Improving piglet birth weight and survival through better maternal hygiene and nutrition in gestation

by

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Declaration

I declare that this thesis is a record of original work and contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief, this thesis contains no material previously published or written by any other person, except where due reference is made in the text.

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Literature Review

Introduction

Profitable pork production is a challenge in an increasingly competitive and diverse market. The implications of increasing interest in welfare-conscious pig production are that pig producers must develop innovative strategies in order to maintain commercial viability (van Barneveld 2003).The Australian pork industry must be able to compete against beef, chicken, lamb and seafood industries. Many variables alter the productivity of a breeding herd. Simplified, these include nutrition, disease, temperature, housing, stocking density and herd age; each affecting the health of the breeding herd and piglets and therefore, determining the productivity.

Traditionally, piglet health has been studied because of its economic importance, as the pig industry is confronted with substantial losses due to piglet mortality (van Rens *et al.* 2005). More recently, increased sensitivity towards animal welfare suggests that there is further need for research in the area (Tuchscherer *et al.* 2000). Foetal growth has been enhanced greatly due to selection, with foetal weights at 110 to 114 days gestation now 50% greater than those reported 27 years ago (McPherson *et al.* 2004).

Many factors affect in utero growth rates of foetal pigs at different stages in gestation. One factor is sow nutrition (McPherson *et al.* 2004). If maternal nutrient intake is insufficient, the health of the piglets is negatively affected, along with the reproductive longevity of the sow or gilt (McPherson *et al* 2004). Implementation of efficient feeding strategies for gestating sows is therefore an important management practice and, as feed prices continue to increase, is also important in the management of production costs (Shelton *et al.* 2009).

This review will discuss the current body of knowledge concerning maternal nutrition in late gestation and the effects of immune system activation on nutritional requirements and sow reproductive efficiency, as assessed by sow fat stores, piglet birth weight, farrowing duration, placental weight and piglet survival.

Nutrient requirements of gestating sows

Approximately two-thirds of a sow's life is spent in gestation. Resources devoted to the sow throughout pregnancy are an important consideration and a major determinant of the success or failure of a farm (Hughes & Varley 1980). Nutrition of sows plays an increasingly important role in sow reproduction, and has become a limiting factor, with nutrient deficiencies possibly explaining the difference between potential and actual performance of sows (Noblet *et al*. 1997). In gestation, maternal nutrients are directed primarily towards the growth and support of foetal tissues (McPherson *et al*. 2004). The nutrient supply for sows during gestation must meet requirements for maintenance, as well as for the development of foetal tissue (NRC 1998).

In early pregnancy, the demands of the litter are relatively low and nutrient requirements are not particularly critical (Mahan & Vallet 1997). Sow nutrient requirements increase exponentially in mid to late gestation, as this is the period of maximum foetal growth, as shown in Figure 1 (Miller *et al.* 2000; McPherson *et al*. 2004; Shelton *et al.* 2009).
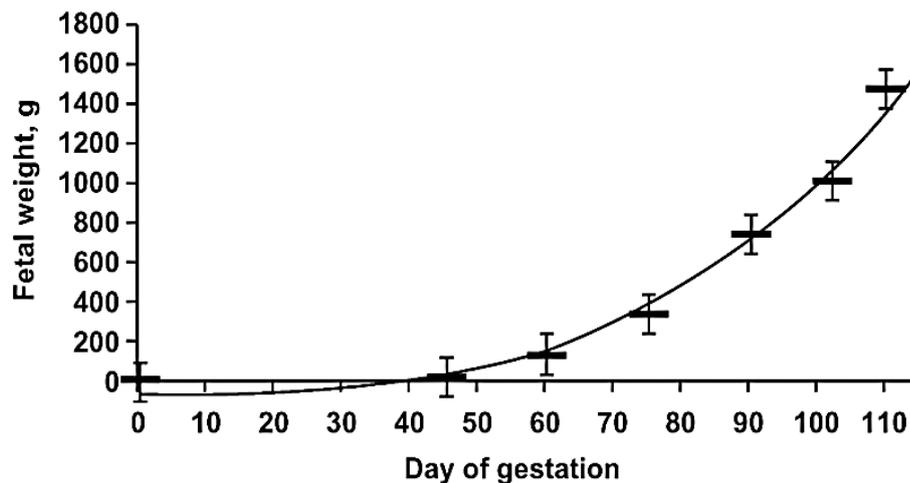
Figure 1: Foetal weight increases cubically (P>0.001) as day of gestation progresses
(Figure from McPherson *et al*. 2004)

The increase in protein required for foetal growth limits the protein available for maternal use (McPherson *et al*. 2004). Additional dietary protein is, therefore, necessary to support mammary gland growth and increased use by piglets. Protein requirements for mammary development are approximately 11 g/d (McPherson *et al.* 2004; Kim *et al.* 2005). One foetus, on average, uses 0.25 g/d of protein for growth, until day 69 of gestation, after which it utilises 4.63 g/d (McPherson *et al*. 2004). Hence, for example, if there were 12 piglets in a litter, the protein allocation for foetal tissues would be 3 g/d before, and 55.6 g/d after, day 69 of gestation. Fat accretion in the foetus also increases following the 69th gestational day (McPherson *et al*. 2004). Moser and Lewis (1981) observed positive effects on piglet survival when fat was added to sow diets in late gestation.

Management of increased amino acid requirements in gestation must allow for both foetal and mammary gland growth, but must avoid excess deposition of fat (Kim *et al.* 2009). In general, the lysine requirement of pregnant sows is higher than at any other stage of the reproductive cycle (NRC 1998). Kim *et al* (2009) found that amino acid requirements increase after day 60 of gestation. The suggested daily intakes of lysine, the first limiting amino acid, from day 0-60 and day 60-114, are 5.57 g and 8.78 g respectively, with the need for other essential amino acids also increasing (Kim *et al.* 2009).

