of the slurry was concomitant with the reduction of CP in the diets with the pigs producing 2.85, 2.64 and 2.10 kg/pig, respectively. The decline in estimated nitrogen emissions, at 1.10, 0.97 and 0.83 kg/pig, also followed the reduction in CP levels.

Sutton et al. (1996) varied dietary nitrogen levels in swine diets and chemically analysed caecal contents, fresh manure and manure stored in simulated anaerobic systems. The diets were as follows: 10% CP (deficient), 10% CP with AA supplementation, 13% CP (standard) and 18% CP (excess). The AA supplemented diet produced 17 to 18% lower Total Kjedldajl Nitrogen (TKN) in cecal contents than the high protein diets. The AA supplemented diet also produced 20 to 41% lower TKN in the fresh manure than the other diets, as well as lower pH.

Feed Additives

Reducing waste nitrogen is useful in reducing the substrate available for the production of undesirable volatiles. However, some undigested material will invariably reach the hindgut. Feed additives currently being investigated influence the formation and release of volatiles further down the sequence of production. Three additives presently being examined include Jerusalem artichoke (JA), yucca extract and zeolite. The mode of action of JA is to provide a substrate to encourage the growth of desirable intestinal bacteria, subsequently suppressing the growth of putrefactive bacteria. Yucca extract has demostrated both absorptive characteristics and the potential to alter the intestinal microbial profile. This extract has been shown to influence the metabolism of putrefactive bacteria, slowing down peptide fermentation. Additionally, the ammonia that is produced can be bound by some fractions of yucca extract. Absorptive materials like zeolite do not directly impinge on the degradation of nitrogenous waste, but are able to mop up large quantities of such volatiles as ammonia. The net potential effect of each of these additives is a reduction in volatiles released in the manure along with the improved health and growth resulting from reduction or removal

of toxic microbial products.

Jerusalem Artichoke

Jerusalem artichoke (*Helianthus tuberosus*), also known as the wild sunflower, is native to temperate North America (Chubey et al. 1985). The Jerusalem artichoke (JA) differs from other *Helianthus* species in its production of tubers (Chubey et al. 1985), which are formed underground on the ends of short stolons. The tubers are tan coloured with white flesh (Chubey and Dorrell, 1982). They range in appearance from round knobby clusters at the base below the main stem to small, smooth and roundish bodies up to 1.6 m from the plant. The tubers are of particular interest because they contain significant quantities of inulin, a chain of fructose units.

The JA begins its growth early in the season, after the soil temperature is above freezing (Chubey et al. 1985). The tubers are initiated at the onset of flowering in August and enlarge until the tops are killed by severe frost. The JA will grow in most soils, but does best in light, well-drained soils such as sandy loam and sandy clay loam. These types of soils will produce more uniform tuber development and make harvesting easier. Generous tuber yields require ample moisture. Tubers may be harvested in the fall or spring, but the composition of the tubers will differ (Chubey and Dorrel, 1974; Chubey et al. 1985; Kiehn and Chubey, 1985) (Table 3).

The plant is very hardy and has no serious insect pests (Chubey et al. 1985). However *Sclerotinia sclerotiorum*, can cause rot, in the field and in storage. The thin skins of the tubers leave them vulnerable to physical damage. Long term storage may be accomplished by slicing and drying to a moisture level of 10%, but this process may be not particularly economical.

Table 3. Relative percentage of soluble fructo-oligosaccharide components in Jerusalem artichoke tubers (cultivar Columbia) stored at 5°C for up to 16 months.[1]

Dp[2]	Duration of storage (5°C)			Std deviation[3]
	2 weeks	12 months	16 months	
1	< 1 to 1.0	6.0	12.3	1.08
2	10.0 - 12.0	32.7	40.9	1.08
3	7.5 - 9.0	16.1	17.6	1.11
4	6.5 - 8.5	12.4	10.9	0.44
5	7.0 - 9.0	9.4	6.8	0.26
6	8.0 - 9.0	7.2	4.7	0.19
7	7.5 - 8.0	5.1	2.9	0.20
8	6.5 - 7.0	3.6	1.6	0.22
9	6.0	2.4	1.1	0.26
>9	30.0 - 39.0	5.2	1.3	2.07

[1] Trimmed, washed and stored in 6 ml polyethylene bags. Planted in April/87 and harvested in Nov/87
[2] Degree of polymerization
[3] Standard deviation based on 15 samples

(Modler et al., 1993)

Modler et al. (1993) found that trimmed and washed JA tubers could be stored for one year in polyethylene bags at 2°C, with virtually no microbial or fungal spoilage. Small buds and rootlets developed on tubers stored at 5 °C for four months, which were not evident in tubers stored at 2°C.

The Columbia variety of JA, developed at the Morden Research Station in Manitoba, is biased in its growth toward tuber production (Chubey et al. 1985). This high tuber output, along with its suitability to the Manitoba environment, make the Columbia variety the best choice for cultivation for swine diets. The top growth reaches a height of 1.35 to 1.7 m and the plant usually produces 4 to 10 basal branches. Each plant produces 20 to 25 large tubers. Tuber yield is in the range of 30 to 75 tonnes per hectare (Kiehn and Chubey, 1985).

The nutritional value of the tuber lies close to its outer surface (Chubey et al. 1985). The dry matter and the sugars it contains decrease from cortex to pith and from stem to bud end (Mazza, 1985). Dry matter content is approximately 20%. Seventy to eighty per cent of the dry matter is composed of inulin (Chubey and Dorrell, 1982).

Fructans

Fructans are naturally occurring polymers, found in variety of plants (Fishbein et al. 1988) including onion, asparagus root, wheat triticale and the tubers of JA (Hirayama et al.1993) and act as energy stores in place of starch (Miller 1973). Fructans are categorized by the number of fructose units (β-D-fructofuranose), or the degree of polymerization (DP), that make up the compound. The DP that characterizes fructans is much less than other types of dietary fibre or starch. Fructans have low molecular weights of up to about 3500 (Roberfroid et al. 1993). The fructose chains are anchored by a sucrose unit, non reducing

d-glucopyranose, and are joined by β(2→1) glycosidic linkages (Fishbein et al. 1988; Miller, 1973; McKellar and Modler, 1989; Roberfroid et al. 1993). Fructans with a higher DP (20 to 60 or more) are generally classified as inulin while those with a lower DP (2 to 20) are called fructosugars, fructo-oligosaccharides (FOS) or oligofructose (Roberfroid, 1993). Neosugar, a sweetener developed in Japan, has approximately 1 to 3 fructose units (Fishbein et al, 1988). The structure of fructans is shown in Figure 4.

Inulin takes on the form of a cylindrical helix (Middleton 1977). It is an intracellular component (Quemener et al. 1994), rather than a cell wall component, and is sparingly soluble in water, with solubility increasing dramatically as temperature rises (Wesenberg, 1988). In storage, inulin converts to lower related fructosans (Modler et al. 1993). Caloric values of fructans are significantly lower than those for digestible carbohydrates, with the caloric value of a fructosyl unit of oligofructose calculated to be 25-35% that of a digested molecule of hexose or approximately 1 kcal/g (Roberfroid et al. 1993; Quemener et al. 1994).

Oligofructose is a product of partial enzymatic hydrolysis of inulin and exists as a linear polymer (Roberfroid et al.1993; Quemener et al.1994). Inulin and oligofructose may be categorized as dietary fibre as they are carbohydrates that resist hydrolysis by monogastric alimentary enzymes but are fermented by some colonic micro flora (Roberfroid, 1993).

Bifidobacteria

Bifidobacteria, natural residents of the hindgut, are Gram-positive rods, bifid rods or branching rods. The name probably originates from the bifurcated forms whose branches end in clubs or balls. Morphology depends on growth media. Bifidobacteria may constitute up to 25% of the normal gut flora of man and animals. The species predominately found in pigs

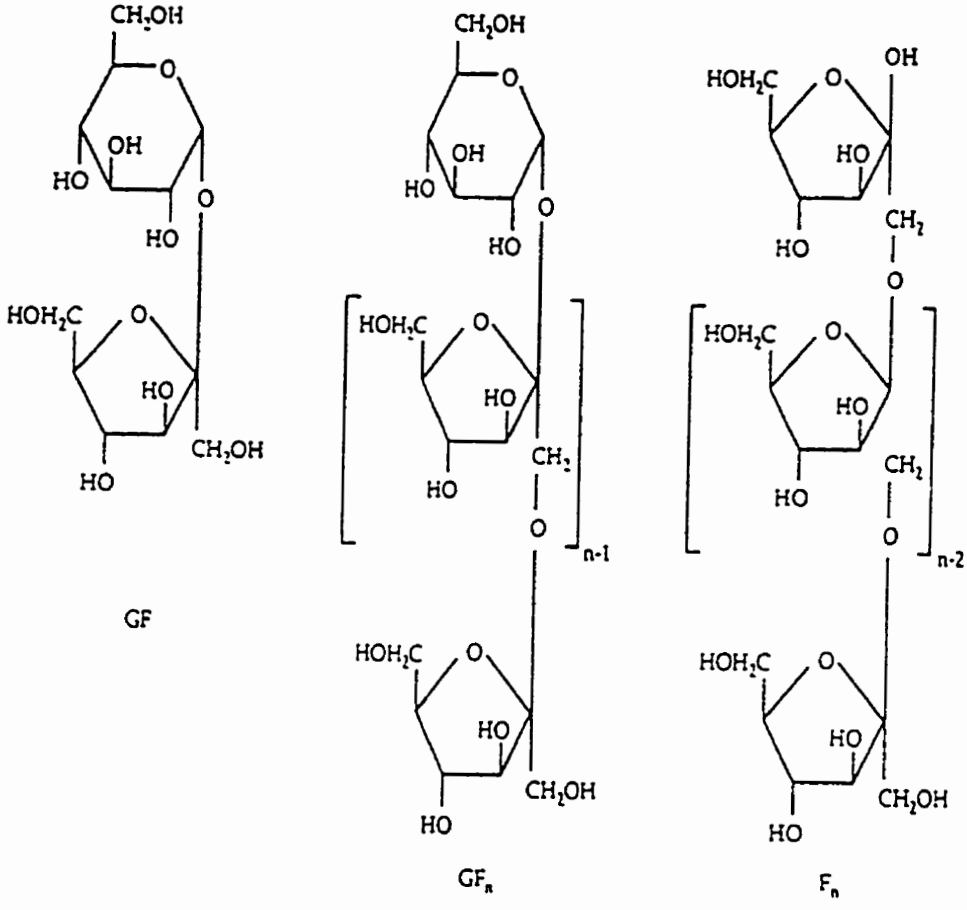

Figure 3. Chemical structure of oligofructose (Hirayama et al. 1993)

is *Bifidobacterium pseudolongum* (Type A) and *Bifdobacterium thermophilum* (Bezkorovajny and Miller-Catchpole, 1989; McKellar and Modler, 1989; Modler et al. 1990). Zani et al. (1974) identified 52 strains of bifidobacteria from specimens of piglet faeces.

Bifidobacteria are classified as anaerobes but demonstrate widely varying ability to tolerate oxygen, with some species being obligate anaerobes and others being able to tolerate oxygen in the presence of carbon dioxide (Bezkorovainy and Miller-Catchpole, 1989; Modler et al. 1990).

