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</table>
Maximizing grain quality for the feed industries.

Allan K. Hardacre

Plant and Food research, Palmerston North and Institut of Food, Nutrition and Human Health, Massey University, New Zealand

Introduction

The future of the grain feed industry in New Zealand is inextricably linked with demand from the dairy, poultry and pork industries. The demand for grain increased over the 2007-2008 harvest years after a period of stability over the 2004 to 2006 seasons. As production efficiencies in other parts of the world increase and international transport becomes cheaper, local crops are increasingly faced with competition from imports of grain and other feed materials such as palm kernel meal. Care must be taken to ensure that these products are free of toxins and constitute a high quality feed ingredients.

Quality in the feed industry is still a great unknown or at best poorly known. In the wheat and barley industries, quality is of paramount importance and is used to enhance the value of bakery and brewing products. However, despite a large amount of work the feed grain industry is, as yet in the dark ages with respect to understanding grain quality and its effect on product quality. Without acceptable quality the value of the grain is low and this will be (should be ?) reflected in the price paid.

Grain quality and uniformity are highly important in maintaining predictable animal production and for the efficient production of food products. Quality and consistency are particularly important for the latter as sophisticated forming machines and processes used for the production of snack and breakfast foods demand a uniform feedstock for efficient operation with low wastage. The production techniques used in the food industry are becoming more common in the feed industry as growers seek higher yields better process and more efficient production techniques. Additionally, there has been a continual improvement in plant genetics since the 1960’s that has delivered better adapted and disease resistant germplasm to growers.

When the figures for feed production are compared for all the NZ industry it is clear that there is decline in the feed production and that this is particularly large for the pork industry. Without acceptable quality the value of the grain is low and this should be reflected in the price paid. In this address I will cover some aspects of grain quality and its relevance to the various components of the maize industry.
Summary of Historical Production Data

<table>
<thead>
<tr>
<th>Year ending</th>
<th>Dec-98</th>
<th>Dec-99</th>
<th>Dec-00</th>
<th>Dec-01</th>
<th>Dec-02</th>
<th>Dec-03</th>
<th>Dec-04</th>
<th>Dec-05</th>
<th>Dec-06</th>
<th>Dec-07</th>
<th>Dec-08</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry - Meat &amp; Breeding</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>250,860</td>
<td>258,670</td>
<td>283,318</td>
<td>305,600</td>
<td>340,237</td>
<td>366,595</td>
<td>391,186</td>
<td>401,236</td>
<td>389,530</td>
<td>382,051</td>
<td>401,471</td>
</tr>
<tr>
<td>Poultry - Layer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layer Flocks</td>
<td>107,257</td>
<td>115,379</td>
<td>115,384</td>
<td>113,360</td>
<td>119,531</td>
<td>102,050</td>
<td>131,830</td>
<td>126,118</td>
<td>112,776</td>
<td>117,166</td>
<td>127,162</td>
</tr>
<tr>
<td>Pig</td>
<td>225,000</td>
<td>220,000</td>
<td>219,999</td>
<td>220,000</td>
<td>215,998</td>
<td>215,180</td>
<td>215,172</td>
<td>215,181</td>
<td>187,200</td>
<td>187,200</td>
<td>182,094</td>
</tr>
<tr>
<td>TOTAL</td>
<td>668,669</td>
<td>683,587</td>
<td>728,316</td>
<td>780,600</td>
<td>810,418</td>
<td>794,878</td>
<td>848,446</td>
<td>850,534</td>
<td>829,424</td>
<td>877,032</td>
<td>965,465</td>
</tr>
<tr>
<td>% change</td>
<td>2.2%</td>
<td>6.6%</td>
<td>7.0%</td>
<td>3.9%</td>
<td>-1.9%</td>
<td>6.7%</td>
<td>0.2%</td>
<td>-2.5%</td>
<td>5.7%</td>
<td>10.1%</td>
<td></td>
</tr>
<tr>
<td>Pig % change</td>
<td>-2.2%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>-1.8%</td>
<td>-0.4%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>-13.0%</td>
<td>0.0%</td>
<td>-2.7%</td>
<td></td>
</tr>
</tbody>
</table>

What is quality.

Quality is optimizing of the value of the grain for end use. It is centred on the issues of consistency, yield, freedom from toxins and anti-feedants and the maintenance of properties such as hardness, protein and oil content.

Grain quality and uniformity are highly important in maintaining predictable animal production and for the efficient production of food and compounded feed products. Quality and consistency are particularly important for the latter as sophisticated extruders use to make pelleted feeds demand a uniform feedstock for efficient operation with low wastage and a consistent product. These manufacturing techniques are becoming more common in the feed industry and it is expected that grain quality will become an increasingly important issue for feed producers.

The importance of quality.

In the food industry, quality is very important for the manufacture of cereal based foods. Corn flakes, our well known breakfast cereal, are produced by milling maize grain to produce large grits. It is essential to have hybrids with large grain and a high proportion of hard endosperm to maximise the production of grits of a suitable size. Similarly, wheat for bread flour is carefully selected for protein content protein type and the lack of sprouted and diseased grain.

In the feed industry, maize grain is primarily regarded as a source of energy in the form of starch, although, in the large quantities it is fed to animals, the protein and oil components are important nutritional factors. It is important to produce grain which performs consistently as a feed to achieve high and predictable rates of animal growth and production.

Maintaining Quality in maize:
**Mycotoxins and Diseased grain:** Mycotoxins are produced by fungi and about 200 are known. It is well known that maize grain can accumulate levels of mycotoxins that can be lethal to pigs (about 0.5 ppb) and which reduce the productivity of chickens. Generally, the low intake of maize in the western diet means that mycotoxins are not a health problem to humans. However, it is possible that fungal contamination of the grain will add off-flavours to the food, furthermore, toxins can accumulate in the by-products from the manufacture of foods.

The best method of reducing the levels of fungal and mycotoxin contamination is by growing hybrids resistant to infection by the causal organisms and by managing harvest times to reduce contamination of the grain. The grain must also be stored dry in well ventilated silos. Screening for mycotoxin contamination is slow, expensive and not yet feasible at the weighbridge.

**Broken Corn and Foreign material (BCFM):** Broken corn is generally the result of poor combining techniques and/or the use of worn or broken equipment, particularly augers. In NZ, a competition among growers was instigated to reduce combine based BCFM among the contractors, BCFM was reduced from 5-6% to 2-3% after the first assessment. Foreign material is generally comprised of broken cob fragments and other foreign material including stones, spanners and combine parts.

**Stress fractures:** Stress fractures result from non homogenous moisture distribution in the kernel or thermal shock during drying and subsequent cooling. Supply contracts often specify low levels of stress fractures; however, stress fractures may vary in severity. In our laboratory, we have found that the cooking or milling performance of grain with simple fractures may not be different from grain which has no fractures. In extreme cases where fracturing is multiple or crazed or checked, it may indicate that the grain has been exposed to very high rates of heating or cooling. This is evidence of major chemical and physical damage to the grain and can compromise processing and storage quality. In general all maize grain that has been artificially dried and stored for at least two months is at least 95% cracked.

**Bulk Density:** Test weight or bulk density is widely used as an estimator of quality, although it is often difficult to discover what is being assessed. From the literature, bulk density seems to be used to estimate hardness, while very low bulk densities (less than about 65kg/hl) are regarded in the US as an indicators of poor nutritional quality and lower starch yields during wet milling.

Usually bulk density is presented as the wet bulk density, this information is practically useless as bulk density changes significantly with the moisture content of the grain (Table 2) and the method of drying. Predicted bulk density increases as the grain is dried to 14% moisture, according to the formula:
**Bulk density@14% = Wet bulkD+0.3(moisture content-14)**

Following fast, high temperature drying, predicted bulk density (BD) may be considerably greater than actual (BD) due to the formation of voids in the endosperm. It is impossible to make blanket comparisons in bulk density among hybrids as the shape and size distributions of kernels from different hybrids causes variation in the bulk density which is unrelated to kernel density.

Bulk density and many other grain characteristics are altered by planting density and climate (Table 2). At higher planting densities bulk density, grain size (1000kWt) and grain hardness (Stenvert hardness) decreased. In the Palmerston North environment, grain yield increased with plant density while at Pukekohe, where water availability was lower grain yield decreased with plant density.

**Table 2.** The variation in grain characteristics of a hybrid in two contrasting environments (Palmerston North ,PN and Pukekohe, Puk) at two sowing densities (89,00/ha, L and 110,000/ha,H).

<table>
<thead>
<tr>
<th>Units</th>
<th>PNL</th>
<th>PNH</th>
<th>PukL</th>
<th>PukH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield T/ha</td>
<td>14.8</td>
<td>16.0</td>
<td>12.0</td>
<td>11.8</td>
</tr>
<tr>
<td>BulkD @14% kg/hl</td>
<td>74.4</td>
<td>73.7</td>
<td>77.4</td>
<td>77.1</td>
</tr>
<tr>
<td>1000KWt G</td>
<td>370</td>
<td>337</td>
<td>344</td>
<td>310</td>
</tr>
<tr>
<td>Stenvert hardness k Joule</td>
<td>7.0</td>
<td>6.2</td>
<td>8.1</td>
<td>7.4</td>
</tr>
</tbody>
</table>

**Grain hardness:** Grain hardness measured as Stenvert hardness (SHT) is an important characteristic which along with grain size (1000KWt) affects the yield of grits from the grain and influences the rate of water uptake during cooking. Grain hardness is controlled genetically (Table 3) but can also be influenced by crop agronomy and the environment. Generally a low level of adaptation to the environment, environmental stress or adverse conditions during growth will reduce grain hardness (Table 2). Grain which naturally has a low bulk density and hardness may be preferred if fast water absorption during processing is desirable. As grain hardness increases, the grit to flour ratio increases.

**Kernel size:** Kernel size (1000KWt) has been previously discussed in relation to its effect on density and its association with grain hardness. Kernel size is also important for the corn flake industry as larger kernels will tend to yield a higher proportion of large grits. For dry milling and processes which involve cooking or steeping the grain, I expect that it is advantageous to select grain types that tend to have a uniform grain size as. Kernels of uniform size are expected to mill more uniformly and will absorb water at a more predictable rate.

All the grain characteristics described above are controlled genetically. The magnitude
of this variation is evident in Table 3. Genetic differences among the hybrids are the most important and grain for different uses should be chosen on the basis of hybrid type and their adaptation to the region in which they will be grown. Often tradeoffs in grain characteristics occur. Oil and protein are energetically more expensive for the plant to produce and consequently (Table 3) are often associated with lower grain yields (Table 3). Grain hardness measured by the Stenvert hardness test (SHT) is also associated with protein content and by implication yield.

Table 3. Variation in grain characteristics for 5 maize hybrids grown in the Manawatu region during one growing season.