Energy intake of sows during gestation is important, as it has been found to determine future reproductive success, sow body condition and lactation success (Long *et al*. 2010). Energy needs depend on required body weight gain and other management and environmental factors (Aherne & Kirkwood 1985).There are many contrasting reports, and clearly further research is required, to determine the energy requirements of gestating sows. For example, the National Research Council Committee on Animal Nutrition highlighted the energy requirements of the sow in gestation as between 6,015 and 6,395 kilocalories (25.18-26.77 MJ) of metabolisable energy per day (NRC 1998). Long *et al.* (2010) concluded that, with the more modern genotype, the energy intake of sows should be between 6,530 and 6,720 kcal

(27.34-28.14MJ) of ME/d, a significant difference from 8,500 kcal (35.59MJ) of ME/d suggested by Dourmad *et al* (1996). Energy intake is positively correlated with piglet birth weight, a major determinant of piglet survival, as illustrated in Figure 2.
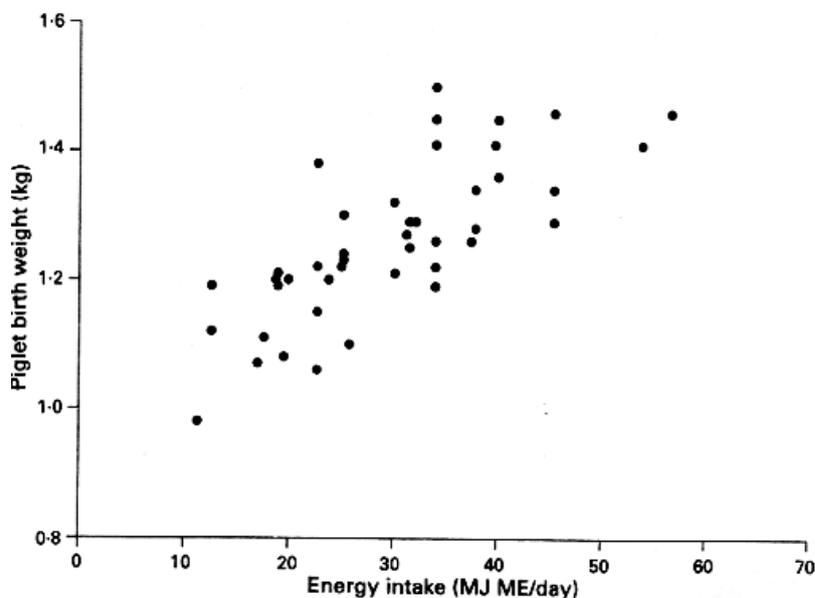
Figure 2: Influence of energy intake of the sow during gestation on piglet birth weight (summary of 14 experiments)
(Figure from Aherne & Kirkwood 1985)

Glucose is another important nutrient in the sow diet and is a major energetic substrate for foetal growth (Han *et al.* 2009). To meet the increasing foetal energy demand, glucose tolerance in sows decreases towards the end of gestation, with greater piglet mortality rates in sows that display less glucose tolerance (Han *et al.* 2009).

Practices of gestational sow feeding

There are contrasting reports regarding the most effective method of gestational sow feeding. Most research conducted on the relationship between feed intake during late gestation and piglet birth weight was conducted primarily in the 1960s to 1980s, using older genotypes (King *et al*. 2006). This research reported that the pattern of feeding during gestation had no effect on sow or piglet performance, suggesting that sows should be fed with no changes to the diet throughout gestation, known as flat rate feeding (Elsley *et al*.1971). However, Barker

et al. (1997) found that piglet birth weight and weaning weight increased as sow intake increased, concluding that a slight increase in feed was beneficial during pregnancy.

Later reports also revealed some benefit to increasing feed in late gestation; such as the study by Miller e*t al*. (2000), in which sow condition was maintained throughout lactation with an increase of 1.6 kg per day. Other authors suggest that, even with the increased feed intake of 2lb (0.9 kg), there is still a significant amount of back fat loss in both sows and gilts during lactation (Shelton *et al.* 2009). One point that is agreed by many papers, according to Aherne and Kirkwood (1985), is that litter size is not correlated with gestation nutrition, as opposed to factors such as sow weight gain and foetal weight.

Phase feeding is the most commonly used method of gestational sow feeding and its use is supported by literature (Cromwell *et al.* 1989; McPherson *et al*. 2004; Young *et al.* 2004; Jackson 2009; Kim *et al.* 2009). Phase feeding involves increasing the feed intake of gestating sows in late gestation, or from day 70 of gestation, correlating with the increase in foetal growth and allowing for increased nutrient requirements (McPherson *et al.* 2004; Kim *et al*. 2005; King *et al*. 2006).

Cost is a major factor when deciding the feeding strategy of sows and phase feeding is cost effective (Kim *et al*. 2005; Jackson 2009). Cromwell *et al*. (1989) suggest that the increase in feed costs over the last 4 weeks of gestation are offset by increased piglet survival, increasing the number of pigs per litter at weaning. However, further research into phase feeding is needed. There are clear differences in experimental results even when presented in the same year (Jackson 2009; Kim *et al.* 2009; Shelton *et al.* 2009). Immune activation, discussed later, could possibly be one explanation for the differences between study outcomes from different research facilities.

Effects of changes to nutrient intake in gestating sows

When nutrients in gestation are insufficient foetal and sow growth can be affected, as well as sow longevity and reproductive efficiency (McPherson *et al.* 2004). Nutritional deprivation throughout gestation may affect sow fertility negatively in subsequent parities (Miller *et al.* 2000). The follicles that ovulate after weaning first emerge from the primordial pool of follicles in late gestation. This is believed to be the reason that fertility is affected for later litters by the alteration of late gestation nutrition, as available nutrients may affect the quality of the emerging oocyte (Miller *et al.* 2000). Increasing intake during late gestation is also believed to prepare the digestive tract for increased food intake during lactation, which also affects follicle function and growth (Miller *et al.* 2000).

Sows enter into lactation in a catabolic state if the constant daily allowance throughout gestation does not meet the increased needs of the sow and the developing litter (Miller *et al.* 2000). The period from 100 days onwards is most commonly the time at which gestational sows become catabolic (Miller *et al.* 2000). Catabolism results in reduced birth weights, weaning weights, poor milk production and increased sow mortality (Baker *et al.* 1997; Jackson 2009).

When sows are fed high energy diets, piglet glycogen stores are greater than controls for 6 hours after farrowing, providing the piglet with a boost of energy in the hours following birth (Elliot & Lodge 1977). The usual high fibre diet that sows are fed frequently has inadequate glucose, providing insufficient energy to maintain foetal growth in the final weeks of gestation (Han *et al.* 2009). Gestating sows are efficient at maintaining the level of nutrients reaching the foetus, by using their body tissues as reservoirs for the necessary nutrients. The implications are that energy restriction usually has a relatively low effect on the piglets due to the sow's buffering system, however, the sow is negatively affected (Elliot & Lodge 1977).

This is also evident with other nutrients. For example, in lactation, phosphorus and calcium are required in large amounts and the sow will draw from her bones in order to maintain adequate levels in the milk (Mahan & Vallet 1997).

Increasing feed intake may also have negative effects. In particular, increased intake in late gestation may increase the incidence of agalactia, a failure to secrete milk following farrowing (Miller *et al.* 2000). Obesity at farrowing may result from increased feed intake, affecting the voluntary feed intake after farrowing and therefore leading to an unwanted weight loss during lactation, which in turn can affect milk production and subsequent reproduction (Kim *et al.* 2009).The contradictions within the literature make it difficult to assess which is the safer option, to restrict gestating sow nutrients or risk overfeeding.