Bifidobacteria can use a variety of carbon sources including such carbohydrate type compounds such as lactose, glucose, galactose, sucrose and fructose. However, those actually fermented in the colon will include only those that reach the large intestine undigested. As such, most simple sugars and those produced by the action of pancreatic enzymes will be absorbed prior to reaching the bifidobacteria population (Bezkorovainy and Miller-Catchpole, 1989). However, these bacteria are unusual in being able to hydrolyse fructans. Both *B.longum* and *B. thermophilum* have been shown to produce cell-associated β-fructocidases or inulinases (McKellar and Modler, 1989).

In addition to a carbon source, only a limited number of nutrients are required for growth: biotin, pantothenate, cysteine or cystine and possibly certain metals (Bezkorovainy and Miller-Catchpole, 1989; Modler et al. 1990) such as Mn, Zn, Cu and Fe.

Bifidobacteria produce lactic and acetic acid in their metabolism of FOS (Fishbein et al. 1988; Hirayama et al. 1993) in an approximate ratio of 3:2, without the production of carbon dioxide (Bezkorovainy and Miller-Catchpole 1989; Modler et al. 1990). Additional volatile fatty acids, excluding butyric and propionic acid, are also produced from the

fermentation of FOS (Quemener et al. 1994; Roberfroid, 1993). Bifidobacteria also make thiamin, riboflavin and vitamins B and K (Modler et al. 1990).

Additionally, Bifidobacteria can utilize ammonia as a nitrogen source via glutamate dehydrogenase and glutamine synthetase, excreting amino acids as an end product (Bezkorovainy and Miller-Catchpole 1989).

Interaction between Fructans and Intestinal Microflora

Fructans are resistant to endogenous mammalian digestive enzymes such as alpha-amylase, sucrase and maltase (Fishbein et al. 1988; Quemener et al. 1994; Hirayama et al. 1993). Hidaka (1986) incubated Neosugar in human salivary enzymes with minimal digestion observed. Subsequent tests using rat pancreatic homogenate and rat small intestine homogenate yielded similar results. Fructans are generally believed to pass through the stomach relatively intact. However, Hadden and Aman (1986) reported that 40% of the fructans of JA are hydrolysed in the stomach.

Intestinal populations of bifidobacteria have been shown to respond favourably to a variety of fructans, including those provided by Jerusalem artichoke. Yamazaki (1994) and Yamazaki and Dilawri (1990) demonstrated that Jerusalem artichoke fructans, as carbon sources, were able to support the growth of three bifidobacteria examined: *B. Infantis*, *B. adolescentis* and *B. longum*. McKellar and Modler (1989) found that *B. adolecentis*, *B. thermophilum* and *B.longum* were all able to utilize crude Jerusalem artichoke flour as a carbohydrate source. The ability of Bifidobacteria, and some bacteroides (Roberfroid, 1993), to metabolize fructans stands in contrast to many putrefactive species such as *Clostridium perfringens*, *C. Difficile* and *Escherichia coli* which are unable to metabolize these

compounds (Hidaka et al. 1986).

Encouraging the growth of bifidobacteria, with FOS or other bifidogenic factors, appears to produce a variety of health benefits, including the amelioration of diarrhea or constipation, immunity activation and anti-tumour activity (Ishibashi and Shimamura, 1993). These benefits seem to be based on the antimicrobial activity of bifidobacteria. However, bifidobacteria do not produce antimicrobial substances per se. Rather, the lactic and acetic acid produced by bifidobacteria lowers the pH in the gut, restricting or prohibiting the growth of many potential pathogens and putrefactive bacteria (Modler et al. 1990). Subsequently, the levels of toxins, volatiles and potential carcinogens that these bacteria produce are reduced. Ibrahim and Bezkorovainy (1993) were able to inhibit the growth of Escherichia coli from 30 to 43% with use of spent bifidobacterial broths. This inhibition was duplicated with the addition of 3:2 actec/lactic acid mixture such as would be produced by bifidobacteria.

Hidaka et al. (1986) observed improvements in intestinal flora, with subsequent relief of constipation, improved serum lipids in hyperlipidemia and suppressed production of intestinal putrefactive substances when human patients were given FOS in the form of Neosugar.

The ability of bifidobacteria to use ammonia as nitrogen source is combined with lowered pH to facilitate the reduction of blood ammonia levels. Ammonium ions will bind hydrogen and form non diffusible NH_4^+ and the urea splitting organisms which produce NH_3 are inhibited (Bezkorovainy and Miller-Catchpole, 1989; Modler et al. 1990). Muting et al. (1968) treated patients with bifidobatceria concentrated milk and observed a subsequent increase in bifido numbers along with a significant decrease of blood ammonia, free serum

phenols and free amino nitrogen. Additionally, there was a significant decrease in the excretion of free phenols and free amino acids in the urine.

Feeding Fructans to Pigs

Fructan supplemented diets have demonstrated the potential to produce a variety of improvements in health, growth performance and faecal characteristics.

Howard et al. (1993) supplemented liquid neonatal pig diets with FOS at the level of 3g/L in order to investigate potential effects of colonic micro flora populations and epithelial cell proliferation. The addition of FOS did not alter the number of caecal bifidobacteria or the number of proximal colonic bifidobacteria. However, caecal epithelial mucosa demonstrated increased cell density.

Bunce et al.(1995) found that FOS in weanling pig diets was able to confer protection from an *E. Coli* challenge. Additionally, p-cresol, indole and skatole decreased by approximately three fold in faeces produced from the supplemented diets.

Farnworth et al. (1991) supplemented piglet milk replacer with JA flour at 2% of a dry matter mix. The JA fed pigs consumed less milk and in 2 of 3 experiments gained less weight than their control counterparts.

Pigs fed diets supplemented with FOS, in the form of JA flour or purified Neosugars, at the level of 1.5% produced no significant changes in faecal smell, VFA or microbiological profile (Farnworth et al. 1992).

Farnworth (1994) supplemented weaned pigs' diets with raw or dried JA, at levels which ranged from 1 to 6%. Pigs whose diets were supplemented with raw or dried JA had greater weight gains. There were no significant differences in feed intake or feed efficiency.

Both diets produced increases in faecal valeric acid.

Farnworth (1995) examined the effects of macerated JA supplementation, at inclusion rates of 0, 1, 3 and 6%, on manure composition and characteristics. Acetic, propionic, butyric, isobutyric and isovaleric (but not valeric) acid content rose significantly in faeces produced from JA supplemented diets. Additionally, the faecal smell was judged to be significantly sweeter, less sharp and less pungent and possessing less of a skatole smell, at the 3 and 6% level of supplementation.

In general, feeding fructans to pigs appears to produce an increase in fecal VFA with a concurrent suppression of production of such volatiles such as p-cresol, indole and skatole along with potential weight gain. The latter may be attributed to reduced toxic effects and absorption of VFA as an energy source.

***Yucca schidigera* extract**

The *Yucca schidigera* is a desert plant which has been used as a forage in Mexico and the desert southwestern US. It has long been used by indigenous populations of the American southwest as a therapeutic agent, has been approved as an additive for human consumption in the US and is commonly used as a flavouring or foaming agent. Extracts of this plant, marketed by a variety of firms, under different trade names, have also demonstrated some potential for odour control in livestock and associated waste systems, along with improvements in growth performance (Killeen et al. 1994; Lyons, 1994).

Yucca extract (YE) contains a variety of steroidal glycosides or steroid saponins collectively known as sarsaponin (Hussain et al. 1996; Wallace et al. 1994). Killeen (1996) suggests that YE may slow peptide fermentation. Both increases and decreases in protein

degradation have been observed in the rumen, as well as the suppression of ciliate protozoa (Wallace et al. 1994). Caecal protein metabolism may be similarly affected in swine. Steroid saponins cannot pass through the epithelial membrane. Therefore, their effects must be manifested within the gut. Saponins have surfactant properties and may therefore condition cell membranes enhancing nutrient absorption across cell membranes (Johnston et al. 1982).

Yucca extract has demonstrated the ability to bind ammonia (Headon et al. 1991). The effectiveness of yucca extract in reducing ammonia levels in a variety of contexts was originally attributed to an inhibition of the enzyme urease because ammonia levels were used as a measure of urease activity (Killeen 1995). However, chickens do not produce urease and yucca extract has been shown to control levels of atmospheric ammonia in poultry houses (Headon et al. 1991). Headon et al. (1991) measured urease activity with radioactive marking rather than ammonia levels. They discovered that low concentrations of yucca extract did not affect urease activity and that increasing concentrations were associated with an increase in urease activity. Killeen et al. (1994) did find that yucca extract weakly and nonspecifically inhibited urease activity *in vitro*, but not at a rate that accounted for the *in vivo* effects on ammonia inhibition that are often observed when yucca extract is added to feed or manure at very low inclusion levels. Headon et al. (1991) also found that the steroidal saponins are not the component of yucca extract responsible for ammonia binding. Yucca extract extracted with butanol yielded two phases: butanol soluble and water soluble. The steroidal saponins in the butanol fraction demonstrated no binding ability in contrast to the water soluble fraction.

Yucca Extract as a Feed Additive

Yen and Pond (1993) supplemented weanling pig diets with the Yucca extract Microaid more than 56 days. There were no differences in growth rate observed with supplementation. Gipp et al. (1988) supplemented weanling diets with yucca extract in two 39 day starter trials, with no observed influence on growth performance parameters.

Mader and Brumm (1987) feed the extract Sarsaponin, a steroid saponin, to grower and grower-finisher swine. Sarsoponin had no significant effect on any performance characteristics except for improvements in feed efficiency in the finisher phase. Since the growers and grower-finishers were housed in the same building, the feed efficiency was not attributed directly to ammonia levels in the air.

Cole and Tuck (1995) found that a pig unit housing swine fed the yucca extract Deodorase® had significantly lower levels of environmental ammonia compared with their control counterparts. However, the drop in environmental ammonia did not occur until after the fourth week of a seven week period. The pigs on supplemented diets also grew 9.4% more quickly.

Zeolite

Even the most efficacious feeding strategies will not completely eliminate the production of all offensive odours. As such, dietary supplements that act as odour absorbers or adsorbers may augment the feeding approaches discussed above. Dietary odour absorbers include calcium bentonite, sagebrush, charcoal and zeolite (SOTF, 1995), and can be added to the slurry as well as the feed.

Zeolites are crystalline, hydrated alumino silicates of alkali and alkaline earth cations.

Like feldspar and quartz, they are tektosilicates. That is, they consist of three-dimensional frameworks of SiO^{-4} tetrahedra with shared oxygen in the corners that effectively reduces the Si:O ratio to 2:1. (Mumpton and Fishman, 1977). Zeolite molecules can be natural or synthesized (Shurson et al. 1984).

The interconnecting channels and voids that make up zeolite structure are very open compared with other tektosilicates. Under normal conditions, these voids are filled with water. However, up to 50% of the volume dehydrated zeolites is represented by open space. Zeolites are able to act as molecular and ionic sieves (Mumpton and Fishman, 1977; Shurson et al. 1984).