<table>
<thead>
<tr>
<th></th>
<th>Yield t/ha</th>
<th>1000 KWt (g)</th>
<th>MC %</th>
<th>BD Kg/hl</th>
<th>SHT kJ 14%</th>
<th>Protein %dwb</th>
<th>Oil %dwb</th>
</tr>
</thead>
<tbody>
<tr>
<td>DK477</td>
<td>13.4</td>
<td>333</td>
<td>11.7</td>
<td>75.1</td>
<td>6.9</td>
<td>8.12</td>
<td>3.76</td>
</tr>
<tr>
<td>P3476</td>
<td>15.4</td>
<td>334</td>
<td>12.4</td>
<td>82.0</td>
<td>8.4</td>
<td>9.2</td>
<td>3.9</td>
</tr>
<tr>
<td>Exp 1</td>
<td>12.4</td>
<td>332</td>
<td>11.4</td>
<td>78.8</td>
<td>9.9</td>
<td>11.08</td>
<td>5.04</td>
</tr>
</tbody>
</table>

Maintaining quality: To produce grain of high and consistent quality as determined from the tests described, all components in the production chain must be optimised. Growing conditions and planting times must be appropriate for the hybrid grown, crop agronomy and fertility must be managed for optimum quality and harvesting and grain drying must be carefully controlled. Once the grain has reached physiological maturity in the field, quality and yield can only deteriorate due to animal, insect and pathogen attack, rain damage or sprouting. For this reason the grain should be harvested as soon as possible after harvestable maturity has been reached. Usually there is little excuse for producing poor quality grain.

One of the most important areas where quality can be maintained is at the dryer. Poorly controlled drying conditions, or fast drying at high temperatures can kill the grain, cause unwanted chemical changes by cooking or altering the physical characteristics by causing stress fractures, low bulk densities (Table 4) and voids in the endosperm. Rapid cooling will cause internal stresses which severely weaken the grain which under a controlled mechanical impact test (MI) will break up into smaller fragments (MI Total). It is also possible that long term storage of dryer damaged grain will result in reduced palatability and perhaps result in the accumulation of undesirable metabolic products.

Table 4. The effect of drying conditions and moisture removal on changes in the bulk density (BD Diff), MI value and cracking of grain.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Harvest Moisture (%)</th>
<th>Moisture removed (%)</th>
<th>BD Diff. (kg/hl)</th>
<th>MI Total (%)</th>
<th>Cracking (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>6.4</td>
<td>1</td>
<td>2</td>
<td>83</td>
</tr>
<tr>
<td>4</td>
<td>27</td>
<td>13.6</td>
<td>-6.3</td>
<td>33</td>
<td>19</td>
</tr>
</tbody>
</table>
Managing for quality.

At present the industry has little control over the quality of grain that it sources and in some cases chooses to ignore this fact. There is an uncertain future for an industry which will accept combine damaged grain which contains up to 40% diseased kernels, which has been dried at air temperatures above 180°C and cooled rapidly. This grain will not produce food-stuffs or grow chickens or pigs of the same quality as grain with little combine damage, no disease and which has been dried at temperatures below 60°C. In extreme instances, inferior grains may be blended to lift the appearance of the poor product. In reality, the good grain is ruined.

The industry is moving to quality standards for the purchase of maize grain. Significant progress is being made now and further progress can be made simply, without a huge investment in long and complicated research projects and without purchasing a lot of expensive hard to use equipment. It is not difficult to assess hybrids for many of the characteristics which are desirable for the grain industries and feed grain acceptance trials prior to their commercial release are easily conducted. At the weigh-bridge, 2-3 classes of grain could be established with discounting, rejection or streaming of all product which fails to meet specification.

The Future:

Transgenic crops can now resist attack by insects, produce insulin, alter the chemistry of the starch stored and add resistance to Fusarium fungi and therefore reduces contamination by mycotoxins. However, because of international resistance to transgenic crops and the as yet unproven advantages of these crops in NZ’s agriculture systems I believe that the industry should not campaign strongly to introduce these crops into NZ’s agriculture system.

It is highly likely that New Zealand will, for the foreseeable future depend on the arable and pastoral industries for a large proportion of its export earnings and production of high quality, manufactured foods. For this reason the arable industries must be well supported with R&D and, in turn, must respond to international pressures to compete in New Zealand’s markets. This will mean producing a high quality stable product attuned to the industries varied requirements.
Determining available lysine in processed feedstuffs

Shane M. Rutherfurd and Paul J. Moughan.
Riddet Institute, Massey University, New Zealand.

Introduction

Many protein sources, commonly used in feedstuffs for pig production, undergo some form of processing. During processing, proteins can be exposed to heat, both wet and dry, pressure and alkali. When feedstuffs are subjected to these kinds of conditions certain amino acids can react with other compounds present in the food resulting in nutritionally unavailable compounds. Lysine is particularly susceptible to this type of modification and can react with compounds, especially reducing sugars, that may be present in a feedstuff to form Maillard compounds (Hurrell and Carpenter, 1981). Maillard compounds are not acid stable and during conventional amino acid analysis a proportion of these Maillard compounds revert back to lysine which leads to an overestimation (as much as 100%) of the amount of lysine present in the feedstuff. The formation of these Maillard compounds causes serious problems when attempting to determine the available lysine content of a processed feedstuff.

Several methods have been developed to determine available lysine including animal growth assays, reactive lysine chemical methods (reactive lysine being the lysine that has remained unmodified during processing) and digestibility assays. Growth assays determine the growth rates of pigs fed increasing levels of lysine, these growth rates are then compared to those of animals fed a test feedstuff and from this comparison the available lysine content of the feedstuff can be estimated. These assays are laborious and time consuming, are highly variable and the results are difficult to interpret. Reactive lysine assays (e.g. FDNB reactive lysine), which are chemical assays that measure the unmodified lysine content of a feedstuff, do provide an accurate estimate of the potentially available lysine in a feedstuff assuming that all the available lysine was digested and absorbed. However, for many protein sources not all the reactive lysine is digested and absorbed from the small intestine of the animal and therefore reactive lysine assays are not always reliable methods for determining available lysine (Moughan et al., 1996). Ileal digestibility assays measure the lysine content in the feedstuff and also the undigested lysine at the end of the small intestine (ileal digesta) of an animal fed that feedstuff. From the difference between dietary lysine and undigested lysine in the digesta the proportion of lysine that has been digested and absorbed can be calculated. The ileal digestibility assay does accurately determine lysine digestibility for unprocessed proteins as well as the digestibility of most amino acids in
processed feedstuffs but, since this method uses amino acid analysis to determine lysine content in diets and digesta, it does not accurately determine lysine digestibility when applied to processed feedstuffs. Essentially, therefore there is currently no reliable method for measuring available lysine in processed protein sources.

The true ileal digestible reactive lysine assay

The true ileal digestible reactive lysine assay (available lysine assay) has been developed by Moughan and Rutherfurd (1996) and has been thoroughly reviewed (Rutherfurd and Moughan, 2007). The assay combines the guanidination method and a true ileal digestibility assay. The guanidination method (a method for determining reactive lysine) involves the conversion of reactive lysine to the stable compound homoarginine which can then be determined by conventional amino acid analysis. Essentially, the test feedstuff is fed to a group of animals and the digesta are collected from these animals. The reactive lysine content of both the diet and digesta are determined using the guanidination method and the digestibility of reactive lysine is then calculated. This digestibility estimate is corrected to a true digestibility estimate by correcting for the endogenous lysine that is secreted into the pigs small intestine in the form of mucus, digestive enzymes and sloughed gut cells. Correction for endogenous loss is made using the enzyme hydrolysed casein technique (Butts et al., 1991; Moughan et al., 1990). The reactive lysine content of the original feedstuff is also determined and multiplied by the reactive lysine digestibility value resulting in an estimate of the true ileal digestible reactive lysine content of the feedstuff. The digestible reactive lysine content is by definition the available lysine content and as such can be used in the formulation of pig diets.

A comparison of digestible reactive lysine (new assay) with conventional digestible total lysine in a variably heated skim milk powder has been reported by Rutherfurd and Moughan (1997) and is shown in Table 1. For all heat treatments, digestible total lysine overestimated the digestible reactive lysine (available lysine) content. The overestimation ranged from 12% after only 1 min heating to a very large 50% after 10 min heating clearly demonstrating firstly, the inaccuracy of the traditional method in determining available lysine in heated proteins, and secondly, the sensitivity of the new assay in detecting differences in available lysine in proteins that have undergone relatively minor heating.

The assay has also been applied to a range of commercially available processed protein sources (Rutherfurd et al., 1997a). For some protein sources under certain processing conditions the digestible total lysine was similar to the digestible reactive lysine, for example, a blood meal sample (85.9 g kg\(^{-1}\) compared to 85.1 g kg\(^{-1}\)). However, for a number of processed protein sources the digestible total lysine was significantly different from the digestible reactive lysine.
(available lysine) content, for example, cottonseed meal (12.9 g kg\(^{-1}\) compared to 10.3 g kg\(^{-1}\)), heated lactose/casein (45.2 g kg\(^{-1}\) compared to 50.5 g kg\(^{-1}\)) and wheat meal (3.2 g kg\(^{-1}\) compared to 2.9 g kg\(^{-1}\)). These results highlight the inadequacy of the traditional digestibility assay and the value of the new assay for determining digestible reactive lysine (available lysine) in processed feedstuffs.

Table 1. Comparison of the digestible total lysine (conventional digestibility assay) and digestible reactive lysine content (available lysine)(g kg\(^{-1}\) sample) in a variably heated skim milk powder. From Rutherfurd and Moughan (1997).

<table>
<thead>
<tr>
<th>Heating time (min)(^1)</th>
<th>Digestible total lysine</th>
<th>Digestible reactive lysine</th>
<th>Overall SE</th>
<th>Significance</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>36.8</td>
<td>38.1</td>
<td>0.09</td>
<td>***</td>
<td>3.4</td>
</tr>
<tr>
<td>1</td>
<td>31.6</td>
<td>28.0</td>
<td>0.53</td>
<td>***</td>
<td>11.5</td>
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<tr>
<td>3</td>
<td>19.8</td>
<td>16.6</td>
<td>0.25</td>
<td>***</td>
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<tr>
<td>5</td>
<td>13.7</td>
<td>11.0</td>
<td>0.62</td>
<td>*</td>
<td>19.8</td>
</tr>
<tr>
<td>10</td>
<td>11.2</td>
<td>5.7</td>
<td>0.73</td>
<td>***</td>
<td>49.5</td>
</tr>
</tbody>
</table>

\(^1\)Skim milk powder was autoclaved at 121°C for 1 to 10 minutes.

Feedstuffs that have undergone processing clearly contain different levels of available lysine than has been originally thought. This new assay not only highlights a weakness in the evaluation of foods, i.e. the inaccurate determination of available lysine in processed protein sources, but also allows for a more accurate assessment of available lysine and consequently more accurate formulation and description of feedstuffs.

The accuracy of the digestible reactive lysine assay has been evaluated using a detailed validation study with growing pigs (Rutherfurd et al., 1997b). The results from this study clearly demonstrated that the assay accurately predicts the uptake of available lysine in heated proteins and that conversely the traditional ileal lysine digestibility assay is inaccurate.

**Summary**

The reaction between O-methylisourea and lysine (guanidination reaction) can be used to determine structurally unaltered lysine residues in heat-processed feedstuffs. Further, it can be uniquely used to determine structurally unaltered lysine residues in the digesta of animals fed these heat-processed feedstuffs. Therefore, if the guanidination reaction is used in conjunction with a true ileal amino acid digestibility assay the digestibility of reactive lysine can be determined.

**References**


Maximising gilt and sow reproductive performance

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Introduction

Efficiency of pig production can be improved by enhancing and/or extending the reproductive performance of the breeding gilt and sow. Domestic sows commonly experience a depression in fertility during late summer and early autumn. Referred to as seasonal infertility, summer depression of fertility is manifested as a reduced proportion of gilts reaching puberty, extended weaning-oestrus intervals in weaned sows and high anoestrus rates in gilts and sows, as well as increased rates of regular and irregular returns (particularly days 25 – 32 post insemination) (Peltoniemi \textit{et al} 2005).