Sow Fat stores

Sow body reserves are directly correlated with reproductive efficiency (Beyga & Rekiel 2010). Adaptation of pregnancy feed supply to maintain or replenish sow body reserves, thus supporting growth and subsequent lactation, is an important management practice (Aherne & Kirkwood 1985; Noblet *et al.* 1997; Young *et al*, 2004). The body condition of sows, determined by both fat and protein stores, directly affects reproductive performance throughout the entire reproductive cycle and is therefore an important factor when attempting to achieve optimal production targets (Maes *et al.* 2004; Beyga & Rekiel 2010). There are two methods commonly used to measure body condition, the objective body scoring system and the more precise method of measuring P2 back fat. Assessment of back fat depth is important as it is linked with altered productivity in subsequent litters, especially in gilts (Maes *et al.* 2004).

The effect of an undesirable fluctuation in body condition during the reproductive cycle may not be apparent for several months or parities (Maes *et al*. 2004). There is a significant negative correlation between back fat and the number of pigs weaned per sow and, additionally, sows with less back fat at the end of gestation produce a higher percentage of

stillborn piglets (Maes *et al.* 2004). High back fat levels in the sow at farrowing may also increase incidences of dystocia (difficult labour), and therefore stillbirths, as well as resulting in more rapid depletion of fat stores throughout lactation (Maes *et al.* 2004; Beyga & Rekiel 2010). Young *et al.* (2004) concluded that back fat can be used as a precise measure of whether individual sows should have increased feed in later gestation. By assigning a target back fat and adjusting feed in late gestation, based on where the sow is in relation to that target, the author found an improvement in the proportion of fat or thin sows at farrowing.

Effect of change to maternal nutrient intake on piglets

Farrowing duration and stillbirth

Many factors affect farrowing duration and stillbirth, including nutrition and environment. The interval preceding birth is an important factor in determining the survival of piglets through parturition. Long farrowing durations, high birth weight, litter size over 9, previous litter size over 12, increasing sow age and parity and late placement in the birthing order all increase the probability of stillbirth (Zaleski & Hacker 1993). Overweight sows are known to be a significant factor for slow farrowing and increased numbers of stillbirths (Zaleski & Hacker 1993). Tuchscherer *et al.* (2000) found that neonates at risk of pre-weaning mortality displayed significantly lower weights at birth and were born later in the birth order.

Piglet birth weight and survival

It is well established that the birth weight of the piglet is influenced by overall nutritional status of the sow during gestation (Elliot & Lodge 1977). As previously shown (Figure 2), piglet birth weight is positively correlated with an increase in digestible energy intake during the last trimester of gestation, when there is an increase in energy demand for foetal growth (Aherne & Kirkwood 1985; Cromwell *et al.* 1989; Miller *et al.* 2000; King *et al.* 2006). Birth weight is one of the major factors shown to be positively correlated with piglet survival (Walker *et al.* 1981; King *et al.* 2006).

It is estimated that an increase in birth weight of 200g can increase weight gain from birth to slaughter by 24 g a day (King *et al.* 2006). Low birth weights are associated with increased mortality, reduced weaned pig quality and slower growth rates (Tuchscherer *et al.* 2000; Walker *et al.* 1981). Approximately 80% of pre-weaning mortality occurs during farrowing and the first three days after birth (Tuchscherer *et al.* 2000). One reason put forward for the correlation between birth weight and survival is that increased weight results in improved insulative protection of the piglets and therefore they are less likely to become chilled after farrowing (Moser & Lewis 1981).

The placenta

Birth weight is highly dependent on placental nutrient supply, which is largely determined by placental size (van Rens *et al.* 2005). The roles of the placenta include the provision of an immune interface between mother and foetus and the transport of nutrients and waste products. Changes in the maternal environment, including nutrition, regulate substrate supply and the hormonal environment of the foetus, affect birth weight, development of the foetus, litter size and postnatal survival rate (Myatt 2006; Vallet & Freking 2007).

Low placental weight and low foetal weight are positively correlated, as placental size limits foetal growth (Myatt 2006). A useful measurement, used from 6 weeks to term, is the foetal/placental weight ratio, which is used as a measurement of placental efficiency (van Rens *et al.* 2005; Myatt 2006; Vallet & Freking 2007). Up to day 60 or 70 of gestation the placenta is in a constant state of growth and differentiation, after which the size of the placenta becomes fixed. Any change in environment, including sow nutrition, after day 70 of gestation will affect the foetus but not placental size. Therefore, placental/foetal weight ratio can be used to determine the change in weight of the foetuses in late gestation following the change in input (Vallet *et al.* 2009).

The impact of immune system activation on nutritional requirement

Hygiene management

In modern, high-density production systems swine live surrounded by pathogenic organisms. It is relatively rare for a pig to become ill, as they are equipped with a highly evolved immune system (Johnson *et al.* 2001). There are many factors affecting the hygiene of the building in which animals are maintained including; ventilation and heating, shape and dimensions of the building, effluent management systems, watering and feeding systems, stocking density and the level of cleaning and disinfection (Cargill *et al.* 2002). Cleaning is an essential aspect of all production systems. In the few studies recorded, pressure hosing was found to be an effective method of cleaning, compared to other methods, such as scraping and non-pressure hosing (Cargill *et al.* 2002). Using disinfectants after cleaning has also been shown to have a positive effect on hygiene (Cargill *et al*. 2002).

Immune system activation

The immune system is part of the host defence against foreign bodies, pathogens and the antigens they exhibit (Saker 2006). The immune system is typically divided into two categories, innate and adaptive. Innate immunity refers to nonspecific defense mechanisms, including physical barriers such as skin, and first response cells such as neutrophils and some macrophages. Adaptive immunity refers to antigen-specific immune responses. Once an antigen has been recognized, the adaptive immune system creates cells specifically designed to attack that antigen (Kubena & McMurray 1996; Saker 2006).

The principal cells involved in adaptive immunity are lymphocytes, which exist as two major types: B cells and T cells (Kubena & McMurray 1996; Saker 2006). B cells are produced in bone marrow; they are stimulated by certain antigens and secrete antibodies. T cells are non-antibody-producing lymphocytes which are also produced in the bone marrow, sensitized in the thymus, and constitute the basis of cell-mediated immunity (Saker 2006).

A complex variety of mediators are released from the cells of the immune system, these include immunoglobulins, complement proteins, platelet-activating factor and cytokines (Grimble 1998). During the acute phase response bacterial products, such as lipopolysaccharides, stimulate the release of cytokines, which are involved in signalling between the cells of the immune system and also in modifying metabolism (Williams *et al.* 1997a; Sauber *et al.* 1999; Stahly 2001; Colditz 2002).