The types of gas that can be captured depend on the species of zeolite. Zeolite species are often differentiated by the degree that silicone is replaced by aluminum and other elements. The metallic ions of alkali and alkaline earth elements are loosely bonded to the framework and can be easily exchanged by washing with a strong solution of another ion. The ion exchange capacity is proportional to the degree of aluminum substitution, as aluminium imparts an increase in charge deficiency. Zeolites of different species have demonstrated varying ability to bind ammonia (Barrington and El Mouedheb, 1995; Mumpton and Fishman, 1977; Shurson et al. 1984).

Zeolites have been used in Japan for years to control the malodour of animal wastes and appear to substantially increase feed efficiencies of chickens and pigs (Mumpton and Fishman, 1977). Japanese and American research also suggests that the incidence of scours in young swine may by reduced with dietary supplementation of zeolite (Mumpton and Fishman, 1977; Marsh, 1982).

Shurson et al. (1984) supplemented swine diets in with varying levels of two species of zeolite, zeolite A or clinoptilolite, in order to determine potential effects on urinary p-cresol excretion, among other parameters. Both free and conjugated forms of urinary p-cresol were linearly reduced with increasing levels of clinoptilolite. However, feed efficiency was decreased in pigs fed diets supplemented with 5% clinoptilolite.

Airoldi et al. (1993) added zeolite to swine rations in farm settings, at 0 and 5%, and to slurry in a laboratory setting, at 0, 5 and 10% in order to determine effects on feed efficiency and ammonia emissions. No significant differences were observed in ammonia emissions in on farm tests or feed efficiencies. Zeolite supplementation at 10% produced significant differences in ammonia emissions in the laboratory slurry tests.

Zeolite supplementation appears to produce inconsistent results. Further research is warranted to determine which species of zeolite are most effective in effecting changes in odour and how such zeolites act in combination with other odour combatting feed strategies.

EXPERIMENTS

MATERIALS AND METHODS

Animal Care

The experimental proposal, surgical procedures and procedures for care and treatment of gilts were reviewed and approved by the University of Manitoba animal Care Committee. The animals used in this experiment were cared for in accordance with the guidelines established by CCAC (1980).

Jerusalem artichoke: Agronomy

Seed artichokes were supplied by the Morden Research Station and planted in a 0.22 hectare plot at the Carman Research Station. Prior to seeding, the plot was treated with 23-24-0 at the rate of 120 kg/ha. Also, Treflan EC was applied at the rate of 120 L/ha and disc incorporated twice at right angles using a tandem discer. The artichokes were planted using a potato seeder. Mature artichokes were harvested in the fall and in the following spring, mostly by hand. Jerusalem artichoke tubers were cut, dried and ground and subjected to proximate analysis in order to determine the following parameters: DM, FE, NDF, EE, Ca, Phos, CP and AA (Table 4).

Proximate Analysis

Feed, freeze dried digesta and freeze dried digesta samples were ground and subsamples were taken for for analysis. Proximate analysis of JA, feed, ileal digesta and/or faeces was carried out using the methods of by AOAC (1984). Energy content was determined with the use of a Parr 1241Adiabatic Calorimeter with a 1720 Calorimeter Controller (Parr Instrument Company, Moline, Illinois). The percentage of nitrogen was

Table 4. Proximate analysis of Jerusalem artichoke tubers

Dry matter (%)	19.37
Gross Energy (kcal/kg)	3862
Chemical Analysis , % (dry matter basis)	
Protein	10.96
Ether Extract	1.04
Neutral Detergent Fibre	6.52
Calcium	0.20
Phosphorus	0.29
Lysine	0.29
Methionine	0.05
Cystine	0.10
Threonine	0.21
Aspartic Acid	0.97
Serine	0.27
Glutamic acid	1.42
Proline	0.21
Glycine	0.18
Alanine	0.33
Valine	0.20
Isoleucine	0.15
Tyrosine	0.20
Phenylalanine	0.34
Histidine	0.43
Arginine	1.67

determined using the Kjeldahl method and a Tecator Kjeltec Auto 1030 Analyzer (Tecator, Höganäs, Sweden). Fat content was determined using a Goldfisch type extractor by Laboratory Construction Company (Kansas City, Missouri) with ether as the solvent. Neutral detergent fibre was extracted from samples by boiling with neutral detergent buffer and heat stable amylase (Sigma A3306, Sigma Chemical Company, St. Louis, Missouri) using Tecator Fibertec System 1021 Hot and Cold extractors (Tecator, Höganäs, Sweden). Calcium, phosphorus and chromium levels were determined by atomic absorption using an Instrumentation Laboratories IL551 Atomic Absorption Spectrophotometer (Wilmington, MA).

Amino acid levels were determined using the methods prescribed by AOAC (1984) as modified by Mills et al. (1989). This involved digestion in 6 N HCl in vacuo for 16 hours, followed by quantification using an LKB 4151 Alpha AA analyser (LKB Biochrom Ltd. Cambridge, England). Samples for the analysis of methionine and cystine were prepared by using performic acid oxidation followed by acid hydrolysis (Hirs, 1967).

Samples were dried in a convection oven at 102°C overnight in order to determine dry matter.

Growth Trials: Data/sample collection

Pig weights and feed consumed were determined weekly. The pigs were shipped to market at 105 kg live weight. During the grower-finisher phase fresh faecal samples were collected by the drop and grab method.

Immediately following collection of the fresh faecal samples, sub samples of 25 g of faeces was mixed with 40 ml of 0.1 N HCl, in order to stop further microbiological activity.

Five ml of strained and diluted faeces was combined with 1 ml of beta phosphoric acid. The faeces/acid solution was centrifuged at 3400 rpm for 20 minutes.

Volatile fatty acid analysis

The supernatant produced was analysed for the volatile fatty acids acetic, propionic, butyric, valeric and isovaleric using a Varian Star 3400 gas chromatograph with an 8100 Auto Sampler (Varian Chromatography Systems, Walnut Creek, California). The column temperature was 165° C for cleaning and 125° C for the sampling run. The detector and injector operated at 195° C and 175° C respectively. The column was 1828mm by 2 mm internal diameter and the packing was GP10%, sp 1200/1% H_3PO_4 80/100 Chromosorb™ WAW (Supelco Inc., Bellefonte, Pennsylvania).

The source samples were frozen, after sub sampling for VFA analysis. These samples were transferred to individual foil trays and subsequently weighed and dried at 60° C (Coldstream drying oven, Fleming Pedlar, Ltd.) and reweighed in order to determine dry matter.

Experiment 1

Diets: The basal diet consisted of barley and soybean meal. Thirty percent of ground JA was substituted for barley in the basal diet. Yucca extract (Deodorase®) was included at the level of 0.015%, as recommended by the manufacturer, in the third diet. All diets included ground chromium oxide at 0.1%. The composition of the diets is shown in Table 5. The feed was provided in mash form and water was available free choice.

Animals: Twelve Cotswold gilts with an average body weight of 48 kg were surgically fitted with a simple T-canula at the distal ileum according to the procedures adapted from

Table 5. Dietary ingredients and chemical composition of experimental diets for digestibility study.

Ingredients (g/100g)	Control	Jerusalem artichoke	Deodorase®
Barley	75.4	45.4	75.4
Soybean meal	20	20	20
Canola oil	2	2	2
Jerusalem artichoke	--	30	--
Deodorase®	--	--	0.015
Premix[1]	2.5	2.5	2.5
Chromium oxide	0.1	0.1	0.1
Chemical composition (as fed basis)			
Protein (%)	15.53	15.67	15.54
Ether extract (%)	3.62	3.63	3.98
NDF (%)	16.31	13.5	16.67
Gross energy (kcal/kg)	4002	3921	3967
Lysine (%)	0.63	0.60	0.62
Threonine (%)	0.56	0.50	0.55
Methionine + Cystine (%)	0.72	0.69	0.71

[1] Premix provides per kg: 360,000 iu vitamin A, 60,000 iu vitamin D, 725 iu vitamin E, 60 mg vitamin K, 10,000 mg choline chloride, 1,175 mg niacin, 1,000 mg calcium pantothenate, 375 mg riboflavin, 40 mg thiamine, 40 mg pyridoxine, 1000 mcg B12, 2000 mcg, 20 mg folic acid.

Sauer et al. 1983. The simple T-cannulations is a surgical procedure which involves the implantation of a simple t-canula 5 to 15 cm anterior to the ilea-caecal valve. With this technique, digesta can be collected only by spot sampling. Chromic oxide was used as the indigestible marker.

During a 14 day recovery period, the gilts were fed a 16% CP grower diet. The gilts were individually housed in stainless steel metabolism crates, with a height of 80 cm, length of 167 cm and width of 37 cm (adjustable to 110 cm). Following recovery, the gilts were fed one of the three experimental diets. Three pigs were randomly assigned to the control diet, five to the JA diet and four to the Deodorase® diet. However one of the pigs on the JA diet was taken off test because of poor feed intake. The gilts were fed 4% of their body weight, per day. They were fed twice daily, equal amounts at each meal, at 0800 and 1630. The pigs were weighed after each period and feed allowance was adjusted accordingly. Water was freely available from a low pressure drinking nipple. Room temperature was kept at approximately 20°C .

Sample Collection: The experimental period lasted ten days. Faecal samples were collected on day (d) 8 into foil trays which were placed in plastic bags. On d 9 and d 10 ileal digesta was collected for a total of 24 hours from 0800 to 1000 on d 9 and thereafter until 0800 on d 10. Ileal digesta was collected in plastic bags that were attached to the barrel of the canulae with metal tags. The bags contained 5 ml of a solution of formic acid (10% vol/vol) to minimize further bacterial activity. The bags were removed and replaced as soon as they were filled with digesta. Digesta was immediately frozen at -20°C, freeze dried and stored for chemical analysis.

Statistical Analysis: Ileal and faecal digestibilities were calculated by comparing the relative concentrations of chromic oxide in the diets, ileal digesta and faeces, according to the methods of Sah and Gilbreath (1991). The ileal digestibility of a nutrient was determined using the following equation:

ileal digestibility of nutrient =

$$\frac{\text{concentration of nutrient in feed}}{\text{concentration of chromic oxide in feed}} - \frac{\text{concentration of nutrient in ileal digesta}}{\text{concentration of chromic oxide in ileal digesta}}$$

$$\frac{\text{concentration of nutrient in feed}}{\text{concentration of chromic oxide in feed}}$$

Digestibilities were subjected to an analysis of variance using General Linear Modelling (GLM) in the Statistical Analysis System (SAS Institute Inc., 1988). The model used was $Y_i = u + t_i$, where Y_i = the digestibility of the diet, u = the population mean and t_i = the effect of the i^{th} diet.

Experiment 2

Diets: The pigs were assigned to one of two dietary treatments: a control basal diet and a basal diet supplemented with the yucca extract Deodorase® . From 8 to 20 kg live weight, the pigs were fed a wheat, corn and soybean meal based diets as shown in Table 6. From 20 to 105 kg, live weight, corn was replaced with barley as shown in Table 7. The Deodorase® diet was supplemented with the additive at the level of 0.012%, as recommended by the manufacturer (Alltech Inc., Kentucky, USA). The feed was provided in pelleted form and water was available free choice from a water nipple.

Animals: Twenty-eight 28 d old Cotswold gilts and barrows, with initial weights averaging

Table 6. Dietary ingredients and analysed chemical composition of experimental diets for yucca extract experiment for 8-20 kg pigs.