Strategies to maximise reproductive performance of gilts and sows

One of the many studies related to maximising lifetime reproductive performance of the gilt and sow conducted by the Pig Reproduction Research Group at the University of Adelaide’s Roseworthy Campus, investigated the effects of heat stress due to prolonged exposure to high ambient temperatures on ovarian function and embryo development (van Wettere \textit{et al}. 2009). More specifically it aimed to determine the effects of supplementing gilts diets with betaine (a potent osmolyte and methyl donor) during summer on (i) the timing of the pubertal response to boar stimulation, (ii) ovulation rate and (iii) embryo survival. A total of 84 purebred maternal (Large White) / terminal (Duroc) line gilts were used. Gilts were fed either a standard finisher diet (CONTROL) or a betaine supplemented (2 g / kg) diet (BETAINES) (n = 42 gilts / treatment). Gilts received 3 kg feed per day (13.0 MJ DE/kg, 15.5% CP, 0.6 g available lys / MJ), with diets fed from 23 weeks of age until puberty attainment. Boar contact commenced at 25 weeks of age, and consisted of 20 minutes / day of full contact. Gilts were artificially inseminated at their first observed oestrus. Reproductive tracts were collected 30.6 ± 0.14 days after first mating. The number of corpora lutea (CL) and viable embryos were recorded. BETAINES gilts tended to reach puberty more quickly in response to boar contact compared to CONTROL gilts: 8.0 ± 1.18 versus 11.3 ± 1.23 days (P < 0.1). BETAINES gilts shed approximately 1.1 more ova at their pubertal oestrus; P < 0.05. The number of embryos present on ~day 30 gestation was unaffected...
by treatment, resulting in an observed decrease in embryo survival in BETaine compared toCONTROL gilts: 0.7 ± 0.04 versus 0.8 ± 0.03 (P = 0.06).

**Summary**

Seasonal infertility represents a considerable problem for pig farmers in that it reduces overall fertility & fecundity and causes unpredictable variation in production. Dietary betaine supplementation prior to puberty attainment, as well as during the peri-ovulatory period and gestation, has the potential to improve the thermotolerance of gilts/sows during periods when heat stress is likely to occur (i.e. summer). The physiological maturity of the antral follicle pool is an important determinant of the timing of the pubertal response to boar contact and the number of ova shed at the pubertal oestrus. The current data suggest that betaine supplementation may have resulted in a more mature antral follicle pool at start of boar contact (van Wettere *et al.* 2009).

**References**


**Acknowledgment**

Support for these studies was provided by the CRC for an Internationally Competitive Pork Industry of Australia, and is gratefully acknowledged.
The growth potential of NZ pigs

Maggie Honeyfield-Ross, Patrick C.H. Morel and Ane Visser
Institute of Food, Nutrition and Human Health, Massey University, New Zealand

Introduction
Quantifying the growth potential of pigs is paramount to establish their nutrient requirements and thus to design optimal feeding strategies. The underlying micro-trait for the economically important traits average daily gain, feed conversion ratio and leanness (back fat thickness in NZ) are the maximum protein deposition potential (PdMax), and the minimum lipid to protein ratio in the whole body (TargetL/P). PdMax represents the maximum daily protein deposition rate (g/d) that can be achieved for a certain type of pig, and TargetL/P represents the energy partitioning between lipid and protein deposition when energy intake, but not protein intake, is limiting. In this paper MinLP refers to the slope of a linear regression between the TargetL/P and the daily digestible energy intake.

Both PdMax and MinLP are used in growth models to characterise pig genotypes and are usually determined in slaughter or nitrogen balance studies (Moughan et al., 2006, Weiss et al., 2004). An alternative to these is to record live weight and feed intake in a growth trial, in which pigs are fed special diets. Feed intake curves are then used as input parameters in the pig growth model and simulations are conducted to determine the combination of PdMax and MinLP, which best fit the observed growth curves (de Lange et al., 2001). The results of such a study are presented in this paper.

Material and Methods
A total of sixty one entire males and females pigs from 4 cross-bred genotypes were included in this trial. The average live weight (LW) of the pigs was 31 kg (± 4 kg, SD) at the start of the trial, and the pigs were slaughtered at an end weight of approximately 73.5 kg (± 3.2 kg, SD). In order to find a value for MinLP, the pigs were initially restricted fed a diet which was restricted in energy, but not limiting in protein and/or amino acids (Table 1), for a period of four weeks. The daily feed allowances were adjusted weekly according to Weiss et al. (2004):

\[
\text{kg feed / day} = \left(10.5 + 0.2 \times \text{LW}\right) / 13.43
\]
Following this, a second diet, which was not limiting in either energy or protein, was fed ad libitum up to slaughter in order to allow expression of PdMax. Individual live weight and feed intake were recorded weekly, carcass weight and P2 backfat were measured at slaughter.

**Table 1:** Ingredient composition of the two experimental diets as well as their calculated analysis on as fed basis.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>MinLP diet</th>
<th>PdMax diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>717.0</td>
<td>666.5</td>
</tr>
<tr>
<td>Soybean Meal</td>
<td>240.0</td>
<td>240.0</td>
</tr>
<tr>
<td>Soybean Oil</td>
<td>0.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Lysine</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Methionine</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Threonine</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Mineral + Vitamin</td>
<td>35.5</td>
<td>35.5</td>
</tr>
<tr>
<td>Digestible Energy (MJ/kg)</td>
<td>13.43</td>
<td>14.69</td>
</tr>
<tr>
<td>Ileal digestible Lysine (g/kg)</td>
<td>11.72</td>
<td>11.54</td>
</tr>
</tbody>
</table>

For each individual pig, a feed intake curve and a growth curve were calculated. The feed intake curve and the diet composition were entered in the growth model, simulations were then made for a range of MinLP and PdMax values. Only simulations, in which MinLP and PdMax were the predominant limiting factors for protein deposition in the initial and final phase of the trial respectively, were considered as valid. For each MinLP x Pdmax combination, the sum of square of the difference between the weekly simulated and observed live weight was calculated. The combination of MinLP and PdMax, which yielded the lowest sum of squares, was considered to give the best representation of these parameters for that pig. A linear model with genotype and sex as fixed effects and their interaction was fitted to the data (Minitab 15, 2006). Experimental procedures were approved by the Massey University Animal Ethics Committee.

**Results**

During the first four weeks of the experiment, when the MinLP diet was fed, male pigs had greater ADG and better FCR than female pigs (P<0.05). Larger ADG and better FCR were observed (P<0.05) for genotypes G1 and G3. No differences in FI and MinLP between sexes or genotypes were observed.

Similar results were obtained in the second phase of the experiment when the PdMax diet was fed. Male pigs had greater ADG and better FCR than female pigs (P<0.05). Larger ADG and better FCR were observed (P<0.05) for genotypes G1 and G3. No difference in FI between sex and genotype were observed.
PdMax was higher for entire male pigs than female pigs (181 g/d vs 158 g/d, P<0.05) and was the lowest for G2 (156 g/d) and the highest for G1 and G3 (177 g/d), whereas PdMax for G4 was intermediate (167 g/d). PdMax between the different cross-bred pigs varied between 172 g/d and 186 g/d in the males and between 139 g/d and 170 g/d in the females (data not shown).

Table 2: Least square means and means square error (MSE) for average daily gain (ADG), daily feed intake (Fi), feed conversion ratio (FCR), minimum lipid to protein ratio (MinLP), and maximum protein deposition rate (PdMax) for male and female pigs of four different genotypes (G1,G2,G3 and G4).

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Sex</th>
<th>N</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>Female</th>
<th>Male</th>
<th>MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MinLP</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>ADG (kg/d)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>0.747ab</td>
<td></td>
<td>15</td>
<td>14</td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>30</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>0.707a</td>
<td>133</td>
<td>1.33</td>
<td>1.338</td>
<td>1.36</td>
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<td>1.349</td>
<td>1.345</td>
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<td>1.787</td>
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<td>1.902</td>
<td>1.728</td>
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<td>1.923</td>
<td>1.792</td>
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<tr>
<td>0.025</td>
<td></td>
<td>0.025</td>
<td>0.028</td>
<td>0.026</td>
<td>0.027</td>
<td>0.028</td>
<td>0.025</td>
<td>0.00028</td>
<td></td>
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<tr>
<td>PdMax</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADG (kg/d)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>1.104b</td>
<td></td>
<td>1104b</td>
<td>0.989a</td>
<td>1.102b</td>
<td>1.033a</td>
<td>0.999x</td>
<td>1.114yb</td>
<td>0.014</td>
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</tr>
<tr>
<td>2.078</td>
<td></td>
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<td>2.113</td>
<td>2.071</td>
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<td>0.0152</td>
<td></td>
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<tr>
<td>1.896a</td>
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<td>2.082b</td>
<td>1.939ab</td>
<td>2.036b</td>
<td>2.079y</td>
<td>1.898x</td>
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<tr>
<td>177b</td>
<td></td>
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<td>156a</td>
<td>177b</td>
<td>167ab</td>
<td>158a</td>
<td>181y</td>
<td>521</td>
<td></td>
</tr>
</tbody>
</table>

a,b Values within row with different superscript indicate difference between genotype (LSD, P<0.05)

x,y Values within row with different superscript indicate difference between sexes. (LSD, P<0.05).

Discussion

Over the years, different approaches have been used to describe the partitioning of retained energy between protein deposition and lipid deposition. After re-analysing the data of 13 different studies dedicated to this topic, de Lange et al. (2008) concluded that a simple linear relationship between daily digestible energy intake (DEi , MJDE/d) and target body fatness (TargetL/P) was sufficient to predict the effect of energy intake on body composition when energy but not protein is limiting (TargetL/P = MinLP x DEi). The slope, MinLP, varies between 0.020 and 0.048 in the 13 studies. In our work, the MinLP values ranged from 0.025 to 0.031 for the different genotype x sex combinations. However, no significant differences in MinLP between genotypes or sex were found.

The maximum protein deposition potential of New Zealand cross-breed pigs was measured on three commercial farms in 1992 and values between 143 g/d to 177 g/d were observed (Morel et al., 1993). In this study, entire males had higher PdMax than females (170
g/d vs 148 g/d). Moughan et al. (2006), in a slaughter study with cross-breed pigs conducted at the same time, reported similar PdMax values for males and female pig (170 g/d and 147 g/d, respectively). In the current study conducted 15 years later, PdMax values for male and females pigs are around 10 g/d higher (181 g/d and 158 g/d, respectively). In this study, a 20 g/d difference in PdMax was found between the best and the worst cross-bred pig genotypes (156 g/d for G2 and 177 g/d for G1 and G3). Using the November 2008 price schedule and feed cost, the growth model with optimisation was used to find a feeding strategy which maximised the gross margin per pig place and year for these genotypes. It was found that the 20 g difference in PdMax between G1/G3 and G2 is equivalent to a $38.5 extra income per pig place and year or $7.5 per pig.

It is concluded that the knowledge of the growth potential of current pig genotypes in New Zealand will allow more accurate diet formulation and thus improve profitability. Also, as the correlation between PdMax and MinLP is low (-0.43), both parameters need to be estimated.