Nutrition, growth and cytokine action

It is now widely accepted that animals in high pathogen environments neither grow well nor eat well, even when there is no clinical disease evident (Johnson *et al.* 2001; Le Floc'h *et al.* 2004). Immune system activation is associated with disruption of several metabolic pathways and modifications of nutrient utilisation (Grimble 1998; Le Floc'h*et al.* 2004). The effect of disease and immune system activation on growth rate and efficiency of food conversion is of economic importance. The potential for increased prolificacy, profitability and welfare has led to many studies into the mechanisms through which immune responses affect growth (Spurlock 1997; Williams *et al.* 1997a; Williams *et al.* 1997b; Williams *et al.* 1997c; Sauber *et al.* 1999; Saker 2006).

Anorexia, depressed protein synthesis and increased protein degradation in skeletal muscle can all be detected in immune system activated animals (Williams *et al.* 1997a; Le Floc'h *et al.* 2004; Saker 2006). The endocrine and metabolic shifts induced by immune activation depress appetite and feed conversion efficiency and result in a reduced rate of growth (Sauber *et al.* 1999; Stahly 2001). Sauber *et al.* (1999) researched the effect of immune system activation, induced by injection of lipopolysaccharides, on the lactational performance of sows and found that milk protein, energy and volume were all negatively affected. Williams *et al.* (1997b) concluded that greater intake requirement, low growth rates, low feed conversion efficiency and low muscle content, all apparent with stimulation of the immune response, were due to cytokine release and the associated endocrine changes. Stimulation of

cytokine release in chicks has been found to decrease feed conversion efficiency by 17% compared to controls (Williams *et al.* 1997b).

Cytokines are peptides and proteins involved in signalling between the cells of the immune system and in modifying metabolism (Grimble 1998). Specifically, cytokines released by lymphocytes are called lymphokines whilst those from macrophages and monocytes are monokines (Martin & Resch 1988). They are stimulators for their own continued production and, therefore, animals may experience a cascade of cytokines (Grimble 1990). The production of cytokines is part of a very effective mechanism for the creation of an environment hostile to pathogens (Grimble 1998).

It has been established that cytokines not only regulate immune function but also modify the growth process and have receptors found commonly on many cell types, allowing for the direct regulation of nutrient metabolism and growth (Spurlock 1997). Cytokines redirect amino acids, via deamination, to energy production, leading to an increased metabolism and a decrease in muscle protein (Cargill *et al.* 2002; Coldtiz 2002). Cytokines, including interleukin-1 and tumour necrosis factor, bring about changes such as increased body temperature, greater rates of gluconeogenesis and glucose oxidation.

Cytokines reduce circulating concentrations of anabolic hormones including growth hormone (GH) and insulin-like growth factor (IGF-1) and stimulate the release of catabolic hormones, including glucocorticoids (Fan *et al.* 1995; Sauber *et al.* 1999). The abundance of these hormones ensures that gluconeogenesis and lipolysis are maintained at a high level in order to nourish the immune system (Grimble 1990). Cytokines are also linked to the induction of insulin resistance and growth hormone resistance in skeletal muscle (Gabler & Spurlock 2007). The loss of anabolic stimuli and the repartitioning of amino acids results in decreased growth in favour of immunological functions (Gabler & Spurlock 2007).

Intakes of certain nutrients, principally amino acids, must be increased to maintain growth in low immune status pigs (Williams *et al.* 1997b; Stahly 2001). Increased need for amino acids comes about from the activation of particular metabolic pathways, such as the immune cell synthesis of immunoglobulins and other compounds, which need to be taken into account in order to maintain muscle growth and animal performance (Le Floc'h*et al.* 2004). However, due to the actions of cytokines, even if food intake is increased, the increase is not correlated positively with tissue growth (Williams *et al.* 1997b). Minimising the level of antigen exposure and immune system activation results in greater growth rate, feed intake, efficiency of feed utilisation and higher protein body content of pigs compared to immune activated pigs (Williams *et al.* 1997b; Williams *et al.*1997c).

Immunonutrition

Many studies using animal models, such as the rat and pig, have proven that nutrition may be used as a tool to control the deleterious effects of the activated immune system (Grimble 1998). The role of cytokines in inducing a catabolic state has so far led to a small number of studies into the development of nutritional strategies to improve health outcomes in immune activated animals, including humans (Colditz 2002). The new area of immunonutrition has been concerned with supplementation of feeding formulae with amino acids, with a view to meeting the increased requirements of the 'patient' (Colditz 2002). Vitamin E and selenium have been successfully employed in many species, such as the pig, chicken, dog, sheep and rat, together protecting unsaturated membrane phospholipids from oxidants produced during immune activation, which may impair their functions (Kubena & McMurray 1996).

Immunonutrition techniques used in industry, such as supplementation of diets with immuno-modulating functions, increase costs, which could be avoided if there was efficient pathogen management, for example, through improved hygiene. Matte and Lessard (2003) suggested that, as nutrition is undoubtedly important in reproduction, immunonutritional supplementation cannot be presumed to be as useful in gestating sows as in other situations.

Conclusion

The literature shows that nutrition is extremely important in late gestational sows. The negative effects of the immune system on the efficiency of nutrient use are highlighted as a problem in livestock industries. There is a delicate and complex balance between immune and nutritional factors and their effects on reproduction. Many studies concentrate on this relationship. However, there are contrasting reports. Management practices which minimise the negative effect of immune system activation in pigs are important to maintain growth efficiency and carcass quality. Studies have proven that nutrition can be used as a tool to control these deleterious effects.

The proposed study is interested in minimising immune activation by good hygiene practice, which, in turn, will minimise the effects of the immune system on the nutrient requirement of sows and their litters. The study is aimed at further unraveling the relationship between nutrition and immune response, by determining the effect of nutrition in late gestation, when gestating sows are housed in hygienic or standard housing conditions.

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Final Paper

Abstract

There are contrasting results regarding the most effective method when feeding gestating sows. Phase feeding is supported as the most effective method, with feed increased in mid to late gestation, correlating with increased nutrient requirements. Activated immune systems may alter the nutritional requirements of animals and alter the effectiveness of feeding strategies. This study aimed to identify the effect of feeding level in late gestation, when gestating sows are housed in hygienic or standard housing conditions. It was hypothesised that an increase in feed allowance, from day 86 to 112 of gestation, would not alter piglet birth weight or viability when gestating sows were housed in high hygiene conditions, but that differences would be noted in sows housed in standard hygiene conditions, due to the nutritional requirements of their activated immune systems. Two feed treatments, standard (2.3 kg/d) and high (3.3 kg/d), mirroring flat rate feeding and phase feeding in production, respectively, and two hygiene treatments, standard and high, were implemented for 123 late gestation, mixed-parity, Large White x Landrace sows. Hygiene did not alter the immune system enough to affect the nutritional requirements of sows in late gestation. No changes in sow weight or P2 back fat depth or piglet weight, the number of stillborn piglets, placental: foetal weight ratio, farrowing duration or neonatal survival to 72 hours post-farrowing were observed (p >0.05). There was no change in the neutrophil: lymphocyte ratio with hygiene levels (p >0.05). These results support flat feeding and standard hygiene in late gestation.