Ingredient (g/100g)	Control	Deodorase®
Wheat	36.5	36.5
Corn	20	20
Soybean meal	20	20
Fish meal	5	5
Whey	7	7
Vegetable oil	5.5	5.5
Premix[1]	5	5
Lysine	0.72	0.72
Threonine	0.28	0.28
Deodorase®	—	0.012
Chemical composition (as fed basis)		
Protein (%)	22.8	24.0
Ether extract (%)	5.6	4.8
NDF (%)	9.53	9.19
Gross Energy (kcal/kg)	4148	4136
Lysine (%)	1.55	1.44
Threonine (%)	1.02	0.95
Methionine + Cystine (%)	0.72	0.68

[1] Premix provided the following per kg: 235,000 iu vitamin A, 30,000 iu vitamin D, 1,000 iu vitamin E, 35 g vitamin K, 15,000 mg choline chloride, 760 mg niacin, 715 mg calcium pantothenate, 200 mg riboflavin, 20 mg thiamine, 20 mg pyridoxine, 550 mcg B12, 2000 mcg biotin, 10 mg folic acid.

Table 7. Dietary ingredients and analysed chemical composition of experimental diets for yucca extract experiment for 20-105 kg pigs.

Ingredient (g/100g)	Control	Deodorase®
Wheat	40	40
Barley	45.2	45.2
Soybean meal	8.5	8.5
Vegetable oil	3	3
Premix	2.5	2.5
Lysine[1]	0.8	0.8
Threonine	0.16	0.16
Deodorase®	—	0.012
Chemical composition (as fed basis)		
Protein (%)	16.3	16.1
Ether extract (%)	2.72	3.12
NDF (%)	11.44	14
Gross Energy (cal/g)	4019	4022
Lysine (%)	1.03	0.98
Threonine (%)	0.61	0.56
Methionine + Cystine (%)	0.58	0.58

[1] Premix provides per kg: 360,000 iu vitamin A, 60,000 iu vitamin D, 725 iu vitamin E, 60 mg vitamin K, 10,000 mg choline chloride,175 mg niacin, 1000 mg calcium pantothenate, 375 mg riboflavin, 40 mg thiamine, 40 mg pyridoxine, 1000 mcg B12, 2000 mcg, 20 mg folic acid.

9 kg, were randomly assigned to and evenly divided among the two diets, with one dietary treatment in each of the two rooms. The pigs were individually housed in 1.2 m x 1.8 m pens.

Statistical Analysis: Growth parameters and VFA content were subjected to an analysis of variance using General Modelling (GLM) in the Statistical Analysis System (SAS Institute Inc. 1988). The model used was $Y_i = u + t_i$ where Y_i = ADI, ADG, AFE or VFA level, u = the population mean and t_i = the effect of the diet.

Experiment 3

Diets: Barley and wheat were the main source of cereals used for the four finisher diets as shown in Table 8. Diet 1 served as a control, with soybean meal as main protein source. Diet 2 also included soybean meal as a protein source, but included Deodorase® as a supplement at 0.012 %. In Diet 3, soybean meal was replaced with lysine, threonine and methionine, at levels designed to match those that the soybean meal would otherwise provide. Diet 4 was identical to Diet 3 except for the inclusion of Deodorase® as supplement at 0.012%. The pigs were fed ad lib. All diets were pelleted and the pigs had free access to water.

Animals: Forty-eight Cotswold gilts and barrows were randomly assigned to and evenly divided among the four diets. The pigs were housed in groups of four in 2.97 m x 1.52 m pens and began the trial at an average initial weight of approximately 60 kg.

Faecal sample preparation: The faeces/acid solution was centrifuged at 3400 rpm for 20 minutes. Five ml of supernatant was combined with 1 mil of beta phosphoric acid. This second faeces/acid solution was centrifuged at 3400 rpm for another 20 minutes.

Statistical Analysis: Growth parameters and VFA content were subjected to an analysis of variance using General Modelling (GLM) in the Statistical Analysis System (SAS Institute

Table 8. Dietary ingredients and analysed chemical composition of experimental diets for yucca extract/amino acid experiment for 60-105 kg pigs.

Ingredient (g/100g)	Diet 1	Diet 2	Diet 3	Diet 4
Barley	53.5	53.48	72.4	72.38
Wheat	20.0	20.0	20.0	20.0
Soybean meal	20.0	20.0	—	—
Vegetable oil	4	4	4	4
Premix[1]	2.5	2.5	2.5	2.5
Lysine	—	—	0.7	0.7
Threonine	—	—	0.3	0.3
Methionine	—	—	0.1	0.1
Deodorase®	—	0.012	—	0.012
Chemical composition (as fed basis)				
Protein (%)	18.4	18.5	12.0	12.2
Ether extract (%)	3.6	3.5	3.9	3.7
NDF (%)	11.8	11.6	11.7	13.3
Gross Energy (cal/g)	4090	4093	4073	4080
Lysine (%)	0.82	0.78	0.82	0.81
Threonine (%)	0.63	0.61	0.62	0.62
Methionine + Cystine (%)	0.67	0.65	0.60	0.58

[1] Premix provides per kg: 360,000 iu vitamin A, 60,000 iu vitamin D, 725 iu vitamin E, 60 mg vitamin K, 10,000 mg choline chloride, 1,175 mg niacin, 1000 mg calcium pantothenate, 375 mg riboflavin, 40 mg thiamine, 40 mg pyridoxine, 1000 mcg B12, 2000 mcg, 20 mg folic acid.

Inc. 1988). The model used was $Y_{ij} = u + a_i + d_j + ad_{ij}$ where Y_{ij} = ADG, ADI, FE or a VFA level, u = the population mean, a_i = the effect of AA source, d_j = the effect of the Deodorase® supplementation and ad_{ij} the interaction of the ith AA source with the jth level of Deodorase supplementation.

Experiment 4

Diets: Barley, wheat and corn were the cereals used for the three diets. The first diet served as a control. The second diet included Jerusalem artichoke (JA) as a supplement at 2.5%. The third diet included JA as a supplement at 5.0%. Each diet was further divided into three phases, A, B and C as dictated by weight categories, 20 to 50 kg, 50 to 80 and 80 to 105 kg live weight, respectively. The diets were formulated to be isocaloric and isonitrogenous, within each phase (Tables 9 to 11). The pigs were fed ad lib. The feed was pelleted and the pigs had free access to water.

Animals: Forty-five Cotswold gilts and barrows, with an average initial body weight of 23 kg, were randomly assigned to and evenly divided among the three diets. The pigs were housed in groups of three or four in twelve 2.4 m x 2.4 m pens, equally divided between three rooms. Two diets were represented in each room, thereby comprising an incomplete block design.The rooms were maintained at approximately 20° C.

Sample Collection: As the two treatments represented in each room shared a common gutter, these gutters were divided so that slurry could be collected from each treatment. Slurry contents were stirred with a hoe and collected in 205 litre plastic storage drums. Two drums were located in each room with one drum per dietary treatment. Faeces scraped from the pens was also added to the drums. Faeces and slurry contents were collected in the drums

Table 9. Dietary ingredients and analysed chemical composition of experimental diets for Jerusalem artichoke experiment for 20-50 kg pigs: Phase A.

Ingredient (g/100g)	Diet 1 (control)	Diet 2	Diet 3
Jerusalem artichoke	0	2.5	5.0
Corn	25	25	25
Barley	47.56	45.03	42.37
Soybean meal	19	19	19.13
Fish meal	2	2	2
Vegetable oil	2.96	2.98	3.0
Grower premix[1]	2.5	2.5	2.5
Lysine	0.15	0.16	0.16
Threonine	0.25	0.28	0.29
Methionine	0.49	0.49	0.49
Binder[2]	0.60	0.60	0.60
Chemical composition (as fed basis)			
Protein (%)	19.04	19.01	18.98
Ether extract (%)	4.8	4.7	5.5
NDF (%)	10.6	11.3	11.8
Gross energy (cal/g)	4129	4128	4007
Lysine (%)	0.96	0.95	0.93
Threonine (%)	0.92	0.89	0.91
Methionine + Cystine (%)	1.15	1.15	1.14

[1] Premix provides per kg: 360,000 iu vitamin A, 60,000 iu vitamin D, 725 iu vitamin E, 60 mg vitamin K, 10,000 mg choline chloride, 175 mg niacin, 1000 mg calcium pantothenate, 375 mg riboflavin, 40 mg thiamine, 40 mg pyridoxine, 1000 mcg B12, 2000 mcg, 20 mg folic acid.

[2] Bentonite (Feedrite Ltd., Winnipeg, Manitoba).

Table 10. Dietary ingredients and analysed chemical composition of experimental diets for Jerusalem artichoke experiment for 50-80 kg pigs: Phase B.

Ingredient (g/100g)	Diet 1 (control)	Diet 2	Diet 3
Jerusalem artichoke	0	2.5	5.0
Corn	25	25	25
Barley	55.15	52.58	50.01
Soybean meal	14.32	14.36	14.41
Fish meal	2	2	2
Vegetable oil	0.41	0.43	0.45
Grower premix[1]	2.5	2.5	2.5
Lysine	0.06	0.06	0.06
Threonine	0.14	0.15	0.15
Methionine	0.36	0.36	0.36
Binder[2]	0.60	0.60	0.60
Chemical composition (as fed basis)			
Protein (%)	17.19	17.76	17.71
Ether extract (%)	3.5	3.3	3.1
NDF (%)	13.3	13.6	13.7
Gross Energy (cal/g)	3979	3968	3942
Lysine (%)	0.76	0.76	0.82
Threonine (%)	0.67	0.69	0.71
Methionine + Cystine (%)	0.90	0.91	0.91

[1] Premix provides per kg: 360,000 iu vitamin A, 60,000 iu vitamin D, 725 iu vitamin E, 60 mg vitamin K, 10,000 mg choline chloride, 175 mg niacin, 1000 mg calcium pantothenate, 375 mg riboflavin, 40 mg thiamine, 40 m pyridoxine, 1000 mcg B12, 2000 mcg, 20 mg folic acid.

[2] Bentonite (Feedrite Ltd., Winnipeg, Manitoba).

Table 11. Dietary ingredients and analysed chemical composition of experimental diets for Jerusalem artichoke experiment for 80-105 kg pigs: Phase C.

Ingredient (g/100g)	Diet 1 (control)	Diet 2	Diet 3
Jerusalem artichoke	0	2.5	5.0
Corn	25	25	25
Barley	55.49	52.74	50.28
Soybean meal	15.2	15.25	15.3
Vegetable oil	0.88	0.90	0.92
Grower premix[1]	2.5	2.5	2.5
Lysine	- -	- -	- -
Threonine	0.06	0.07	0.07
Methionine	0.25	0.25	0.26
Binder[2]	0.60	0.60	0.60
Chemical composition (DMB)			
Protein (%)	17.61	17.41	17.51
Ether extract (%)	3.2	3.3	63.3
NDF (%)	14.5	13.7	13.9
Gross Energy (cal/g)	3960	3918	3920
Lysine (%)	0.72	0.67	0.69
Threonine (%)	0.66	0.63	0.63
Methionine + Cystine (%)	0.85	0.93	0.92

[1] Premix provides per kg: 360,000 iu vitamin A, 60,000 iu vitamin D, 725 iu vitamin E, 60 mg vitamin K, 10,000 mg choline chloride, 175 mg niacin, 1000 mg calcium pantothenate, 375 mg riboflavin, 40 mg thiamine, 40 mg pyridoxine, 1000 mcg B12, 2000 mcg, 20 mg folic acid.