References


New developments in pig growth modelling

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Introduction

Pig growth simulation models are used to determine feeding strategies that improve profitability on commercial farms (Parsons et al., 2007). This paper briefly describes recent developments in a commercial pig growth model (PorkMaster) and in a research model (BaconMax).

PorkMaster (www.porkmaster.com)

Paylean: The model is able to estimate the effects of including Paylean in the diet on the growth performance of the pig. Both the dietary inclusion levels of Paylean and the duration of feeding are considered to adjust PdMax and MinLP.

Methane production: Methane production is now calculated by the model.

Nitrogen excretion: The model calculates nitrogen excretion provided that the crude protein and digestible protein contents of the diets are known.

Phosphorus excretion: The total phosphorus content of the diet as well as the apparent faecal phosphorus digestibility are used to calculate Phosphorus excretion. The impact of adding the enzyme Phytase to the diet on phytate-phosphorus availability can also be taken into account. The small increase in energy and amino acid availability when Phytase is added to the diet is also represented.

Genotype Characterisation: Both PdMax and MinLP can be estimated by the model for a given genotype. On-farm recorded live weight and feed intake curves for pigs fed special diets are used as input parameters in the model. Simulations are then conducted to determine the combination of PdMax and MinLP, which best fit the observed growth curve.

Decision Support System (DDS): This version of the model is aimed at optimizing the management strategies on pig production units, and has an enormous potential to improve profitability. The DSS version makes use of a large number of pre-run model simulations (combinations of pig types, feeding strategies, age or weight at slaughter) to quickly evaluate animal and financial performance for a given farm situation.
BaconMax

Pig growth simulation models are used to determine feeding strategies that improve profitability on commercial farms. However, for a given farm, the number of diets fed, their energy (d), amino acid content (r), the quantity fed (p) and the diet period (t) can vary, thus giving a very large number of possible feeding strategies ($F$, as many as $10^{50}$). Adding nonlinear optimisation methods to a growth model allows to find an $F$ yielding the maximum for a given objective function (Alexander et al., 2006). BaconMax links a linear program for least-cost diet formulation, a stochastic pig growth model and a genetic algorithm (GA) to find the $F$ giving a best solution.

A feeding strategy $F$ is a finite set of diets, $F = (d_1, r_1, p_1, t_1; d_2, r_2, p_2, t_2; \ldots; d_n, r_n, p_n, t_n)$, where each diet consists of a quadruple ($d, r, p, t$). The objective function to be maximised is usually the gross margin per pig or per pig place and year but it can be modified to take into account nitrogen excretion cost if there is a need to reduce nitrogen excretion and maintain profitability.

When finding $F$ for maximum profitability, the gross margins obtained by the GA I are higher than that found by random search or by feeding pigs to their maximal lean growth (Figure 1). The objective function is shaped like a high dimensional “craggy mountain” with one peak (Figure 2) (Alexander et al., 2006)

**Figure 1.** Comparison of a genetic algorithm with pure random search, used to maximise gross margin per pig place per year.

**Figure 2.** The approximately conical shape of a section through the objective function at the best known solution.
Minimizing Nitrogen excretion: A simulation study was conducted to investigate how different pig genotypes (fat, normal, lean) and different relative economic weighting for gross margin and nitrogen excretion affect the nitrogen excretion and profitability under practical or optimised feeding strategies in Switzerland (Morel and Wood, 2005). It was found that nitrogen excretion is reduced and profitability increased when the pigs are from a leaner genotype and that a 45% reduction in nitrogen excretion can be achieved with only a 3.5% drop in profitability when diets designed to maximise profitability and to minimise nitrogen excretion are fed (Figure 3).

![Figure 3: Gross margin per pig place and year (GMPPY) and kg Nitrogen excreted per pig place and year for Fat (Δ), Normal (□) and Lean (○) pig genotypes fed either three practical diets (dotted line) or three optimized diets (solid line).](image)

**Stochasticity.** In the growth model, pig genotypes are characterised by the following three quantities: maximal protein deposition potential (Pdmax), minimum lipid to protein ratio (MinLP) and the energy intake potential (p). Variances and covariances of these quantities can be used to grow a population of pigs instead of an average single pig when searching for a feeding strategy which maximizes profitability. In studying the effect of adding stochasticity to the model, it was found (Morel et al., 2008) that for each genotype, the optimal feeding strategy determined for a single pig had a lower lysine to energy ratio than that determined for a population (Figure 4). Feeding the diet which maximises gross margin for a single pig to a population of pigs resulted in lower gross margin for Fat, Normal and
Lean genotypes (NZ$14.1, NZ$11.5 and NZ$6.4, respectively). Therefore, when growth models are used on a commercial farm, it is important that the stochastic parameters (number of pigs, variances and covariances) matches those observed on the farm.

![Graph showing Lysine to digestible energy ratio (r; g/MJ) to maximise profitability for a single pig (solid line) or a population of 125 pigs with a 10% coefficient of variation with (dotted line,) covariance between pig parameters, for Fat (Δ), Normal (□) and Lean (○) genotypes.]

**Figure 4:** Lysine to digestible energy ratio (r; g/MJ) to maximise profitability for a single pig (solid line) or a population of 125 pigs with a 10% coefficient of variation with (dotted line,) covariance between pig parameters, for Fat (Δ), Normal (□) and Lean (○) genotypes.

**Reference**


Development of an animal based tool for the on-farm welfare assessment of pigs

Ian Barugh

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Introduction

The New Zealand Pork Industry has the Code of Welfare 2005 (Pigs) as its primary welfare legislation. It is based on twenty minimum standards and has recommendations for the care of pigs. The minimum standards are primarily facilities based.

The objective of the project detailed here was to quantify animal based welfare outcomes by observing pigs and pig behaviour and linking this into good husbandry practices. Firstly welfare indicators were identified to assess and quantify the on-farm welfare status of pigs. Secondly a system (welfare assessment tool) was developed to interpret these indicators and link them to the 20 minimum standards contained in the Code of Welfare 2005 (Pigs). The “tool” developed had to fit the following criteria; be a valid measure of pig health and welfare, accurate in providing a true reflection of the current welfare status, reliable and repeatable, robust and practical and clear and adaptable. Thus the tool would be suitable for use by various inspectors, in a range of production systems.

Welfare indicators

The welfare indicators were selected in consultation with parties of interest including pork producers, pork industry representatives and technical staff, pig veterinarians, National Welfare Advisory Committee and the Royal New Zealand Society for the Prevention of Cruelty to Animals.

The aim of the project was to “capture” in a formal manner the husbandry skills of farm staff and to quantify the concept of “stockmanship” and “stock sense”.

Welfare assessment tool

The “tool” developed had a series of primary animal based indicators including, vocalisation/noise, appearance (skin and body condition), behaviour, mobility and faeces condition linked to minimum standards.

Supplementary sheets were developed to expand and quantify the primary indicators listed to provide indices for reference and provide ranges of acceptable limits. These
supplementary sheets included a body condition score chart and tables for calculations of prevalence of lesions and injuries.

Supplementary information: Hunger and thirst

a. Animal indices

Interpretation of the generic animal based indicators, specifically applied to hunger and thirst, includes the following:

Vocalisation / noise
If the animals have insufficient access to water, the noise level may be elevated, and there may be squealing etc. This is related to Behaviour and Mobility (see below).

Physical appearance
- Primarily consider the body condition score (refer to an appropriate chart):
  - This should be appropriate for the production stage
  - It is also important to note the variability (between individuals and between groups)
  - No animals should have a score under 2.5, except where the caver can demonstrate that remedial action is being undertaken. Depending on the cause, euthanasia may need to be considered as an alternative to alleviate suffering
- Hunger and thirst may also lead to competitive aggression, which may be visible as skin abrasions and lesions.
- Indicators of chronic underfeeding may include prominent backbone and a flabby appearance. There may be a higher prevalence of unhealthy sows than expected.
- In some (especially in outdoor systems), the Zucker shape may indicate too little access to water.

Behaviour
Behavioral indicators of hunger and thirst include:
- Agitation and restlessness, fighting.
- Restlessness.
- Attraction to water: the pigs will smell and compete for a bucket of water, if introduced into the pen.

Figure 1: Primary animal based indicators

Scoring animal based indicators

The animal based indicators were scored by the assessors via a traffic light system of green, amber and red. If an amber or red score was recorded, follow up action to identify the cause was undertaken to determine if there was a breach of minimum standard as per the Code of Welfare 2005 (Pigs).

The tool is designed to be modular, i.e.: tailored to farm-specific production features / system thus allowing assessment of multi site and multi shed production systems which are common in New Zealand’s pork production industry.
On-farm experience

On-farm experiences using the animal based indicators tool demonstrated the tool was:

- Practical and quick to use
- Different assessors achieved similar scores
- It was animal-focused first, environment-focused second
- It was sensitive, i.e. highlighted the issues
- The query / comments section on the sheet was useful to expand upon various observations

Future use

Development of this “welfare assessment tool” and its validation by on-farm experience has lead to the submission of a research proposal to validate the tool as a true indicator of animal welfare. Validation is crucial in providing assurances and demonstrating that the subjective assessment provided by the “welfare assessment tool” meets the standards of the objective measures provided by the Code of Welfare 2005 (Pigs).
Movement of disease conveyors between New Zealand pig farms:
frequency and distance patterns

Eric Neumann, Massey University; Alan Pearson, Prime Consulting International Ltd; Robert Sanson, AsureQuality Ltd; Karen Nicol, AsureQuality Ltd, and Frances Clement, New Zealand Pork Industry Board

Introduction

A study was conducted with the aim of identifying movement patterns of disease conveyors in the New Zealand pork industry. The extent of interactivity between farms in commercial, para-commercial, and non-commercial sectors was evaluated.

Principal objectives were:
Objective 1: Identify the movement patterns of potentially important disease conveyors amongst pig holdings in New Zealand; and
Objective 2: Determine the social network structure within and between the commercial, para-commercial, and non-commercial pig sectors of the New Zealand pork industry.

Methodology

The study was carried out in three phases, involving a combination of postal questionnaires and telephone interviews. Existing databases held by NZ PORK and AsureQuality Ltd (AgriBase) were used as base data to generate the study sample frame.

Phase I – Postal Questionnaire Study

The first phase of the study was a postal questionnaire mail out comprising an AgriBase update form (to update/capture basic farm profile information) and a supplementary questionnaire designed to capture specific information directly related to the objectives of the study. The questions included coverage of the following areas of interest:

- All major disease conveyors known to be involved in the transmission of Foot and Mouth Disease and Classical Swine Fever;
- Type and number of conveyors involved (pigs, semen, feed, effluent, people, trucks and others);
- Frequency and distances for movement occurrences;
- Direction of movement (away from the farm, toward the farm, between farms); and
- Miscellaneous other relevant characteristics.
Data from the completed postal questionnaires were entered into a database format by AsureQuality staff. The data from the AgriBase update form were entered into AgriBase and the supplementary information specific to this study were entered into a separate relational database developed specifically for the project. The database was constructed in SQL-Server, and the data-entry forms were designed and implemented as Web forms using Cold Fusion. When data entry was completed, data from both databases were extracted and merged into a combined Microsoft Access dataset that was provided to Massey University for quantitative analysis.

**Phase II – In-depth Telephone Interviews**

For the second phase of the study, data from the postal questionnaires were stratified into three sector groups (commercial, para-commercial and non-commercial) and 20 in-depth telephone interviews were conducted per sector on a random sampling basis. The purpose of these interviews was to provide context to the quantitative data collected in the first phase of the study and to understand better the social and relational networks operating within and between the three identified sectors of the pig industry.