Introduction

The implication of the increased interest in welfare-conscious pig production is that pig producers must develop innovative strategies in order to maintain commercial viability (van Barneveld 2003). Traditionally, piglet health has been studied because of its economic importance, as the pig industry is confronted with substantial losses due to neonatal piglet mortality (van Rens *et al.* 2005). Recently, increased sensitivity amongst the general public

towards animal welfare has highlighted that there is further need for research in the area (Tuchscherer *et al.* 2000).

Many variables alter the reproductive potential of a breeding herd. These include nutrition, disease, ambient temperature, housing, stocking density and herd age; each affecting the health of the breeding herd and piglets and therefore determining herd productivity. Foetal growth has been enhanced greatly due to genetic selection, with modern foetal weights at 110 to 114 days of gestation now 50% greater than those reported 27 years ago (McPherson *et al.* 2004).

In modern, high-density production systems, pigs live surrounded by potentially pathogenic environmental organisms. It is relatively rare for a pig to become ill, as they are equipped with a highly evolved immune system (Johnson *et al.* 2001). However, it is now widely accepted that animals in high pathogen environments neither grow well nor eat well, even when there are no disease symptoms present or clinical disease evident (Johnson *et al.* 2001; Le Floc'h *et al.* 2004). The endocrine and metabolic shifts induced by immune activation depress appetite and feed conversion efficiency and thus result in a reduced rate of growth (Sauber *et al.* 1999; Stahly 2001).

The effect of disease and immune system activation on animal growth rate and the efficiency of food conversion is of economic importance. The potential for increased prolificacy, profitability and welfare has led to several studies into the mechanisms through which immune responses affect growth (Spurlock 1997; Williams *et al.* 1997a; Williams *et al.* 1997b; Williams *et al.* 1997c; Sauber *et al.* 1999; Saker 2006). Reducing the level of antigen exposure and immune system activation results in a greater growth rate, increased feed intake, enhanced efficiency of feed utilisation and higher body protein content of pigs, compared to immune activated pigs (Williams *et al.* 1997b; Williams *et al.* 1997c).

The animals' level of antigen exposure can be controlled using better hygiene practices. Many

factors have the ability to affect the hygiene of the building in which animals are maintained; including ventilation and heating systems, the shape and dimensions of the building, waste management systems, watering and feeding systems, the stocking density and the level of cleaning and disinfection employed (Cargill *et al.* 2002). In the few studies recorded, pressure hosing was found to be an effective method of cleaning compared to other methods, such as scraping and the use of non-pressure hosing. The use of disinfectants after cleaning has also been shown to have a positive effect on hygiene (Cargill *et al.* 2002).

Several studies have shown that nutrition can be used as a tool to control the deleterious effects of the activated immune system (Grimble 1998). The immune system-induced catabolic state has so far led to a small number of studies into the development of nutritional strategies to improve health outcomes in immune-activated animals (Colditz 2002). In early pregnancy, the demands of the litter are relatively low and their nutrient requirements are not significant (Mahan & Vallet 1997). Nutrient requirements increase exponentially in mid to late gestation which correlates closely with the period of maximum foetal growth (Miller *et al.* 2000; McPherson *et al.* 2004; Shelton *et al.* 2009). In gestation, maternal nutrients are directed primarily towards the growth and support of foetal tissues (McPherson *et al.* 2004), but the nutrient supply for sows during all phases of gestation must also meet their own requirements for maintenance, including those of their immune system (NRC, 1998).

Implementation of efficient feeding strategies for gestating sows is an important management practice (Noblet *et al.* 1997; Shelton *et al.* 2009). There are many contrasting reports as to the most effective method of gestational sow feeding. It is possible that these contrasting reports are due to differing immune activation status in the research animals. The strongest argument for a particular feeding strategy is that put forward in favour of two phase feeding (Cromwell *et al.* 1989; McPherson *et al.* 2004; Young *et al.* 2004; Jackson 2009; Kim *et al.* 2009). This strategy involves increasing the intake of late gestational sows, corresponding to the increase in foetal growth in this period (McPherson *et al.* 2004; Kim *et al.* 2005; King *et al.* 2006).

This study aimed to identify the effect of feeding level in late gestation, when gestating sows are housed in hygienic or standard housing conditions. It was hypothesised that an increase in feed allowance, from day 86 to 112 of gestation, would not alter piglet birth weight or viability when gestating sows were housed in high hygiene conditions, but that differences would be noted in sows housed in standard hygiene conditions, due to the nutrient requirements of their activated immune systems.

Materials and Methods

Animal management and treatments

This study was conducted in accordance with the guidelines set out in a joint publication by the National Health and Medical Research Council of Australia (NHMRC), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Agricultural Council, 'Code of Practice for the Care and Use of Animals for Scientific Purposes' (Canberra 2004) and with the approval of The University of Adelaide Animal Ethics Committee (Animal Ethics Number: S-2011-176A) and the Department of Primary Industries and Resources of South Australia (PIRSA) Animal Ethics Committee. All animal work was carried out at the University of Adelaide's Piggery, Roseworthy, South Australia. The study involved 123 mixed parity Large White x Landrace sows, and was conducted in four blocks between April and August, 2012. Six sows were excluded from the trial, due to death, being non-pregnant, needing antibiotics for infective foot lesions and spontaneous abortion (due to unknown reasons).

Sows were introduced into the trial at day 86 of gestation (28 days before farrowing) and were randomly allocated to either high hygiene treatment housing or standard hygiene treatment housing. Each pen of 4 sows was then randomly allocated, within hygiene treatment, to receive either 2.3 kg (29.9 MJ DE) or 3.3 kg (42.9 MJ DE) per day of a standard gestation diet (Table 1). Prior to the commencement of the treatment, sows had been receiving 2.5 kg/d of the same diet. The sows were fed once daily, in the morning, with 4 distinct drops, to

discourage sharing. The sows remained on these diets for the duration of the experiment. Water was freely available throughout the experimental period.