[2] Bentonite (Feedrite Ltd., Winnipeg, Manitoba).

for one week. Samples were taken from the drums at d 55, 69, 83 and 111. Prior to sampling the barrels were each stirred for 5 minutes Approximately 50 ml of sample were taken and subsequently frozen for subsequent analysis. Additionally, faeces was collected from individual pigs and was frozen for later analysis.

Faecal/Slurry Sample Preparation: In preparation for VFA analysis, the faecal or slurry samples were thawed and 25 g of sample was mixed with 40 ml of 0.1 N HCl, in order to stop further microbiological activity. The faeces/acid solution was centrifuged at 3400 rpm for 20 minutes. Five ml of supernatant was combined with 1 ml of beta phosphoric acid. This second faeces/acid solution was centrifuged at 3400 rpm for another 20 minutes.

Statistical Analysis: Growth parameters and VFA content were subjected to an analysis of variance using General Modelling (GLM) in the Statistical Analysis System (SAS Institute Inc. 1988). The model used for analysis of growth parameters, within each phase and overall, was $Y_i = u + ti$, where Yi = ADG, ADI or FE, u = population mean and t_i = the effect of dietary treatment. The model used for faecal VFA levels and overall slurry VFA levels was $Y_i = u + ti$, where Y_i = the level of VFA, u = the population mean and t_i = the effect of dietary treatment. The model for slurry analysis was $Y_{ijkl} = u + t_i + r_j + s_k + p_l + t_i*r_j*s_k + p_l*t_i + p_l*r_j + p_l*s_k$, where Y_{ijkl} = VFA level, t_i = the effect of treatment, r_j = the effect of room, s_k = the effect of sampling order, p_l = the effect of period, $t_i*r_j*s_k$ = the interaction of the ith treatment, jth room and kth sample order, p_l*t_i = the interaction of lth period and the ith treatment, p_l*r_j = the interaction of the lth period and the jth room and p_l*s_k = the interaction of the lth period and the kth sample order.

Experiment 5

Diets: Barley, wheat and corn were the cereals used for the two experimental finisher diets. The first diet served as a control. The second diet included Jerusalem artichoke (JA) as supplement at 5.0%. Chromium oxide was also included in the feed as a marker at 0.10%. The diets, shown in Table12, were formulated to be isocaloric and isonitrogenous.

Animals: Eight Cotswold gilts and barrows were randomly assigned to and evenly divided among the two diets. The pigs were housed individually in raised stainless steel metabolism crates measuring 175 cm x 47.5 cm in one room. The pigs began the trial at an average initial weight of approximately 80 kg. The pigs were given a 7-day adaptation period before sample collection began. They were initially fed 4% of their individual body weights, with morning and afternoon feedings. However this was subsequently reduced to 3%, 4 days into adaptation period, as considerable amounts of feed were leftover initially. The feed was in mash form and the pigs had free access to water. The rooms were maintained at relatively constant 20° C.

Data and Sample Collection: Following adaptation, faeces and urine were collected for 48 h. Urine was collected in screened pans below the crates. The pans contained 0.5 M H_2SO_4 in order to prevent evaporative loss of ammonia. The urine was weighed and the volume was measured. During the two-day collection period, the urine was stored in covered containers at ~2 to 4° C and subsequently sub samples were collected and frozen at -20° C. The faecal samples were also frozen and stored at -20° C. Feed intake was also measured.

Analysis: The diets were analysed for dry matter, crude protein and chromium levels. Faeces was analysed for dry matter, crude protein and chromium levels. Urine was analysed for

Table 12. Dietary ingredients and protein content of experimental diets for Jerusalem artichoke nitrogen balance experiment.

Ingredient (g/100g)	Diet 1 (control)	Diet 2
Jerusalem artichoke	0	5
Corn	25	25
Barley	56	51
Soybean meal	15.2	15.3
Vegetable oil	0.88	0.92
Grower premix[1]	2.5	2.5
Threonine	0.06	0.07
Methionine	0.25	0.26
Chromium	0.1	0.1
Biotin	0.01	0.01
Protein, % (as fed basis)	17.4	17.5

[1] Premix provides per kg: 360,000 iu vitamin A, 60,000 iu vitamin D, 725 iu vitamin E, 60 mg vitamin K, 10,000 mg choline chloride, 175 mg niacin, 1000 mg calcium pantothenate, 375 mg riboflavin, 40 mg thiamine, 40 mg pyridoxine, 1000 mcg B12, 2000 mcg, 20 mg folic acid.

nitrogen levels. Total urinary nitrogen output over the two-day trial was extrapolated from the analyzed nitrogen concentration in the samples and the know total volume. Total faecal nitrogen output was calculated using an estimate of faecal output. This estimate of output was based on overall digestibility of the feed and known weight of feed consumed. Overall digestibility is determined as follows:

overall digestibility of =

$$\frac{\text{concentration of all nutrients in feed}}{\text{concentration of chromic oxide in feed}} - \frac{\text{concentration of nutrient in ileal digesta}}{\text{concentration of chromic oxide in ileal digesta}}$$

$$\frac{\text{concentration of all nutrients in feed}}{\text{concentration of chromic oxide in feed}}$$

The concentration of all nutrients is determined by subtracting the percentage of chromic oxide from one hundred. Calculation of faecal output was determined as follows: (amount of feed consumed)(100 - overall digestibility of feed). Faecal nitrogen ouput was estimated by multiply faecal output by the percentage of nitrogen in the faeces.

Statistical Analysis: Nitrogen balance was subjected to an analysis of variance using General Modelling (GLM) in the Statistical Analysis System (SAS Institute Inc. 1988). The model used was $Y_i = u + t_i$, where Y_i = N balance, u = population mean and t_i = the effect of dietary treatment.

RESULTS AND DISCUSSION

Experiment 1

The ileal and total tract digestibilities of JA and Deodorase® supplemented diets are shown in Table 13 . Though the mean ileal NDF digestibility of the JA diet appeared to be markedly higher than that of the control (19.8% versus 13.4%, respectively), the difference was not significant ($p>0.05$). There were no significant differences ($p>0.05$) in total tract NDF digestibilities.

The ileal energy digestibility of the JA diet was 23% less ($p<0.05$) than that of the control diet (61.9 vs 47.7%, respectively). Since the fructans of JA they are not degraded by endogenous enzymes, they are expected to pass through the small intestine relatively intact (Fishbein et al. 1988; Quemener et al. 1994; Hirayama et al. 1993) though Hadden and Aman (1986) reported that 40% of the fructans of JA are hydrolysed in the stomach. Total tract energy digestibility of the JA diet was similar to that of the control ($p>0.05$). The lack of difference in total tract energy digestibilities suggests that most of the fructans that remained intact through the small intestine were fermented into and absorbed as volatile fatty acids (VFA) in the large intestine. Microbial fermentation plays a significant part in carbohydrate digestion in the pig (Kidder and Manners, 1978). If overall microbial VFA production has increased, it appears to be adequate to compensate for the lack of energy digestibility in the small intestine. Though there were no differences in CP ileal digestibilities ($p>0.05$), total tract CP digestibility of the JA diet was 13% ($p<0.05$) less than that of the control (61.5% and 70.9%, respectively). This may be a reflection of an increased colonic bacterial mass, particularly bifidobacteria, rather than inferior dietary CP utilization. Soluble dietary fibres

Table 13. Ileal and faecal digestibilities of control, JA and Deodorase® diets.

	Ileal digestibilities of NDF (%)	SEM
Control	13.4	8.4
JA	19.8	7.3
Deodorase	17.5	7.3
	Ileal digestibilities of Energy (%)	
Control	61.9 a	3.1
JA	47.7 b	2.7
Deodorase	57.1 ab	2.7
	Ileal digestibilities of CP (%)	
Control	61.9	2.8
JA	68.2	2.4
Deodorase	66.6	2.4
	Total tract digestibilities of NDF (%)	
Control	27.6	5.6
JA	23.7	4.8
Deodorase	32.0	4.8
	Total tract digestibilities of Energy (%)	
Control	73.2 a	1.1
JA	70.8 b	1.0
Deodorase	71.6 ab	1.0
	Total tract digestibilities of CP (%)	
Control	70.9 a	2.1
JA	61.5 b	1.8
Deodorase	65.2 ab	1.8

Different letters denote significant differences at $p < 0.05$

have been shown to increase faecal bulk and faecal nitrogen (Eggum, 1995). Fermentable fibres, including fructooligosaccharides, have also been shown to increase urea disposal in the rat cecum (Younes et al. 1994).

The results from the JA portion of this study suggest that JA warrants consideration as a routine dietary supplement, as total tract digestibilities of this diet (with the exception of crude protein) were similar to the control. Growth trials, using varying levels of JA supplementation, are required in order to determine effects on performance. Total colonic VFA production and absorption and individual VFA levels should be examined. Total tract CP digestibility results suggest, superficially, that CP utilization is inferior to conventional dietary sources. However, given the insignificant absorption of protein digestion products in the colon, it is more likely that the differences in total tract digestibility suggest a shift in the ratio of nitrogen excretion from urine to faeces. Future JA studies should examine the effects on this ratio, as well as colonic bacterial mass and profile, with particular attention to bifidobacteria.

Deodorase® has surfactant qualities which could potentially affect nutrient absorption (Johnston et al. 1982). Additionally, it has exhibited some ability to bind ammonia (Headon et al. 1991) and influence protein degradation in the rumen (Wallace et al. 1994). However no differences ($p>0.05$) were found between the Deodorase® diet and the others in any of the digestibility parameters examined.

Experiment 2

There were no significant differences in ADFI and ADG, as shown in Table 14. Deodorase® supplementation improved feed efficiency by 4% ($p<0.05$) in the starter phase.

Table 14. Performance of pigs fed Deodorase®

Diet:	Control	Deodorase®	SEM[1]	p value
(9-20 kg)				
ADG (g)	707	682	26	0.49
ADFI (g)	1151	1058	47	0.17
F/G	1.62 a	1.55 b	0.02	0.03
(20-105 kg)				
ADG (g)	1005	1061	38	0.84
ADFI (g)	2869	2779	123*	0.61
F/G	2.90	2.74	78	0.14
(9-105 kg)				
ADG (g)	844	829	28	0.71
ADFI (g)	1971	1838	88	0.30
F/G	2.34	2.25	38*	0.11

[1] S]tandard error of means (* indicates averaged SEM)
Different letters denote significant difference ($p<0.05$)

There were no differences ($p>0.05$) in faecal volatile fatty acids except for a reduction ($p<0.05$) in the level of butyric acid as shown in Table 15.