**Phase III – Regionally-based Farm Service Provider Study**

In order to cross-validate information gained from pig owners in the earlier parts of the study and to explore further the network of off-farm interactions, a regional service-provider based study was undertaken as the final phase of data collection.

This study was designed to collect detailed information on the nature and quantity of pig farmer/owner interactions with other pig farmers/owners, industry vendors, feed suppliers and other social contacts. Through consultation with MAF, central Canterbury (bounded roughly by the Waimakariri River on the north and the Rakaia River on the south) was chosen as the specific focus region for this work.

A list of farm service providers operating in the area was collated from various industry sources and a standardised data capture form developed. Respondents were contacted by telephone to obtain the data required.

**Findings**

**Response Rates**

The commercial sector questionnaire was posted to a total of 275 pork producers registered with NZ PORK and of these, 127 were returned. This equated to an overall response rate of 46.2% thus meeting the 40% minimum desired response rate. Out of the 127 surveys that were returned, 114 respondents (90.6%) reported currently having pigs on their premises.
The non-commercial/para-commercial survey was mailed to 6980 farms that were identified as owning pigs and of these, 1814 (26.0%) responded to the survey. This exceeded the 20% minimum desired response rate for this sector. 1363 of the 1814 (75.1%) that responded reported they still owned pigs and were included in the final dataset for analysis. All respondents not owning pigs were purged from the dataset and analysed separately. In total, 1477 records were obtained for quantitative analysis.

Representativeness and Data Reliability

The responses obtained were geographically representative of the known distribution of the New Zealand pork industry. In terms of demographic representation there is little or no existing reliable demographic data with which to compare the survey results. Detailed commentary on data reliability is presented in the full report.

Key Risk Conveyors

Key disease risk conveyors identified were:

- Pigs and other livestock;
- Semen;
- Vehicles;
- Household/kitchen waste; and
- People

InterSpreadPlus Parameters

An important outcome of the current work has been the development of seven farm type definitions suitable for use in ISP. These farm type definitions captured elements of pig inventory (and phase of production), their risk of transmitting disease onward to another farm (their “movement off” profile), and their stability over time (i.e. were they highly motivated to be in the business, or more likely to go in/out as conditions changed?).

Movement frequency and distance parameters were calculated for movements of potential disease conveyors on/off and between the seven ISP farm types.

Importantly, this study was able to generate information from an adequate number of farms (n=1477) such that estimates of disease conveyor movement frequencies and distances will be per farm valid.

These estimates have been supplied to MAF so that additional analyses may be done to support current and future disease modelling efforts.

Social Network Analysis
Whilst extensive information was obtained in this study to describe the general patterns of movement of pigs and disease risk conveyors in the NZ pork industry and also related risk behaviours, detailed social network diagrams were unable to be constructed as that would have required a level of precision in the data that was not available.

**Conclusions**

The major conclusions of this study are as follows:

- Risk factors for disease introduction and transmission vary by farm enterprise type;
- Farm staff and feed (notably kitchen waste on less commercial farm types) appear to be the most common potential disease conveyors arriving onto NZ pig farms;
- For specific farm types (particularly larger commercial farms with breeding sows), introduction of germplasm through semen or live breeding stock was also a frequent occurrence and for others, weaner pigs coming onto the property was a potential source of disease introduction;
- People (staff and visitors, travelling both to homes and saleyards), abattoir-destined pigs, and cattle movements are frequent events in terms of movements off farms where there are pigs;
- Vehicle movements potentially are a major risk factor for disease transfer between farms (although it is important to note that most of the vehicle movements on and off farms in this study were not to/from another farm);
- It is common for stock both on and off properties to travel long distances from point to point.

Combined with the relatively low density of pig farms in many areas of New Zealand, this suggests that an exotic disease in the pork industry may appear as resulting from a multi-point source introduction of an agent, when in fact it could have as likely been caused by a single introduction, but spread rapidly over long distances through movement of livestock or other vectors.

- Interaction between the three main farm types (commercial, para-commercial and non-commercial) appears limited.
- Proportionately, the para-commercial sector has more movements of store/weaner pigs and more pigs kept outdoors than the other two sectors as well as fewer movements of pigs direct to abattoirs for slaughter. The practices in this sector may warrant future study to evaluate the relative risks arising from their more extensive use of outdoor facilities.
- Saleyards are used more by the non-commercial and para-commercial sectors. However, the use of saleyards, even by these sectors, appears to be an infrequent
event. Relatively, not many pigs go through the saleyard with most movements of pigs instead being direct from farm to farm.

- 80% of stock moved off farms in the commercial/ non-commercial sectors go to abattoirs, as do 70% of stock moved off para-commercial properties. Abattoir movements need more study. Even if the per-event risk is small, the frequency and distances make the ultimate risk of disease transmission a concern. Abattoirs are certainly important as surveillance points in this sector.

- Other cloven-hoofed livestock are common on New Zealand farms that also have pigs, making interspecies disease transfer a realistic possibility.

- Staff are the most frequent movements on/off many farms. We don’t know if they really contribute much individual risk (how long does a pig pathogen last on your hair, your tonsils, your boots, etc?) but in sum, they are responsible for a lot of on/off movement.
Environmental update: issues and opportunities

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The New Zealand pork industry is a relatively small but significant sector of the Country’s agricultural economy, with a strong track record in pro-active environmental management.

Notwithstanding this situation, New Zealand pork producers are heavily regulated under the current Resource Management Act (RMA). Because the RMA is administered by local Councils and applied through their staff, the levels of control applied vary from region to region and from district to district. This variation applies across the full gamut of activity classifications – from permitted, through controlled, through restricted discretionary to discretionary.

For a relatively small farming sector, operating in regions with similar land use profiles and similar environmental issues, the variation is extraordinary.

The cost to the pork industry of engaging in policy making processes, and for individual pork producers in complying with consent requirements, is out of all proportion to the scale of the sector, the nature and scale of effects, and any real gains for the environment.

The recently elected Government has committed to a wide-ranging programme to reform the RMA, presenting significant opportunities to re-balance the administration of the RMA in support of sustainable pork production.
Introduction

The number and nature of compounds responsible for the flavour of pork is not known, and for those compounds that do seem to have an effect, the nature of that effect is seldom well understood, as it will often depend on the level present and on the presence of other compounds that it interacts with.

The study of pork flavour, and meat flavour generally, is further complicated by the fact that the overall perception of flavour at the brain level is a result of the combined inputs from the taste-buds in the tongue and the aroma sensors in the nose. In addition, the concept of what constitutes an acceptable flavour may differ significantly between individuals. The latter problem can be overcome to some extent, however, by using trained sensory panellists who have been selected on the basis of their ability to detect small differences, and then trained to provide consistent descriptions of certain flavour “notes”.

Despite these challenges, a large amount of research into factors affecting pork flavour has been conducted around the world, as it is an aspect of pork quality that consumers place considerable importance on.

In this short paper some of the concerns about the flavour of New Zealand pork on the Singapore market will be considered, along with an outline of some approaches that are being taken to address this issue through research at Massey University in collaboration with the Singapore Polytechnic.

Concerns about pork flavour on the Singapore market

Anecdotal comments from Singapore over several years have suggested that there are aspects of the flavour of pork from New Zealand and Australia that make it somewhat less acceptable than pork from pigs raised in Indonesia. The problem flavour note has been variously described as “milky” or sometimes “mutton-like”. In order to investigate this formally, Leong, et al. (2008) conducted a survey amongst pork-consuming Singaporeans and found that, relative to pork from Indonesia, that from New Zealand:

- Was purchased less because of its tastiness (33.8% of respondents vs 82.7% for Indonesian pork),
- Had “flavour” identified as a reason for not buying it more often (70.2% of respondents vs 20.9%),
Had “Milky flavour” as well as “Mutton-like flavour” identified as being more relevant as descriptions of undesirable flavours aspects.

These results, although based on a relatively small sample of consumers (n = 202), were consistent with the anecdotal evidence already available and indicated that methods of minimising these undesirable aspects of the pork flavour should be investigated.

**Approaches to overcome flavour concerns**

If it is accepted that there is something of a problem as described above for pork flavour, then means of overcoming or minimising it need to be considered. The two approaches adopted at the research level so far have been:

1. To investigate ways of masking the undesirable flavours by adding a desirable flavour of some sort. Some preliminary work has been done at Massey in this area (Janz et al. 2007)

2. To conduct feeding trials with pigs in order to identify dietary components that may be responsible for these flavour notes.

**The use of flavourful herbs and spices with pork in Singapore**

It was considered that items to be tested for their potential to mask undesirable flavours should be natural products that are normally consumed with pork in Singapore, so a survey of 112 consumers who used natural products when cooking or consuming pork was conducted. In this survey the extent of use of 39 plant-based flavourful items was determined. On a scale where 0 indicated no use and 4 indicated that an item was used always when cooking or consuming pork, garlic received the highest average score (3.21), closely followed by onion and ginger (Leong et al. (2008). On the basis of these results it was decided that the use of garlic oleoresin to improve the acceptability of NZ pork should be investigated.

**Approaches to incorporating garlic flavour into pork**

Two possible approaches to incorporating garlic flavour into pork are:

1. To introduce the oleoresin after the pork has been produced by mixing it with a minced product or by injecting it into an intact piece of pork, and

2. To include it in the diet of pigs at a level that will produce a garlic flavour in the resulting pork products.

Both of these approaches are being investigated, because, while the former method probably can be more controlled and almost certainly would require less garlic oleoresin, it results in a product that is not pure pork in the way that the second approach does. Pure unadulterated garlic-flavoured pork from the second approach may be more acceptable to some consumers.

The first step in research of this nature is to determine the amount of garlic oleoresin that is required in order to impart the desired flavour notes. This was done initially in an oil
base with minimal flavour (rice bran oil), and then the results obtained were used to determine the amounts that should be added to pork mince. Threshold levels have been determined for consumers from both New Zealand as well as Singapore over a range of eight concentrations in rice bran oil, and four concentrations within pork mince. The results obtained from the two countries were similar with increasing concentrations of garlic oleoresin leading to increases in garlic taste intensity (as expected), and a decrease in mutton taste intensity for the mince. The patterns were more clear-cut with the Singapore consumers, possibly because they were more familiar with the garlic taste and had an aversion to the seldom experienced mutton taste. In addition the acceptability of the garlic taste within mince increased as the concentration increased for consumers in Singapore, but not for New Zealand consumers.

For a trial where garlic oleoresin was added to the diet of pigs for a period of 57 days prior to slaughter (final weight = 88 kg), there were three levels of garlic oleoresin administered and half the pigs received a diet without animal products to give a total of eight groups. Triangle tests with consumers in both New Zealand and Singapore were unable to distinguish between the control pork and that from the low garlic group pigs, but did detect the garlic at the medium and high garlic levels for diets with or without animal products.

Evaluation of the same pork by a trained sensory panel in Singapore for a range of aroma and taste notes showed that with increasing garlic oleoresin in the diet, the strength of garlic flavour increased and the strength of mutton flavour decreased regardless of whether the diets had included animal products. However, the strength of mutton flavour was assessed as being greater when animal products were included in the diet of the pigs.