Table 1: Composition and dietary specifications of the dry sow diet used for both feed treatments

Ingredients	%	Calculated Nutrient composition	%	
Barley	19.25	Protein	13.83	
Wheat	42.33	Fat	3.44	
Millrun	30.0	Fibre	5.00	
Canola Expeller Se 36/8.5	2.1	Lysine	0.69	
Meat Meal	3.0	Threonine	0.49	
Tallow	0.5	Tryptophan	0.17	
Choline Chloride	0.07	Methionine + Cysteine	0.54	
Limestone	1.45	Methionine	0.22	
Biofos Mdcp	0.23	Calcium	0.93	
Salt (Sodium Chloride)	0.35	Phosphorus	0.43	
Lysine Sulphate	0.25	Isoleucine	0.47	
Threonine	0.01	Linoleic Acid	1.21	
Alimet	0.003			
Phyzyme Xp 5000 Liquid	0.01			
Breeder Premix + Bioplex	0.25			
Biofix	0.2	DE	12.999	MJ/kg

*Diet produced by Lienert Australia, Roseworthy

The high hygiene treatment housing was cleaned prior to sows being moved in. This involved cleaning all surfaces, by pressure cleaning (SpitWater HP201/SAE pressure cleaner), disinfection (Virkon S, produced by DuPont, distributed by Lienert Australia, Roseworthy) and covering of the floors with hydrated lime (calcium hydroxide, Adelaide Brighton Cement Ltd.), which inactivates most viruses and bacteria. For the duration of the experiment, the high hygiene housing was pressure cleaned every Monday, Wednesday and Friday after sows had been moved into a separate pen. Standard hygiene sows were similarly moved, to avoid introducing unwanted variation caused by differences in human handling and movement between treatment groups, but their pens were not cleaned. For the duration of the trial, the sows remained in the piggery's dry sow shed. Each pen of 4 sows allowed for 1.95 m^2 of floor space per sow.

At three days prior to the expected farrowing date, sows were moved to the farrowing house, where they were allowed to farrow naturally. At entry into the farrowing shed, all treatments ceased. The litters were then monitored during the 72 hours post-farrowing to determine neonatal mortality.

Animal measurements

Sow liveweight and body composition

Sows were weighed (with Test EziWeigh 2 scales) and P2 back fat depth was measured on entry to the sow shed and prior to being moved into the farrowing house. The P2 back fat depth was measured using real time ultrasound over the last rib, 65 mm from the midline with a 5 MHz linear probe (Aquila Vet, Pie Medical Equipment). Measurement of sow weight and back fat depth are valuable tools to monitor health status and were used to analyse change in sow condition (Maes *et al.* 2004; Beyga & Rekiel 2010; Kim 2010). There is also a significant negative correlation between back fat and the number of pigs weaned per sow (Maes *et al.* 2004; Young & Aherne 2005).

Collection of blood samples

Single blood samples were taken on entry into the dry sow shed and prior to being moved into the farrowing rooms. Samples were collected by jugular venipuncture into Vacuette 9ml EDTA (Ethylenediaminetetraacetic acid) tubes for determination of full blood cell counts with differential white cell counts.

Reproductive measurements

Piglet and placenta

Farrowing was observed throughout and the times of piglet births were recorded. Piglets (including stillbirths but excluding mummified foetuses) were weighed individually at birth, using a Wedderburn, UWHS Digital Hanging Scale, with 7.5 kg capacity and 5 g accuracy.

The number of stillborn and mummified foetuses was recorded. Birth weight is one of the major factors positively correlated with piglet survival but can be detrimental for farrowing performance, with larger piglets potentially increasing the risk of dystocia (Walker *et al.* 1981; King *et al.* 2006). The variance within litter weights was examined, as it is an important factor in the survival and growth of piglets up to weaning (Campos *et al.* 2012). The proportion of piglets under 1.0 kg was recorded, as these piglets have a reduced chance of survival and their performance in lactation is also poor (Quiniou *et al.* 2002).

At the end of farrowing, the placenta was collected and weighed (Wedderburn, UWHS Digital Hanging Scale). The ratio of placenta to foetal weights allowed analysis of the changes in piglet weight following the time at which the placenta thought to be fully developed, coinciding with the beginning of our treatment period (Vallet & Freking 2007; Vallet *et al.* 2009). Low placental weight and low foetal weight are positively correlated (Myatt 2006).

Survival post-farrowing

At 72 hours after completion of farrowing the number of piglet deaths was recorded, along with the reason for the death. Survival to 72 hours post-farrowing was studied because this is the period in which 80% of preweaning mortality occurs, and is known to be negatively correlated with piglet birth weights (Tuchscherer *et al.* 2000).

Analysis

Full blood cell counts

A Cell Dyn 3700 automated cell counter was used to measure red blood cells (RBC), white blood cells (WBC) and platelet counts. Flow cytometry was used to measure the optical WBC count and differential. Following this, a manual differential cell count was done. A blood film was made by placing a drop of blood onto a clean slide and a blood film spreader was used to

create the film. The blood film was then stained with Wright Giemsa stain and 100 cells assessed, using an Olympus BX53 microscope.

Statistical analysis

The data were analysed using IBM SPSS 20.0 (Statistics Package for Social Sciences), using both mixed models and general linear models. For parts of the analysis, using mixed models, the piglet was the unit, allowing for close analysis of the effects of the treatments on each individual piglet. For the majority of the analysis, the sow was the unit, and in these cases a general linear model was used for the analysis. The model included parity and litter size as covariates and the pen, block and treatment as fixed effects. A total of 117 sows completed the trial but, due to some incomplete measurements, only 113 sows were used in the final analysis of the data. The neutrophil: lymphocyte ratio was calculated as a simple ratio between the absolute neutrophil and lymphocyte counts and the change in this ratio, when comparing the bleeds, was used for final analysis of the data. Haematology from block 4 was discounted because collection of pre-farrowing samples was not completed as a result of earlier than expected farrowing, due to incomplete artificial insemination data. Data are expressed as least squares means ± the standard error of the mean (SEM).

Results

Sow liveweight and body composition

The change in sow weight from the beginning of the feeding trial to farrowing did not differ between treatments. Across all treatments, the sows gained 15.8 kg on average in the last four weeks of their gestation (p= 0.94). There was no significant difference in the change in P2 back fat thickness between the treatments. All sows lost back fat independent of treatment, with the average loss being 0.9 mm (p = 0.43). The mean weight gain was different between blocks. Weight gain in block 1 was significantly less compared to block 2 (p<0.005), block 3 (p<0.05) and block 4 (p<0.05) (Table 2).