The increased feed efficiency may be due to the suppression of ammonia. Ammonia can exacerbate a variety of respiratory diseases in swine (Visek, 1984). The stress of ammonia toxicity could lead to reduced feed efficiency. Deodorase® may influence the production of other nitrogen sourced volatiles that produce toxic and subsequently growth inhibiting effects. Additionally, the surfactant quality of saponins may have affected nutrient absorption by conditioning cell membranes (Johnston et al. 1982). Similarly, the intestinal microbial profile may have been altered to enhance beneficial or harmless bacteria while suppressing the growth of others. Improvements in feed efficiency were only observed in the starter phase. This suggests that younger animals may be more vulnerable to the effects of toxic volatiles. Mader and Brumm (1987) noted improvements in feed efficiency in the finisher phase when diets were supplemented with yucca extract. Yen and Pond (1993) and Gipp et al. (1988) did not observe any differences in growth performance when feeding weanlings yucca extract. The suppression of butyric acid was determined in the finisher phase. The reduction of butyric acid indicates that the production of odour components other than ammonia may also be suppressed by Deodorase® and suggests that yucca extract can make a contribution to the reduction of swine odour.

Experiment 3

The growth performance of pigs is shown in Table 16. There were no observed differences in ADI or FE ($p>0.05$). The ADG for diets 2 and 3 were different ($p<0.05$). The ADG for diet 3 was 17% lower than that of diet 2 (790 g/day vs 949 g/day, respectively).

Table 15. The effect of Deodorase® supplementation on faecal volatile fatty acids[1]

VFA (mmol/L)[2]	Control	Deodorase®	Significance[3]
Acetic	117.4 ± 5.7	108.1 ± 6.1	NS
Propionic	57.2 ± 3.6	51.8 ± 3.8	NS
Isobutyric	5.1 ± 0.3	4.6 ± 0.4	NS
Butyric	37.9 ± 3.2	24.8 ± 3.4	*
Isovaleric	7.3 ± 0.6	6.7 ± 0.6	NS
Valeric	8.7 ± 0.8	8.0 ± 0.8	NS

[1] Average values ± standard error of the mean
[2] Dry matter corrected
* Statistically significant difference at $p<0.05$

Table 16. Growth performance[1] of pigs on diets supplemented with amino acid and/or Deodorase®

Diet	Supplement[2]	ADG (kg)	ADI (kg)	FE (feed/gain)
1	SBM	0.875 ± 0.39	2.79 ± 0.25	2.94 ± 0.29
2	SBM + Deo	0.949 ± 0.39 a	2.66 ± 0.25	2.85 ± 0.29
3	AA	0.790 ± 0.39 b	2.79 ± 0.25	3.38 ± 0.29
4	AA + Deo	0.886 ± 0.41	2.82 ± 0.25	3.12 ± 0.29

[1] Average value ± standard error of the mean

[2] SBM = soybean meal, Deo = Deodorase® and AA = amino acid substitution for soybean meal. Different letters denote significant differences at $p<0.05$

Potential improvements in growth due to Deodorase® to Diet 2 may have highlighted otherwise undetectable reductions in gain resulting from reducing CP content overall. Table 17 shows growth performance as influenced by yucca extract supplementation or amino acid substitution. No significant differences were observed with amino acid supplementation ($p=0.05$). However, the addition of Deodorase® in diets resulted in improved daily gain ($p<0.05$) by approximately 10%.

Tables 18 and 19 show the influence of Deodorase® supplementation or amino acid substitution on faecal volatile fatty acids. The only effect of Deodorase® on VFA observed was a 28% increase ($p<0.05$) in the level of propionic acid. Diets with AA substitution produced faeces with significantly ($p<0.05$) less acetic, propionic and butyric acid, reduced by 27, 24 and 35%, respectively. The performance of pigs fed AA supplemented diets supports the contention that growth need not be significantly affected by a substantial reduction in dietary nitrogen, though the 8% reduction ($p<0.10$) in ADG may be economically important. Substitution of SBM with the amino acid mixture represented a drop from 20% to 13% CP on DM basis. This underlines the importance of formulating diets on the basis of apparent ileal digestibility of amino acids (Tuitoek et al. 1977) rather than crude protein. Tuitoek et al. (1977) and Bolduan et al. (1992) were also able to reduce protein in weaner, growing and finishing pigs with no effects on performance, providing there was adequate amino acid supplementation.

The reduction of nitrogen along with increased digestibility of amino acids should produce less nitrogenous waste (Jacob, 1995; Latimier and Dourmand, 1993). This reduced nitrogenous waste is apparently reflected in lower levels of VFA observed in the faeces. The

Table 17. Effect of amino acid substitution or Deodorase® supplementation on growth performance in finisher pigs

Diets	Supplement[1]	ADG (kg/day)	SEM[2]	Signficance[3]
1 and 2	SBM	0.912	0.028	**
3 and 4	AA	0.838	0.028	
1 and 3	No Deo	0.832	0.028	*
2 and 4	Deo	0.917	0.028	
		ADI (kg/day)		
1 and 2	SBM	2.72	0.18	NS
3 and 4	AA	2.81	0.18	
1 and 3	No Deo	2.79	0.18	NS
2 and 4	Deo	2.74	0.18	
		FE (feed/gain)		
1 and 2	SBM	2.89	0.20	NS
3 and 4	AA	3.25	0.20	
1 and 3	No Deo	3.16	0.20	NS
2 and 4	Deo	2.98	0.20	

[1] SBM = soybean meal, AA = amino acid substitution and Deo = Deodorase©

[2] SEM = standard errors of the mean.

[3] * = signifance at $p<0.05$, ** = significance at $p<0.10$, NS = not signficant

Table 18. Effect of Deodorase® supplementation on faecal volatile fatty acid profile, mmol/L, dry matter basis.

Diets	Supplement[1]	Acetic	SEM[2]
1 and 3	No Deo	91.69	3.22
2 and 4	Deo	96.19	3.38
		Propionic	
1 and 3	No Deo	46.69 a	2.55
2 and 4	Deo	59.94 b	2.47
		Isobutyric	
1 and 3	No Deo	5.01	0.26
2 and 4	Deo	4.53	0.27
		Butyric	
1 and 3	No Deo	29.53	1.96
2 and 4	Deo	31.17	2.05
		Isovaleric	
1 and 3	No Deo	7.40	0.44
2 and 4	Deo	6.59	0.46
		Valeric	
1 and 3	No Deo	9.60	0.75
2 and 4	Deo	9.38	0.79

[1] Deo = Deodorase®
[2] SEM = standard errors of the mean
Different letters denote significant differences at p=0.05

Table 19. Effect of amino acid substitution on faecal volatile fatty acid profile, mmol/L, dry matter basis.

Diets	Supplement[1]	Acetic	SEM[2]
1 and 2	SBM	108.23 a	3.38
3 and 4	AA	79.65 b	3.22
		Propionic	
1 and 2	SBM	60.56 a	2.47
3 and 4	AA	46.06 b	2.35
		Isobutyric	
1 and 2	SBM	5.14 a	0.27
3 and 4	AA	4.40 a	0.26
		Butyric	
1 and 2	SBM	39.12 a	2.05
3 and 4	AA	25.58 b	1.96
		Isovaleric	
1 and 2	SBM	7.45 a	0.46
3 and 4	AA	6.45 a	0.44
		Valeric	
1 and 2	SBM	10.52 a	0.79
3 and 4	AA	8.46 a	0.75

[1] SBM = soybean meal and AA = amino acid substitution for soybean meal.
[2] SEM = standard errors of the mean.
Different letters denote significant differences at $p<0.05$

reduction of VFA could possibly be due, in part, to the reduction of the indigestible carbohydrate contribution of soybean meal. The lowering of propionic, acetic and butyric acid suggest that lowering dietary nitrogen has the potential to significantly affect swine odour.

Supplementation with Deodorase® did not result in the reduction of faecal VFA. However, ADG was improved. This improved growth may be due to the reduction of other toxic intestinal volatiles, not measured here, such as ammonia, hydrogen sulphide, indole skatole and phenol. Yucca extract is believed to slow peptide fermentation (Killeen, 1996). The surfactant properties of yucca extract may also have enhanced nutrient absorption by conditioning cell membranes (Johnston et al. 1982). Deodorase® produced a rise in propionic acid in the faeces. This may reflect an influence on the microbial profile in the large intestine.

Experiment 4

There were no differences ($p>0.05$) in growth performance over the entire trial between control diets and those supplemented by Jerusalem artichoke (JA) as shown in Table 20. During the 20-50 kg phase, pigs fed 5% JA diets were 9% more efficient than those fed 2.5% JA (1.87 vs 2.10 feed/gain).

Faeces, collected on day 75 of the experiment and produced from the diets supplemented with 2.5% JA had 26% less isobutyric acid and 23% less isovaleric acid than that of the control diets ($p<0.05$) as shown in Table 21. Those diets supplemented with 5% JA did not produce significantly different levels of volatile fatty acids (VFA), relative to the control diet.

At d 55, stored slurry from diets with 2.5% JA supplementation contained 83% more valeric acid than slurry from the control diet (at $p<0.05$) as shown in Table 22. The 5% JA

Table 20. Effect of JA supplementation on growth parameters

Growth Phase	Level of Jerusalem artichoke supplementation (%)			
20-50 kg	0.0	2.5	5.0	SEM[1]
ADFI (g)	1667	1785	1803	121
ADG (g)	856	849	958	66
Feed/gain	1.96 ab	2.10 a	1.87 b	0.04
50-80 kg				
ADFI (g)	2629	2573	2585	143
ADG (g)	1019	1041	1003	41
Feed/gain	2.58	2.47	2.57	0.08
80-105 kg				
ADFI (g)	2595	2094	2337	176
ADG (g)	912	810	879	95
Feed/gain	2.88	2.69	2.71	0.40
20-105 kg				
ADFI (g)	2232	2172	2169	96
ADG (g)	930	901	943	55
Feed/gain	2.40	2.33	2.31	0.08

[1] SEM = standard error of the mean

Different letters denote significant differences at $p<0.05$

Table 21. Effect of JA supplementation on faecal volatile fatty acid profile, mmol/L[1], dry matter basis.

JA%	0.0	2.5	5.0
Acetic	117.9 ± 8.9	99.9 ± 8.9	121.7 ± 12.6
Propionic	55.2 ± 5.3	52.2 ± 5.3	61.1 ± 7.5
Isobutyric	5.0 ± 0.3 a	3.7 ± 0.3 b	4.9 ± 0.4 ab
Butyric	28.5 ± 4.9	27.0 ± 4.9	24.8 ± 6.8
Isovaleric	7.7 ± 0.4 a	5.9 ± 0.4 b	7.6 ± 0.6 ac
Valeric	6.1 ± 0.3	4.8 ± 0.3	6.7 ± 0.5

[1] Average value ± standard error of the mean
Different letters denote significant difference at $p<0.05$

Table 22. Effect of JA supplementation on slurry volatile fatty acid profile at d 55, mmol/L, dry matter basis.

JA%	0.0	2.5	5.0	SEM[1]
Acetic	1053	1868	1424	154
Propionic	331	436	401	48
Isobutyric	56	78	65	10
Butyric	298	236	189	32
Isovaleric	79	142	97	11
Valeric	48 a	88 b	49 a	7

[1] SEM = standard error of the mean
Different letters denote significant difference at $p<0.05$

diet did not produce significantly different levels of VFA in the stored slurry.