**Effects of different diets on the acceptability of pork flavour**

Investigations into the effects of dietary components on the strength of various flavour notes (including mutton-flavour notes) has been investigated in conjunction with trials assessing dietary approaches to improving the nutritive value of meat. One trial led to the development of the supplement Sanovite®, which resulted in pork with elevated levels of Se, vitamin E, and CLA, along with some other improvements (Morel et al., 2008). The same trial included diets containing no animal products, but a trained sensory panel in New Zealand detected no significant differences in a range of flavour and odour notes between pork from pigs that had or had not received animal products in their diets (Janz et al., 2008).

This was not the case for a trained sensory panel in Singapore, however. They found that pork from pigs that had animal products in their diet had a stronger mutton flavour and a weaker meaty flavour. This suggests that even after training, the Singapore panellists were more sensitive to the mutton flavour note than those in New Zealand.
Studies are currently underway to determine the extent to which this undesirable mutton-like flavour may be linked to concentrations of skatole and indole, as these compounds have been shown to be associated with undesirable flavour in other contexts.

More research needs to be conducted to determine which of the animal products (meat & bone meal, tallow, blood meal) in the finishing diet was responsible for these differences.

Conclusions

- Pork flavour is an important quality characteristic for consumers that is not fully understood.
- Pork from New Zealand has been characterised by studies in Singapore as being more likely to have a “mutton-like” flavour.
- Preliminary studies suggest that this undesirable flavour note may be effectively masked by garlic oleoresin for Singapore consumers. The garlic oleoresin may either be added to the pork or to the diet of pigs.
- There is some evidence that the mutton-like flavour note is detected more readily by Singaporeans than New Zealanders, and that its source may be from animal products in pig diets.

References


Pork storage and shelf life

*Yvette Cottam, Brian H.P. Wilkinson, Karin Weidgraf and Roger W. Purchas*
Introduction

The shelf life of fresh pork is largely determined by three factors: the number of bacteria that are present on the freshly cut pork surfaces at the time of packaging; the temperature at which the pork is stored; and the type of packaging material and gaseous environment surrounding the pork in the package. If all four factors are optimised then microbial numbers present on the freshly cut surfaces prior to packaging should be at a minimum and their subsequent growth rates should also be at a minimum thus ensuring long shelf life pork.

To achieve storage of ≥ 7 weeks the bacterial load on the eviscerated cooled pork carcasses must be ≤ 2 log cfu cm$^{-2}$, as by 8 weeks of vacuum package storage this bacterial load (mainly lactic acid bacteria) is ≥ 6 log cfu cm$^{-2}$, the maximum number for acceptance by some consumers (Holley et al., 2004).

Where do the microbes come from?

There are many sources of microbial contamination in the slaughter of pigs and it is important from both a health and a shelf life perspective that the contamination points be identified and controlled. The three major contamination sources are: faecal, pharyngeal and environmental (Borch et al., 1996a). The number and types of bacteria present on the carcass, and hence the cuts, arises as a consequence of both indirect and direct contact with the animal’s skin, trotters, gut contents, faecal material and of course contaminated equipment and table surfaces (Huis in’t Veld et al., 1992). The extent of the microbial transfer between these sources depends on the hygiene and sanitation practices before and during processing and handling, and of course storage and distribution of the finished product (Koutsoumanis and Sofos, 2004). The stages of possible contamination are presented in Figure 1.

The microbial numbers and types present on the freshly slaughtered carcasses is a reflection of the micro-organisms acquired by the animal on the farm, between the farm and the slaughter-house, and on the slaughter-house floor, i.e., equipment and surfaces (Huis in’t Veld et al., 1992).

Whilst risk management programmes, hazard analysis and critical control point (HACCP) programmes (part of a risk management programme) and the sanitation standard operation procedures (SSOP) (also a part of a risk management programme). HACCP programmes have all been instituted by most New Zealand slaughter plants, there is a need for these programmes to be extended from the processing plant back to the farm and from the slaughter-houses to the final customer.
Microflora

There are two types of micro-organisms of interest to the pork industry: those that cause illness (food-poisoning), and those that cause spoilage (Huis in't Veld et al., 1992). Meat and meat products are responsible for a major fraction of all food-borne infections (Huis in't Veld et al., 1992). The main pathogenic microflora of interest to the pig slaughter industry include Aeromonas hydrophila, Campylobacter coli/jejuni, Listeria monocytogenes, Salmonella spp., Staphylococcus aureus and Yersinia enterocolitica (Borch et al., 1996a). Aeromonas and Shewanella spp. are facultative anaerobes, can grow at –1°C, and are often found in vacuum-packed pork (Holley et al., 2004). Campylobacter jejuni/coli is an important cause of enteritis in humans, although they do not grow below 30°C, have a low heat resistance and are sensitive to drying and freezing, so are not a major problem if pork is stored under normal cold storage conditions (Borch et al., 1996a). The pig is the most important source of Yersinia enterocolitica infection in humans (Nesbakken et al., 1994).

Salmonella typhimurium appears to be the most important serotype in pigs (Huis in't Veld et al., 1992), and Salmonellosis is well recognized as a major health threat to consumers of pork and pork products (Beloeil et al., 2004). An estimated 15% of all salmonellosis cases in The Netherlands were associated with the consumption of pork (Berends et al., 1998a). Both Salmonella and Pseudomonads are the predominant spoilage bacteria in pork products (Liu et al., 2006). One study in the Netherlands demonstrated that there was a direct relationship between the prevalence of Salmonella-positive pigs, carcasses and pork, and pork-associated Salmonellosis (Berends et al., 1998a). If this is something that is happening in general then a reduction in the number of positive pigs will lead to a decrease in Salmonellosis in humans. In general, Salmonella typhimurium does not cause clinical illness in pigs (van der Gaag et al., 2004).

The main spoilage micro-organisms on pork are Pseudomonas, Lactobacillus, Brochothrix thermosphacta, Clostridium perfringens, Aeromonas putrefaciens (produces hydrogen sulphide) and Enterobacteriacea. A complete list of genera associated with the contamination of meat/poultry can be seen in a paper by Koutsoumanis and Sofos (2004). The bacterial species that ultimately causes the spoilage of meat is dependent on a number of factors, such as the dominant species at the time of packaging, the pork pH, the storage temperature and the gaseous environment surrounding the meat in the pack.

Table 1. Micro-organisms from pork implicated in food-borne disease, their minimal growth temperature and method of eliminating or restricting their growth
<table>
<thead>
<tr>
<th>Organism</th>
<th>Ideal growing conditions</th>
<th>Killed by</th>
<th>Notes</th>
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<tbody>
<tr>
<td><em>Salmonellae</em></td>
<td>Intestinal parasites</td>
<td>min 7°C</td>
<td>Inhibited by CO₂</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>Intestinal</td>
<td>min 7°C</td>
<td></td>
</tr>
<tr>
<td><em>Campylobacter jejuni</em></td>
<td></td>
<td>min 32°C</td>
<td>Cooking</td>
</tr>
<tr>
<td><em>Yersinia enterocolitica</em></td>
<td></td>
<td>min –1°C</td>
<td></td>
</tr>
<tr>
<td><em>Listeria monocytogenes</em></td>
<td>Humans/pig carriers</td>
<td>min 0°C</td>
<td></td>
</tr>
<tr>
<td><em>Clostridium perfringens</em></td>
<td></td>
<td>min 12°C</td>
<td></td>
</tr>
<tr>
<td><em>C. botulinum</em></td>
<td></td>
<td>min 3°C</td>
<td></td>
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(McClure, 2002)
(Sivertsvik et al., 2002)

Generalised pork production summary.

Figure 1 presents a summary of a generalised pork production flow diagram showing possible sources of microorganisms (MOs) together with approaches to minimising the number of microorganisms from each source and/or minimising the growth of those microorganisms already present. Some plants may not use some of the operations in their slaughter process. For instance a number of New Zealand plants do not use singeing and if they do it is often just a very light singe.

Approaches to reduce or minimize microbial numbers on pigs before arrival at plant

Live animals can be carriers of pathogenic bacteria, with high numbers of bacteria present on the skin, both ‘normal flora’ of the skin and organisms of soil, water and faecal origin (Koutsoumanis and Sofos, 2004). There are many factors influencing the numbers/species of organisms present on the animals, including climate, geographical location, method and distance of transportation and holding conditions at the plant. For example, soil bacteria are more common on animals raised on pasture, whereas enteric origin
bacteria are more common in animals raised in pens (Koutsoumanis and Sofos, 2004). The number of live animals that carry *Salmonella* spp. is strongly correlated with the number of contaminated carcasses at the end of the slaughter line (Berends et al., 1997), with this cross-contamination estimated to account for 29% of the positive carcasses (Botteldoorn et al., 2003).

If we take Salmonella as an indicator organism, it has been found that the spread of this microbial contaminant, and hence other micro-organisms, is very likely to occur during transportation, where animals are in close contact with each other (via body contact) and with floors/surfaces contaminated by other infected animals (Koutsoumanis and Sofos, 2004). Research has failed to establish a relationship between visibly dirty animals and the microbial condition of the carcass, therefore it is thought that the processing is more important than the condition of the skin (Koutsoumanis and Sofos, 2004).

The cleaning and disinfection of lairage pens has been shown to decrease the prevalence of culturable *S. enterica* in these pens, but the ability of this to reduce the prevalence in live pigs was not conclusive (Schmidt et al., 2004). An alternative to the use of holding pens at abattoirs and the associated risk of the spread of *Salmonella enterica* between pigs, is to hold the pigs in the transport trailers until slaughter. This has been shown to decrease the levels of infected animals entering the slaughter plant (Rostagno et al., 2005). The microbial condition of the live animal is of paramount importance for the microbiology and food safety of the consumer end products in relation to food-borne infections (Huis in't Veld et al., 1992). A reduction in the numbers of Salmonella and other micro-organisms in the intestines at pre-harvest can reduce the contamination at later stages (Beloeil et al., 2004). The feeding of coarse-ground grains in comparison to fine-ground grains is known to decrease the proportion of Salmonella-positive pigs, as the coarse particles stimulate the microbiota and the production of organic acids such as lactic acid, lowering the
**Figure 1.** A generalised pork production flow diagram showing possible sources of microorganisms (MOs) together with approaches to minimising the number of MOs from each source and/or minimising the growth of those MOs already present (adapted from Borch et al., 1996a).
pH in the stomach (Kim et al., 2005). The inclusion of sodium chlorate in pre-slaughter feed suppresses pathogen numbers in the gut (Anderson et al., 2001).

The time between the last meal and slaughter does affect the fullness of the stomach, a full stomach will pose a higher risk of puncture during dressing (Borch et al., 1996a) and the numbers of bacteria released from the stomach/caecae are affected by feed withdrawal. Coliform numbers and *E. coli* biotype 1 numbers in the stomach were not affected by feed withdrawal (for 15 hours prior to dispatch from the piggery to the abattoir) but the holding time (holding at abattoir for an additional 0-1, 2-3 or 4-5 hours) showed a decrease in the numbers between the 0-1 and 4-5 hours (Nattress and Murray, 2000). Caecal coliforms and *E. coli* biotype 1 increased as a result of feed withdrawal, and also as a result of holding time up to 4-5 hours. These results show that in the event of the release of stomach or caecal contents onto the carcass, larger numbers of *E. coli* would be released from the caeca and fewer from the stomachs of those pigs not subject to feed withdrawal (Nattress and Murray, 2000). The prevalence of caecal lacerations was not associated with feed withdrawal time, suggesting that feed withdrawal will not increase contamination of carcasses by increasing caecal lacerations (Morrow et al., 2002). Recommendations of time between last meal and slaughter range from 16 to 24 hours (Murray, 2000).