Table 2: Sow weight change over the last four weeks of gestation according to treatment block in sows (least squares means ± SEM)

	Block 1 (n=30)	Block 2 (n=26)	Block 3 (n=30)	Block 4 (n=27)
Sow weight change (kg)	7.55 ± 2.90^a	20.60 ± 2.91^{b1}	17.18 ± 2.63^{b2}	17.85 ± 2.85^{b2}

Values that do not have a common superscript ([a], [b]) differ significantly, [a, b1] ($p < 0.005$), [a, b2] ($p < 0.05$)


Blood sample analysis

There were no significant differences between the treatment groups in the neutrophil: lymphocyte (n:l) ratio change. There were large variances in the results of these tests between sows. A non-significant increase in the n:l ratio change was observed in the standard hygiene treatment (Figure 1).
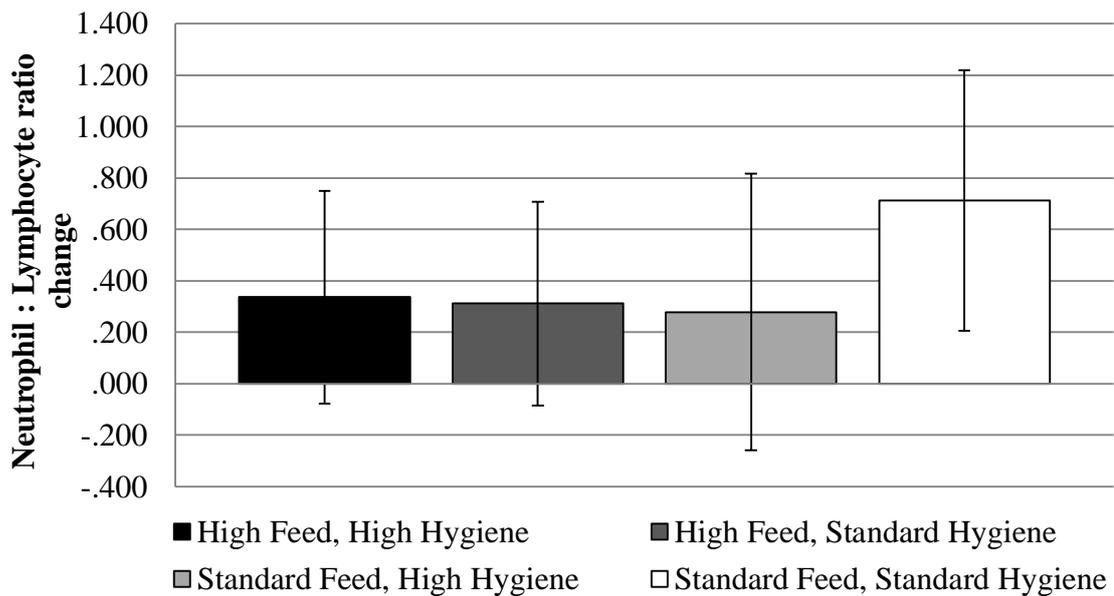
Figure 1: The neutrophil : lymphocyte ratio change, in sows subjected to high and standard hygiene and high (3.3 kg/d) and standard (2.3 kg/d) feed, in the last 4 weeks of gestation (least squares means ± SEM)

There was a significant difference found for the effect of block on this ratio change, with block 1 and block 2 differing significantly from each other ($p < 0.05$, Figure 2).
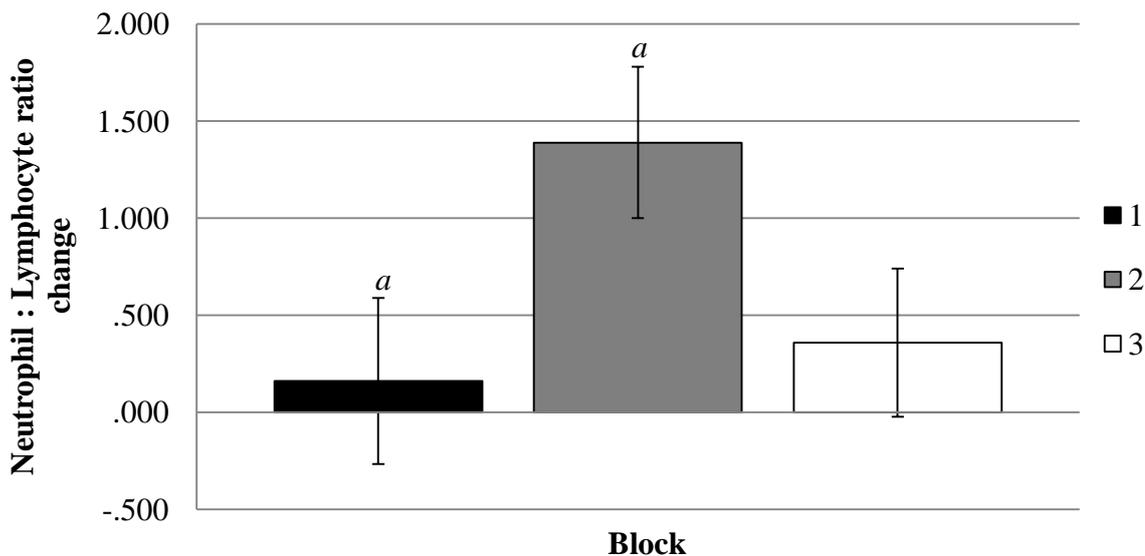
Figure 2: The neutrophil : lymphocyte ratio change, in sows subjected to high and standard hygiene and high (3.3 kg/d) and standard (2.3 kg/d) feed, in the last 4 weeks of gestation (least squares means ± SEM), as affected by block, *a*= significantly different (p < 0.05)

Reproductive measurements

Piglet birth weight was not significantly altered by treatment (Table 3). There were significant differences in piglet birth weight associated with piglet gender and the litter size. In all treatments, males were significantly heavier than females ($p<0.001$) and, as litter size increased, the birth weight of the piglets decreased ($p<0.001$).

The uniformity of the piglet birth weights within litters was assessed using analysis of the standard deviation of piglet birth weight. There were no significant differences in the uniformity of the litters among treatments (Table 3). The variability in weights of piglets within the litter altered with litter size, with an increase in litter size increasing the uniformity ($p<0.005$). The proportion of piglets in a litter that weighed less than 1.0 kg was not influenced by the treatments (Table 3), but increased with litter size ($p<0.001$).