At d 69, stored slurry from diets with 2.5% JA contained 83% more acetic acid, 116% more isovaleric acid and 97% more valeric acid than slurry from the control diet ($p<0.05$) as shown in Table 23. Slurry from diets with 5.0% JA contained 100% more acetic acid, 65% more propionic acid, 101% more isobutyric acid, 126% more isovaleric acid and 53% more valeric acid than the control ($p<0.05$).

At d 83, stored slurry from diets with 2.5% JA contained 28% less butyric acid and 75% more isovaleric acid ($p<0.05$) as shown in Table 24. Slurry from diets with 5.0% JA contained 70% more acetic acid, 57% more isobutyric acid, 31% less butyric acid and 68% more isovaleric acid than the slurry from control diets ($p<0.05$).

At d 111, stored slurry from diets with JA supplementation contained no significant ($p>0.05$) differences in VFA content as shown in Table 25. The variation in VFA levels was uniformly large.

No significant relationship between length of storage time and individual VFA levels was observed ($p>0.05$) though a trend toward a general rise is indicated as shown in Table 26.

There were no significant ($p>0.05$) differences between diets for individual slurry VFA levels averaged over the entire storage period, except for increases in acetic acid of 73% and 89% for diets supplemented with 2.5% and 5.0% JA, respectively as shown in Table 27.

The results outlined above indicate that JA supplementation at levels up to 5.0% does not affect growth performance. The differences in feed efficiency between those fed 2.5 and 5.0 % JA in the 20 to 50 kg phase may reflect an increased production and absorption of

Table 23. Effect of JA supplementation on slurry volatile fatty acid profile at d 69, mmol/L, dry matter basis.

JA%	0.0	2.5	5.0	SEM[1]
Acetic	1008 a	1853 b	2121 b	126
Propionic	342 a	413 a	563 b	27
Isobutyric	52 a	86 ab	105 b	7
Butyric	287	250	226	19
Isovaleric	74 a	160 b	167 b	10
Valeric	45 a	89 b	69 b	8

[1] Standard error of the mean
Different letters denote significant difference at $p<0.05$

Table 24. Effect of JA supplementation on slurry volatile fatty acid profile at d 83, mmol/L, dry matter basis.

JA%	0.0	2.5	5.0	SEM[1]
Acetic	1059 a	1624 ab	1796 b	116
Propionic	346	341	489	31
Isobutyric	58 a	82 ab	91 b	6
Butyric	283 a	204 bc	196 c	11
Isovaleric	85 a	149 bc	143 c	10
Valeric	48	74	55	8

[1] Standard error of the mean
Different letters denote significant difference at $p<0.05$

Table 25. Effect of JA supplementation on slurry volatile fatty acid profile at d 111, mmol/L, dry matter basis.

JA%	0.0	2.5	5.0	SEM[1]
Acetic	981	1540	2252	549
Propionic	361	277	761	206
Isobutyric	92	104	147	46
Butyric	380	148	491	228
Isovaleric	122	178	214	61
Valeric	55	73	99	40

[1] Standard error of the mean
Different letters denote significant difference at $p<0.05$

Table 26. Effect of storage on slurry volatile fatty acid profile, mmol/L, dry matter basis.

Days stored	55	69	83	111	SEM[1]
Acetic	1392	1661	1493	1591	152
Propionic	377	439	392	467	58
Isobutyric	62	81	77	114	13
Butyric	226	255	227	339	63
Isovaleric	100	134	126	177	16
Valeric	58	68	59	76	11

[1] Standard error of the mean

Table 27. Average effect of Jerusalem artichoke on slurry volatile fatty acid profile, mmol/L, dry matter basis.

JA%	0.0	2.5	5.0	SEM[1]
Acetic	1000 a	1730 ab	1890 b	175
Propionic	340	368	552	54
Isobutyric	63	88	102	14
Butyric	307	211	274	58
Isovaleric	89	158	155	18
Valeric	48	82	67	12

[1] Standard error of the mean
Different letters denote significant differences at $p<0.05$.

volatile fatty acids, from the fermentation of JA inulin. However, this was not reflected by differences in the VFA profile.

The volatile fatty acid levels in the faeces and the slurry can be influenced albeit inconsistently. The VFA profile from the isolated faecal sampling stands in contrast to the trends observed in the slurry. The inclusion of waste feed, water and urine along with the effects of time may probably create markedly different environment than that of the colon.

The rise in acetic acid in the slurry is not unexpected as fructans are known to encourage the bifidobacteria growth and acetic acid (along with lactic acid) is one of the byproducts of bifido metabolism. The general though inconsistent rise in most of the other volatile fatty acids tested for concurs with the rise in faecal volatile fatty acids that Farnworth (1993) noted in supplementation of diets with JA. Though the drop in butyric acid was not significant at each testing period, there was a clear pattern of decrease up until the last testing period. Butyric acid is not produced by bifidobacteria. An increase in bifidobacteria numbers could have displaced butyrate producing bacteria.

The inclusion of JA in the diet can alter the VFA profile in faeces and thus demonstrates the potential to affect swine odour. Whether or not these changes are of a magnitude to substantially change or improve the odour perceived is not known. Though VFA are considered to be important components of swine odour, a rise in swine VFA may be accompanied by an improvement in odour quality (Farnworth et al. 1995). This illustrates the complex nature of odour. Zhu et al. (1997) suggest that the total amounts of VFA may not be an adequate gage of swine odour and that offensiveness is more dependent on the types and characteristics of certain acids regardless of the quantities. Future studies should

include the use of an odour panel as well as analysis for the levels of other known important odour components such as skatole, phenol, indole and p-cresol. Levels of specific components need to be correlated with odour offensiveness in order to more accurately determine their relative contributions to swine odour.

Experiment 5

There were no significant ($p>0.05$) differences in the in the ratio of urine N/faecal N excreted as shown in Table 28.

Encouraging increased numbers of bifidobacteria can potentially displace putrefactive bacteria, including urea splitting organisms. Urea may be absorbed through the colon and subsequently routed to the liver where it can be used for amino acid synthesis (Sanford, 1982). Soluble fibres have been shown to increase faecal bulk and faecal nitrogen (Eggum, 1995). A change in the colonic microbial profile may be reflected in the ratio of urine N/fecal N excreted (Younes et al. 1994). However, the lack of observed change suggests that microbial nitrogen fermentation was not substantially altered. Alternately, changes may have been undetectable due to the large variation within treatments.

Table 28. Effect of JA supplementation on nitrogen balance.

% of JA supplementation	urine N output/faecal N output	SEM[1]
0.0	1.42	0.74
5.0	2.81	0.74

[1] Standard error of the mean

SUMMARY AND CONCLUSION

The rapid expansion of the swine industry in Manitoba has initiated research that addresses the problem of swine odour. Manure characteristics can be altered by modifying the nitrogen content of the diet and can also be altered by the use of additives which affect the microbiological profile of the digestive tract. Supplementing protein reduced diets with amino acids can reduce nitrogenous wastes by providing amino acids that are more available and more likely to be used by the pig. Less nitrogenous waste should result in reduced peptide fermentation and subsequently less production of obnoxious odours. Deodorase®, a yucca extract, has been shown to inhibit some rumen protozoa and bacteria and bind ammonia and has shown indications of slowing peptide fermentation. Jerusalem (JA) artichoke, has been demonstrated to encourage the growth of bifidobacteria. JA is an abundant source of inulin. Bifidobacteria are relatively unique in being able to hydrolyze inulin which is resistant to mammalian enzymes. Bifidobacteria produce lactic and acetic acid. The resulting lowered pH inhibits the growth of some putrefactive bacteria.

The purpose of this study was to evaluate the effects of yucca extract supplementation, amino acid substitution and Jerusalem artichoke supplementation on growth performance and manure volatile fatty acids. The first experiment was a digestibility study. Jerusalem artichoke (JA) was evaluated for ileal and total tract digestibilities of gross energy, crude protein and neutral detergent fibre. Deodorase®, included at 0.015%, was evaluated for its effects on the same digestibility parameters. Deodorase® supplementation produced no significant ($p>0.05$) differences in any digestibilities examined. There was a 23% decrease the ileal digestibility of energy with the JA diet, relative to the control. However, this

difference was not observed for total tract digestibilities. The only other difference ($p<0.05$) noted was a 13% decrease in total tract crude protein digestibility. This is believed to reflect an increased faecal bacterial mass. The second experiment determined the effects of Deodorase® on growth performance and volatile fatty acids. There were no significant differences in growth performance except for a 4% increase of feed efficiency in the starter phase. No differences in faecal VFA content were observed except for a reduction in the butyric acid level. The third experiment examined the effects of amino acid substitution and Deodorase®. Average daily gain was higher in those animals treated with Deodorase®, but no differences in feed intake or feed efficiency were observed. The improvements in growth noted with Deodorase® supplementation may be attributed to binding of ammonia, the inhibition of peptide fermentation and/or an improvement in nutrient absorption. Enhanced nutrient absorption may occur as the sarsaponin component of yucca extracts acts as a surfactant. The reduction in butyric acid could be due to the inhibition of peptide fermentation. Acetic, propionic and butyric acids were lower in those diets supplemented with amino acid substitution, but no differences in growth were observed. This suggests that reducing excess nitrogen in the diet can reduce the production of volatile metabolites without adversely affecting growth. The fourth experiment examined the effects of JA supplementation. JA did not affect growth performance but was able to alter the manure VFA profile over several sampling periods, albeit somewhat inconsistently. The fifth experiment examined the effects of JA on nitrogen utilization but yielded no differences. The results from the JA experiments indicate that the production of volatiles in swine manure can be influenced by supplementing the diet with inulin. However, the trend in this case, with the

exception of butyric acid, was that of a general rise in volatile fatty acids. This rise may be the direct product of an increased bifidobacteria population in the digestive tract. Farnworth et al. (1995) also observed an increase in faecal volatile fatty acids with JA supplementation. However, a concurrent improvement in odour quality and a reduction in skatole smell in the faeces was also observed. Bunce et al. (1995) supplemented swine diets with FOS and noted reduction in the fecal excretion of p-cresol, indole and skatole. Organoleptic tests were not conducted. The findings of Farnworth et al. (1995) suggest that the concentration of faecal VFA may not be the best indicator of odour in all situations. This underscores the complex nature of odour. Williams (1984) found that VFA were correlated to offensiveness under certain treatment conditions. Spoelstra (1987) considered VFA to be potentially useful indicators for testing odour abatement methods as they are strongly related to the degradation of protein and plant fibre. However, a consensus as to which components, if any, stand on their own as objective measures of odour has yet to be arrived at.

While these experiments demonstrate the ability of yucca extract, Jerusalem artichoke and nitrogen reduction to significantly alter the volatile fatty acid profile in faeces, it remains to be seen how effectively these strategies are in reducing odour as a composite. Zhu et al. (1997) suggests that the odour offensiveness is not directly associated with the total amount of the VFAs in the manure, but rather, is dependent upon the types and characteristics of certain acids regardless of quantities. Concurrent organoleptic testing is required in order to conclusively ascertain whether these odour abatement methods are truly effective. Additionally, analysis for other important odour constituents such as p-cresol, phenol, indole, ammonia, amines and sulphur compounds is required. Correlating a particular odour profile

with offensiveness may provide a fingerprint for swine odour which may prove useful for the development of more sophisticated sensory devices, such as electronic sensors. This profile should also facilitate more effective management of swine waste.