There is potential for a change in the bacterial flora in the digestive tract due to feed withdrawal, with the concentration of *E. coli* biotype 1 (an indicator species), for example, increasing by one order of magnitude with 20 hours compared with 5 hours fasting post-slaughter (Nattress and Murray, 2000). This suggests that feed withdrawal may decrease the potential of nicking the GI tract, but if any content does leak out the consequences may be magnified. The information is summarised in Table 2.

**Table 2. Effect of 20hrs off feed on microbial numbers in stomach and caecum**

(Murray, 2000) 20h feed withdrawal on farm vs abattoir

<p>| | |</p>
<table>
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<tbody>
<tr>
<td>Stomach pH</td>
<td>- 12%</td>
</tr>
<tr>
<td>Lactic acid bacteria</td>
<td>- 3.5%</td>
</tr>
<tr>
<td>E.coli</td>
<td>- 8%</td>
</tr>
<tr>
<td>Caecum pH</td>
<td>+ 1%</td>
</tr>
<tr>
<td>Lactic acid bacteria</td>
<td>same</td>
</tr>
<tr>
<td>E.coli</td>
<td>+ 8%</td>
</tr>
</tbody>
</table>

**Approaches to reduce or minimize microbial numbers on pigs when they arrive at the meat plant.**
The time in lairage has been shown to affect the spread of pathogenic bacteria, with pigs known to lie down after about 1½ hours after arrival at the slaughter plant, therefore increasing the risk of cross-contamination (Warriss, 2003).

Visible contamination of the living animal has little effect on the microbiological condition of the carcass (Gill, 2004), and washing the pigs pre-slaughter has no effect or even increases the microbiological contamination of carcasses (if the pigs are wet). This concurs with the results of Bolton et al., (2002), who found washing the pigs pre-slaughter (power-hosing at 1030 kPa, water 19°C) decreased the number of Salmonella on the skin of pigs, from 27% (on-farm) to 10% (after washing) incidence, although subsequent stunning/bleeding increased the incidence to 50%, so pre-slaughter washing was not considered an effective control measure. However, recent studies with cattle and sheep at New Zealand plants suggests that washing these animals with chlorinated water (100 ppm free chlorine) has been quite effective in reducing subsequent carcass microbial numbers and as a consequence leading to extensions in shelf life (Personal communication, Neil Smith, Silverfern Farms).

**Approaches to reduce or minimize microbial contamination during stunning, bleeding and dehairing.**

The first possible contamination step in the pig slaughter process is sticking, which is a potential source of microbial contamination from contaminated equipment. This is usually not a problem if good manufacturing principles are followed.

The following pig dressing processes that include scalding, dehairing, singeing, polishing are major sources of cross-contamination (Koutsoumanis and Sofos, 2004). Despite the clean appearance of the pig carcass after these processes, these carcasses may be heavily contaminated with bacteria (Gill and Bryant, 1993).

Scalding, the immersion of the carcass in a tank of water (60°C for 8 minutes) results in the destruction of most bacteria on the surface of the skin (Koutsoumanis and Sofos, 2004). However, scalding at temperatures less than 60°C results in little kill of Salmonella and E.coli species (Koutsoumanis and Sofos, 2004). Scalding can also be carried out in a vat of steam (Borch et al., 1996a). A time-temperature combination of 60°C for 1.4 min was required to achieve a 1 log reduction in Salmonella in scald water, which is equivalent to 65°C for 0.18 minutes (Bolton et al., 2003). Gill et al., (1995) found that a temperature of 85°C for 20 seconds reduced the total numbers of bacteria by 2 orders of magnitude, and reduced non-thermoduric spoilage bacteria from 50% to 10%. No further reduction in surviving flora numbers/composition was observed with a higher temperature or a longer time.

Dehairing, the mechanical removal of the hair by rotating drums with scraper blocks which rotate the carcass and remove the hairs, is a source of recontamination by faecal matter
It is well known that the dehairing step has a large potential for cross-contamination of carcasses (Warriner et al., 2002). Dehairing equipment is a likely source of contamination of pork by mesophilic enteric pathogens (Gill and Bryant, 1993), which are removed with the scalding but are re-deposited on carcasses by dehairing equipment. One way to prevent the contamination by dehairing equipment is the use of chemical dehairing (Koutsoumanis and Sofos, 2004).

The greatest reduction of skin bacterial load is achieved by singeing or flaming, with recontamination commonly occurring at the scraping/polishing step (Huis in't Veld et al., 1992). Singeing (800-900°C) or flaming (1000°C) for a total of 10-15 seconds, reduces the microbial count on the skin but is dependant on the temperature/time combination used (Borch et al., 1996a). Reduction in microbial numbers only occurs when the skin is singed/flamed at temperatures that will produce a toasted colour to the skin (Borch et al., 1996a). If singeing and flaming only raise the surface temperature of the carcass, but does not produce a toasted colour, then it fails to reduce or eliminate the bacterial contamination on the surface of the carcass (Yu et al., 1999; Borch et al., 1996a; Gill and Bryant (1992)).

Research has shown that \textit{E.coli} from the scraper/dry polisher became distributed on wet polisher blades, band saws and butchers’ hands, even though the carcasses went through a singing step after being dry-polished (Warriner et al., 2002).

Polishing is carried out by stainless steel scrapers or nylon brushes, and contributes to spreading the microbial population over the surface of the carcass as bacteria may become established on the brushes/scrapers (Borch et al., 1996a). Scraping and polishing have been reported to re-contaminate carcasses (Rivas et al., 2000; Yu et al., 1999; Gill and Bryant, 1993), whereas Gill and Bryant (1992) found bacterial numbers to decrease after polishing. The microbiological condition of polished carcasses can be improved by heating the carcass surface with sheets of water at 85°C (pasteurizing treatment) (Gill and Jones, 1997), although these carcasses are recontaminated during the dressing period (Gill and Jones, 1998).

Berends (1997) estimated that, after singeing, 5-15% of contamination of carcasses with \textit{Salmonella} spp occurred during the polishing step, 55-90% during current evisceration practices and 5-35% from further processing.

The gut contents is well known as a major source of carcass contamination (Bolton et al., 2002). Therefore, skilled, trained operators are very important, as damage to the intestines and contamination of the skin must be avoided (Huis in't Veld et al., 1992).

As a consequence, evisceration is a key step in cross-contamination by Enterobacteriaceae, with significant (P<0.05) increases in carcass counts on post-eviscerated carcasses (Warriner et al., 2002). This concurs with the results found by Rivas et al., (2000). One of the major ways of stopping some of this cross-contamination is by sealing off the rectum with a plastic
bag immediately after it has been freed. The enclosed rectum is then withdrawn from the body thorough the abdominal incision with the intestines attached. A study has shown that the spread of *Y. enterocolitica* O:3/biovar4 to pig carcasses can be considerably reduced by this procedure (Nesbakken et al., 1994).

Decontamination of carcasses can be carried out by ‘safe’ substances such as lactic acid (Berends et al., 1997). However, steam pateurization cannot be used because it increases the deleterious effects of PSE and results in excessively pale muscles of non-PSE susceptible pigs (Gill and Jones, 1997). However, such decontamination procedures are still not allowed for most species here in New Zealand.

**Approaches to reduce or minimize microbial contamination on carcasses during chilling and retail cut preparation.**

The muscle tissue of healthy pigs is in principle free of micro-organisms (Huis in't Veld et al., 1992). Some species of micro-organism, such as *Campylobacter* spp., are not very hardy, according to Huis in't Veld et al., (1992) who showed, for example, that there is very low survival of these organisms after overnight chilling. The conditions during storage, processing and handling have a more important impact on the types of micro-organisms present on carcasses than the initial density (Koutsoumanis and Sofos, 2004).

The temperature of a carcass increases from 37°C to 40°C immediately post-slaughter, due to metabolic activity taking place in the muscle pre-rigor (Koutsoumanis and Sofos, 2004). The application of an efficient cooling process is extremely important, to decrease the possibility of rapid pathogenic bacterial growth on the warm carcass surface (Koutsoumanis and Sofos, 2004). A temperature of 7°C is accepted as the lower limit below which most pathogenic bacteria do not proliferate, therefore the carcass must be chilled to this temperature before it is sent for further processing (Koutsoumanis and Sofos, 2004). A number of factors influence the efficiency of the cooling process, including chilling capacity, patterns of air flow in the chiller, arrangement and spacing of carcasses (Koutsoumanis and Sofos, 2004).

The drying of the skin of the carcass can also affect the microbial population, the drying out causes a decrease in bacterial load, although the loss of carcass weight is economically undesirable (Koutsoumanis and Sofos, 2004). The spraying of chilled water during the first few hours of cooling prevents these weight losses, and can assist in the cooling process as a consequence of evaporative cooling.

Normal carcass chilling procedures are rapid chilling followed by slower chilling. Blast chilling (-30°C to -10°C for 1 to 1.5 hours) to reduce the surface skin temperature as quickly as possible to the air temperature followed by cold room storage (3 to 5°C overnight to 3 days) (Borch et al., 1996a). Under commercial conditions, the exposure of carcasses to a
blast of freezing air before conventional chilling is likely to substantially improve the hygiene efficiency of the chilling process (Gill and Jones, 1992). However, care must be taken to ensure that cold-shortening does not occur as this can lead to unacceptably tough pork.

Carcass cooling processes must be well controlled to contain the possibility of rapid proliferation of both pathogenic and spoilage bacteria on the meat while it remains warm (Gill and Jones, 1997). Carcasses may be contaminated during the chilling process by contact with contaminated surfaces/hands, water splashes or from the air, although the main concern during the cooling process is not new contamination, but the growth/survival of existing organisms (Koutsoumanis and Sofos, 2004).

The cleaning of equipment plays a role in the spread of bacteria, if equipment is not effectively cleaned and sanitized, the potential for debris to be left behind in machinery such as bandsaws, conveyor belts, trolleys or in bins or table tops leads to contamination of carcasses (Yu et al., 1999). It is known that many bacteria are susceptible to drying, therefore the cleaning and drying of equipment used in processing is an important step in improving microbiological safety of pork (Gill and Landers, 2004). Effective cleaning/disinfecting of workers hands plays an important role in reducing the potential for contamination of carcasses (Koutsoumanis and Sofos, 2004).

**Approaches to reduce bacterial numbers and/or growth by packaging and/or storage conditions**

- packaging-types (air, high O₂-MA, vacuum, no O₂ MA, 100% CO₂)
- temperature

Spoilage is generally due to a small fraction of initial microflora, which become dominant through handling and storage of the products. Pork products which undergo the most handling and processing are likely to be of the poorest microbiological quality (Duffy et al., 2001). Storage of meat under chill temperatures inhibits the growth of some pathogenic microorganisms, but not others (Sivertsvik et al., 2002). For example, *Listeria monocytogenes* is able to multiply under chill temperatures, and *Clostridium botulinum* is able to multiply in anaerobic conditions. Interactions between the different species of microflora are also important in the overall spoilage of pork products (Liu et al., 2006), for example, lactic acid bacteria show antagonistic activity on coliforms and *Salmonella*, whereas yeasts were antimicrobial on lactic acid bacteria.