Organoleptic testing needs to standardized so that odour abatement methods may be more effectively evaluated. This standardization should include both the panel assessment and the methods of manure sampling and analysis (Zhu et al. 1997).

A fuller understanding of the microbiological community in the intestine is crucial to developing feeding strategies that both enhance growth and reduce obnoxious volatiles. Future studies should include an in depth look at the microbiological profile of digesta and faecal material, with specific culturing of those bacteria which have been identified in the production of known volatiles.

Further studies into the mode of action of yucca extract, beyond its ability to bind ammonia, are also warranted. Its potential to inhibit peptide fermentation and the key mechanisms of this process should be more fully investigated. The effects of sarsaponin on cell membranes and nutrient absorption also warrant consideration.

The study of odour management in the future is likely to combine a variety of complimentary strategies possibly in the form of a hybrid feed additive. Such an additive should include components which promote the growth of beneficial intestinal bacteria, as well as agents that possess absorptive and volatile binding qualities. Reduced protein content, multi-phase feeding, protease supplementation and greater use of amino acids may be employed to reduce nitrogenous wastes.

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Appendix 1. Amino acid composition of experimental diets for digestibility study.

Amino acid (%)	Control	Jerusalem artichoke	Yucca extract
Aspartic acid	1.00	1.04	1.03
Threonine	0.56	0.50	0.55
Serine	0.70	0.6	0.70
Glutamic acid	3.26	2.69	3.21
Proline	1.33	1.03	1.32
Glycine	0.67	0.59	0.66
Alanine	0.62	0.56	0.61
Valine	0.62	0.54	0.60
Isoleucine	0.40	0.34	0.38
Leucine	0.97	0.81	0.95
Tyrosine	0.66	0.31	0.39
Phenylalanine	0.34	0.58	0.65
Histidine	0.63	0.30	0.33
Lysine	0.69	0.60	0.62
Arginine	0.74	1.15	0.74
Cystine	0.40	0.39	0.40
Methionine	0.31	0.30	0.31

Appendix 2. Amino acid content of diets in yucca extract experiment for 8-20 kg pigs.

Amino acid (%)	Control	Yucca extract
Aspartic acid	1.88	1.79
Threonine	1.02	0.95
Serine	1.08	1.02
Glutamic acid	4.62	4.32
Proline	1.47	1.44
Glycine	0.95	0.91
Alanine	0.96	0.94
Valine	0.78	0.74
Isoleucine	0.62	0.60
Leucine	1.53	1.47
Tyrosine	0.59	0.55
Phenylalanine	0.98	0.95
Histidine	0.48	0.47
Lysine	1.55	1.44
Arginine	1.10	1.08
Cystine	0.38	0.37
Methionine	0.34	0.31

Appendix 3. Amino acid content of diets in yucca extract experiment for 20-105 kg pigs.

Amino acid (%)	Control	Yucca extract
Aspartic acid	1.05	1.02
Threonine	0.61	0.56
Serine	0.73	0.71
Glutamic acid	3.75	3.55
Proline	1.35	1.28
Glycine	0.59	.58
Alanine	0.56	0.54
Valine	0.51	0.47
Isoleucine	0.36	0.31
Leucine	0.92	0.87
Tyrosine	0.36	0.34
Phenylalanine	0.70	0.66
Histidine	0.31	0.30
Lysine	1.03	0.98
Arginine	0.71	0.66
Cystine	0.33	0.32
Methionine	0.25	0.26

Appendix 4. Amino acid content of diets in yucca extract/amino acid experiment for 60-105 kg pigs.

Amino acid (%)	Diet 1	Diet 2	Diet 3	Diet 4
Aspartic acid	1.57	1.55	0.62	0.63
Threonine	0.63	0.61	0.62	0.62
Serine	0.95	0.92	0.51	0.53
Glutamic acid	4.04	3.99	2.78	2.83
Proline	1.42	1.39	1.13	1.11
Glycine	0.74	0.72	0.43	0.44
Alanine	0.73	0.71	0.41	0.42
Valine	0.66	0.64	0.45	0.42
Isoleucine	0.50	0.47	0.26	0.25
Leucine	1.21	1.17	0.66	0.66
Tyrosine	0.49	0.45	0.27	0.27
Phenylalanine	0.86	0.85	0.53	0.52
Histidine	0.41	0.39	0.21	0.21
Lysine	0.82	0.78	0.82	0.81
Arginine	0.98	0.93	0.46	0.44
Cystine	0.37	0.36	0.28	0.28
Methionine	0.30	0.29	0.32	0.30

Appendix 5. Amino acid content of diets for Jerusalem artichoke experiment for 20-50 kg pigs.

Amino acid (%)	Diet 1(control)	Diet 2	Diet 3
Aspartic acid	1.57	1.60	1.58
Threonine	0.92	0.89	0.91
Serine	0.89	0.89	0.87
Glutamic acid	3.59	3.55	3.47
Proline	1.32	1.31	1.26
Glycine	0.75	0.74	0.72
Alanine	0.84	0.83	0.82
Valine	0.73	0.64	0.67
Isoleucine	0.56	0.48	0.50
Leucine	1.36	1.31	1.31
Tyrosine	0.51	0.50	0.49
Phenylalanine	0.88	0.85	0.84
Histidine	0.42	0.40	0.40
Lysine	0.96	0.95	0.93
Arginine	1.01	0.99	0.99
Cystine	0.34	0.33	0.32
Methionine	0.72	0.72	0.74

Appendix 6. Amino acid content of diets for Jerusalem artichoke experiment for 50-80 kg pigs.

Amino acid (%)	Diet 1(control)	Diet 2	Diet 3
Aspartic acid	1.33	1.36	1.43
Threonine	0.67	0.69	0.71
Serine	0.78	0.78	0.83
Glutamic acid	1.69	3.13	3.32
Proline	1.20	1.16	1.23
Glycine	0.63	0.65	0.67
Alanine	0.75	0.75	0.78
Valine	0.61	0.58	0.62
Isoleucine	0.41	0.42	0.44
Leucine	1.18	1.17	1.21
Tyrosine	0.45	0.44	0.44
Phenylalanine	0.76	0.76	0.78
Histidine	0.35	0.35	0.37
Lysine	0.76	0.76	0.82
Arginine	0.83	0.85	0.89
Cystine	0.32	0.31	0.31
Methionine	0.58	0.60	0.60

Appendix 7. Amino acid content of diets for Jerusalem artichoke experiment for 80-105 kg pigs: Phase C.

Amino acid (%)	Diet 1(control)	Diet 2	Diet 3
Aspartic acid	1.38	1.34	1.36
Threonine	0.66	0.63	0.63
Serine	0.86	0.81	0.84
Glutamic acid	3.64	3.45	3.46
Proline	1.43	1.37	1.35
Glycine	0.67	0.63	0.64
Alanine	0.77	0.74	0.75
Valine	0.64	0.61	0.58
Isoleucine	0.45	0.43	0.41
Leucine	1.25	1.19	1.19
Tyrosine	0.47	0.45	0.44
Phenylalanine	0.84	0.79	0.79
Histidine	0.38	0.36	0.37
Lysine	0.72	0.67	0.69
Arginine	0.87	0.86	0.86
Cystine	0.32	0.33	0.32
Methionine	0.53	0.60	0.60

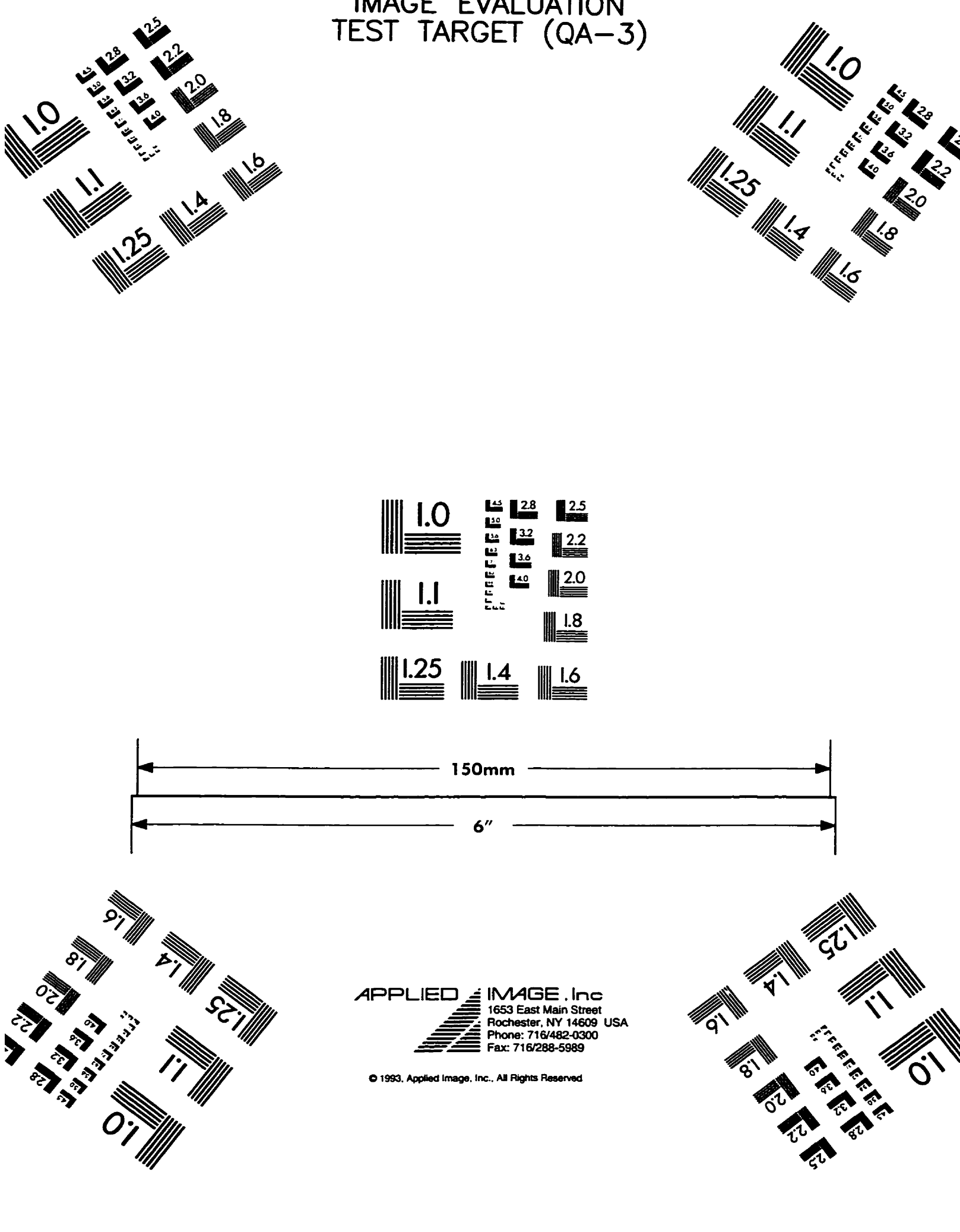
IMAGE EVALUATION
TEST TARGET (QA-3)
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
150mm
6"
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