Before storage, pork has been found to have a flora of around $10^3$ cfu cm⁻², including a number of spoilage organisms such as pseudomonads, enterobacteria, *Brochothrix thermosphactica* (Gill and Jones, 1996). Spoilage of moist fat occurs when the microbial
population is $\geq 10^6 \text{ cm}^{-2}$, whereas muscle spoils when microbes $\geq 10^8 \text{ cm}^{-2}$, therefore bacterial spoilage of fat is likely to precede that of muscle tissue due to fat surfaces being more heavily contaminated initially than muscle surfaces and the lower levels needed (Gill and Jones, 1996).

**Modified Air Packaging**

The development of modified air packaging (MAP), mainly to extend shelf life of products, has resulted in increased shelf life and higher quality, in response to consumer demand (Sivertsvik et al., 2002). MAP involves replacing the air in a package with a fixed gas mixture, the 3 main gases used are oxygen, nitrogen and carbon dioxide, usually in combinations of 2 or 3 (Sivertsvik et al., 2002). These gases have different properties, carbon dioxide inhibits the growth of bacteria and moulds, nitrogen inhibits the oxidation of fats and pack collapse, and oxygen prevents anaerobic growth (Rao and Sachindra, 2002). For products with high levels of unsaturated fats, like pork, with shelf-life limited by microbial growth and oxidative rancidity, a gas mixture of CO$_2$ and N$_2$ is recommended, with complete removal of O$_2$. Many other gases have been tested, for example carbon monoxide, ozone, helium, ethylene oxide, but regulations, safety concerns, reduced sensory quality or economic factors have limited their use. The microflora development of vacuum-packaged pork cuts stored for 8 weeks was related to the pH and also the fat content of the meat, with faster and more extensive microbial growth on cuts of higher pH and fat content (Blixt and Borch, 2002).

The atmosphere in MAP changes with time. The gas composition changes with time owing to the diffusion of gases in and out of the product, the permeation of the gases in/out of the pack (no pack except aluminium foil laminated pouches exclude the diffusion of gases) and the product and microbial metabolism (Church, 1994). Also the effect of the modified atmosphere has different effects on the various types of micro-organisms in the pack, for example *Pseudomonas* and enterobacteriaceae are more inhibited by MAP than lactic acid bacteria (Rao and Sachindra, 2002).

Vacuum and CO$_2$ packaging has been shown many times to reduce or inhibit the survival or growth of pathogens on meat products, for a summary of these see review by Rao and Sachindra (2002). For example, CO$_2$ has an inhibitory effect on Salmonella, and the degree of inhibition is increased as the storage temperature decreases. Lactobacilli replace spoilage organisms in MAP fresh meat as they are less sensitive to CO$_2$ (Rao and Sachindra, 2002).

For retail cuts of meat, if the time between meat cutting and display is short, then simple over-wrapped trays are used (Gill and Jones, 1996). If longer storage is desired, it is necessary to use modified atmospheres such as the addition of N$_2$. After one or two days the
stored pork had a less desirable appearance than fresh product. If longer storage times are required then vacuum or CO₂ storage is best (Gill and Jones, 1996). This same study showed that if chops were stored under either N₂ or CO₂ then their appearance was similar to fresh pork chops after 42 days of storage. Moreover, chops stored under vacuum or CO₂ for 42 days showed no objectionable odours, whereas those stored under N₂ for 28 days or longer, or O₂+CO₂ for 21 days or longer had stale sour odours. The results of the study indicated that the storage time of pork chops under N₂ or O₂+CO₂ was around a week, and was >3 weeks if stored under CO₂ (Gill and Jones, 1996). Other studies have shown that storage lives of ≥ 8 weeks are feasible so long as the hygiene in the cutting room is superb, the pork is packaged in CO₂ packs and the stored packs are held at – 1.5°C (Holley et al., 2004).

MAP and VP products are ‘safe’ so long as they are held at correct chill storage temperatures (≤ 4°C) (Rao and Sachindra, 2002), whereas under inadequate storage conditions both Clostridium botulinum and C.perfringens could grow and produce toxins, causing food poisoning.

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Healthy pork

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Introduction

Animal fats are generally perceived as having negative health effects. However, research has shown the fatty acid composition of the meat/fat from production animals can be changed to provide a healthier fatty acid profile by altering the animals’ feed. Fatty acids such as omega-3 and CLA have been found to have a variety of positive health effects such as improving the immune system and reducing inflammation. The opportunity therefore exists to produce ‘healthy pork’, a product which confers measurable health benefits to the consumer by altering the fatty acid composition of the meat and fat through the pig’s diet.

Previous research at Massey University (Morel et al., 2008; Janz et al., 2008) produced a ‘healthy pork’ meat that contains elevated levels of omega 3 fatty acids, CLA and selenium, each of which are known to stimulate the immune system. This work showed that these changes in nutrient composition could be achieved efficiently and effectively. In this study, mice were fed either a standard diet as a control or a ‘healthy pork’ based diet to determine if consumption of the healthy pork based diet resulted in a measurable enhancement of the immune system.

Material and Methods

Forty male 6-7 week old BALB/c mice bred and housed at the Small Animal Physiology Unit, Massey University Palmerston North were used for this experiment. The mice were housed as pairs in cages in a controlled atmosphere with a temperature of 22±2°C, humidity of 55±2°C and a 12 hour light-dark cycle. Before the experiment began, all mice received the control diet for a two week period as a washout for the effects of their previous chow feed diet. After the end of this two week pre-feeding period, the mice were randomly allocated to either the control or experimental diet, with each diet group and cage of paired mice balanced for weight. Feed and water were available ad libitum, and feed intake was recorded daily. The ‘healthy pork’ based diet contained nutritionally enhanced pork meat as the protein component and fat from the nutritionally enhanced pork as the fat component, whereas in the control diets these nutrients came from wheat/ casein and coconut oil respectively. The ingredient and chemical compositions of the diets are presented in Table1.
The test and control diets were fed for four weeks following which the mice were humanely killed by isofluorane overdose. Blood was collected via cardiac puncture into EDTA vacutainer tubes for use in the whole blood phagocytosis assay (Rutherfurd-Markwick et al., 2005). Peritoneal macrophages were harvested for phagocytosis and spleens were removed aseptically for use in the cell proliferation assay (modified version of Rutherfurd-Markwick et al., 2005). The mice were then skinned, the head, feet and tail removed and discarded, and the remaining carcass kept frozen until the body composition (water, ash, protein and fat content) was chemically determined. All experimental procedures were approved by the Animal Ethics Committee of Massey University. Data was analysed by ANOVA using a general linear model using Minitab statistical software. A P value of <0.05 was considered as statistically significant. Results for spleen weights and body composition were adjusted for live weight.

### Table 1: Ingredient composition and analytical compositions of the diets

<table>
<thead>
<tr>
<th>g/kg</th>
<th>Control</th>
<th>Healthy Pork</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>596</td>
<td>596</td>
</tr>
<tr>
<td>Casein</td>
<td>200</td>
<td>0</td>
</tr>
<tr>
<td>Pork Meat (90% Dry Matter)</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>Coconut oil</td>
<td>150</td>
<td>0</td>
</tr>
<tr>
<td>Pork Fat</td>
<td>0</td>
<td>150</td>
</tr>
<tr>
<td>Others</td>
<td>54</td>
<td>54</td>
</tr>
</tbody>
</table>

| % Dry matter | 628.0   | 671.2        |
| % Ash        | 33.8    | 38.7         |
| %Protein     | 251.3   | 261.9        |
| %Fat         | 188.9   | 194.3        |

- % Saturated fat 893.8 | 436.7
- % Monounsaturated fat 61 | 260.9
- % Polyunsaturated fat 45.5 | 301.5
Total CLA (mg/100g) ND | 0.052
Total Omega 3 (mg/100g) ND | 0.078
Total Omega 6 (mg/100g) 0.0024 | 0.040
Vitamin E (ug/g) 37.64 | 36.75
Selenium (mg/kg) 0.21 | 0.86

ND= Not detected

**Results**

Mice fed the pork diet had a higher growth rate and a better feed conversion ratio than mice fed the control diet (Table 2). There were no differences in chemical body composition (data not shown: 18.0 % protein, 10.0 % fat, 3% ash and 67.2 % water) between the mice fed on the 2 different diets. Mice fed the ‘healthy pork’ diet had a greater level of peripheral blood leukocyte phagocytic activity than those fed the control diet (table 2, 60.1 % vs 39.7 %, P< 0.001), however, peritoneal macrophage phagocytic activity was not affected by the dietary treatment. Lymphocyte proliferative responses to mitogens are widely used to assess
T- and B-cell function. Mice fed the pork diet had a higher level of lymphocyte proliferative activity after stimulation with the T-cell mitogen concanavalin A than those fed the control diet (Table 2, 289 vs 128 P<0.05). A similar enhancement of lymphocyte proliferative responses to the B-cell mitogen lipopolysaccharide was observed in mice consuming the pork diet compared to the control fed animals (Table 2, 169 vs 99, P<0.05).

Table 2: Least square means and standard error (SE) for growth and immune parameters of mice fed the control diet or the pork diet.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Pork</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Growth Parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growth rate (g/d)</td>
<td>0.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.19&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.006</td>
</tr>
<tr>
<td>Feed Intake (g/d)</td>
<td>5.45</td>
<td>5.28</td>
<td>0.095</td>
</tr>
<tr>
<td>Feed conversion ratio</td>
<td>33.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>29.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.02</td>
</tr>
<tr>
<td>Starting Weight (g)</td>
<td>21.2</td>
<td>21.1</td>
<td>0.57</td>
</tr>
<tr>
<td>Final Weight (g)</td>
<td>25.7</td>
<td>26.3</td>
<td>0.65</td>
</tr>
<tr>
<td><strong>% Cells with Phagocytic Activity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood leukocyte</td>
<td>39.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>60.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.69</td>
</tr>
<tr>
<td>Macrophage</td>
<td>84.1</td>
<td>87.1</td>
<td>2.56</td>
</tr>
<tr>
<td><strong>Lymphocyte proliferation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phytohaemagglutinin (T-cell)</td>
<td>77.1</td>
<td>99.4</td>
<td>15.6</td>
</tr>
<tr>
<td>Concanavalin A (T-cell)</td>
<td>128&lt;sup&gt;a&lt;/sup&gt;</td>
<td>289&lt;sup&gt;b&lt;/sup&gt;</td>
<td>49.0</td>
</tr>
<tr>
<td>Lipopolysaccharide (B-cell)</td>
<td>99&lt;sup&gt;a&lt;/sup&gt;</td>
<td>169&lt;sup&gt;b&lt;/sup&gt;</td>
<td>21.2</td>
</tr>
</tbody>
</table>

<sup>a,b</sup> Values with different superscripts within rows are different from each other (P<0.05)

Discussion

While the pork diet significantly enhanced the feed conversion ratio and growth rate, this did not follow through to differences in body composition between the groups. The fact that leukocyte phagocytosis and lymphocyte proliferative responses increased following consumption of the healthy pork diet indicates that this diet is able to specifically enhance aspects of natural and specific cellular immune function in mice. Since an optimally functioning immune system is essential for host defence against invading pathogens and diseases, consumption of a diet which is able to enhance immune function may lead to greater resistant to infection and disease. The burgeoning functional foods industry, coupled with consumers becoming more health aware means there could be an opportunity for a product such as this in the market place. However, further research is first needed to establish if similar enhancement of immune responses would occur in human subjects consuming ‘healthy pork’ and also to determine what aspects of the meat produce the immune enhancement seen.

Reference