Table 3: Piglet weights, deviation of piglet weights from the mean and the percentage of piglets weighing under 1 kg at birth, in sows subjected to high and standard hygiene and high (3.3 kg/d) and standard (2.3 kg/d) feed, in the last 4 weeks of gestation, with no significant differences created by treatment (p>0.05) (least squares means ± SEM)

	High Hygiene		Standard Hygiene	
	High Feed (n=31)	Standard Feed (n=28)	High Feed (n=28)	Standard Feed (n=26)
Piglet birth weight (kg)	1.46 ± 0.041	1.47 ± 0.042	1.52 ± 0.045	1.47 ± 0.047
Within- litter variation (kg)	0.30 ± 0.015	0.30 ± 0.017	0.27 ± 0.016	0.28 ± 0.017
Piglets < 1 kg at birth (%)	9.2 ± 1.9	7.0 ± 2.1	7.1 ± 2.0	8.1 ± 2.1

Treatment had no effect on stillbirth numbers or survival of neonatal piglets. Litter size was positively correlated with the number of stillborn piglets in a litter (p<0.001, Figure 3). Sow parity also had an effect, with sows over parity five producing greater numbers of stillborn piglets (p<0.05, Figure 4).
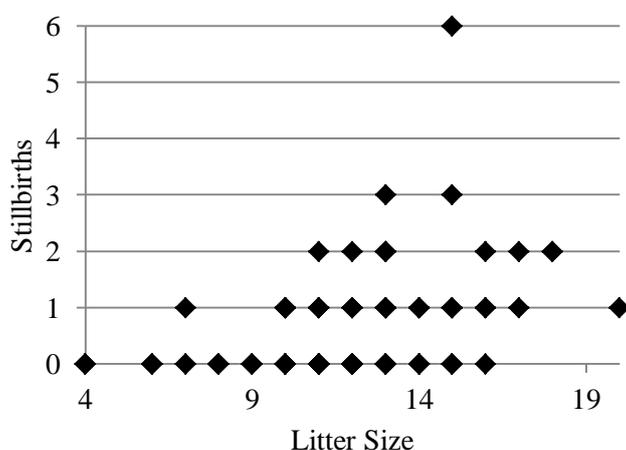
Figure 3: The effect of litter size on stillbirths in the last 4 weeks of gestation
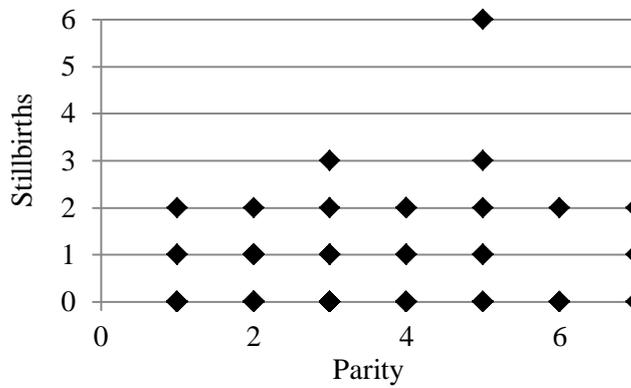
Figure 4: The effect of parity on stillbirths in the last 4 weeks of gestation

Following pairwise analysis, a block effect, on the proportion of piglets surviving to 3 days, was noted, with blocks 2 and 4 being significantly different from each other (p<0.05, Table 4).

Table 4: The effect of treatment block on the proportion of piglets to survive to 72 hours post-farrowing, in sows subjected to high and standard hygiene and high (3.3 kg/d) and standard (2.3 kg/d) feed, in the last 4 weeks of gestation (least squares means ± SEM)

	Block 1 (n=30)	Block 2 (n=26)	Block 3 (n=30)	Block 4 (n=27)
Proportion survival (%)	96.0 ± 1.1^{ab}	91.3 ± 1.7^{a}	93.1 ± 1.6^{ab}	96.8 ± 1.7^{b}

[a,b] Within rows, values that do not have a common subscript differ (p<0.05)

The placental: foetal weight ratio, farrowing duration and the average time between piglet deliveries were not affected by the treatment and none of these variables were affected by non-treatment factors (eg. block or parity).

Discussion

The results of this study contrast with other studies which examined the effect of increased feeding during gestation. It is generally accepted that an increased feed intake during late gestation is of benefit to the reproductive outcome of the sow, such as piglet birth weight and sow fat stores. Phase feeding, a dietary strategy that involves an increase in intake in late gestation, is the most commonly used method of gestational sow feeding and its use is widely

supported by the literature (Cromwell *et al.* 1989; McPherson *et al.* 2004; Young *et al.* 2004; Jackson 2009; Kim *et al.* 2009). The increase in feed intake in late gestation correlates with the increase in foetal growth and allows for the increased nutrient requirements of a rapidly growing litter (McPherson *et al.* 2004; Kim *et al*. 2005; King *et al*. 2006). In this study, consumption of an extra 1 kg of feed a day during the last four weeks of gestation did not improve the reproductive performance of the sow, in terms of piglet weight or viability after birth, placental efficiency or sow liveweight and back fat depth. The lack of effect on piglet birth weight explains the lack of effect on farrowing duration, stillbirth numbers and neonatal survival.

The main difference between studies that found beneficial effects of phase feeding and those that did not, is the daily energy provided to gestating sows. There are variations in the suggested energy requirements for gestating sows. The National Research Council (NRC) Committee on Animal Nutrition proposed that the energy requirement of the sow, in gestation, is between 25.2 and 26.8 MJ of metabolisable energy (ME) per day (NRC 1998). Long *et al.* (2010) concluded that, with today's modern genotype, the energy intake of sows should be between 27.3 and 28.1 MJ of ME/d, a significant difference from the 35.6 MJ of ME/d suggested by Dourmad *et al* (1996). Noblet *et al* (1990) concluded that the amount of digestible energy per day required by a gestating sow was between 25.1 MJ and 41.8 MJ of digestible energy. They suggest that a single amount cannot be recommended as there is too much variation in factors such as genotype, environment, bodyweight and activity levels, within and between populations.

Interestingly, studies that found significant effects of late pregnancy nutrition either on sow or piglet condition, or both, had different energy intakes than those suggested by Noblet *et al.* (1990) as well as those used in the current study. The most striking example of this is found in the paper by Elliot and Lodge (1997), in which the lowest digestible energy intake was 5.9 MJ/d and the highest 30.5 MJ/d. This trend continues with other papers that reported

significant effects from increased feed intake (Noblet *et al.* 1985; Cromwell *et al.* 1989). For these latter studies, the basal feed treatments fell under the recommended daily needs of a gestating sow. Thus, rather than increasing the feed within the requirements, these studies underfed for one treatment and fed within sow requirements for the other. With this effective under-nutrition in one group, it is not surprising that an effect of treatment was seen.

In the present study, both dietary treatments were close to the lower and higher recommendations (29.9 MJ and 42.9 MJ), and so neither underfed nor overfed the sows. King *et al* (2006), using similar digestible energy levels to our study, with the lower at 28.4 MJ and the higher at 43.9 MJ, obtained similar results to the current study, with no significant change found in the sow condition or piglet birth weight. These intakes are within the suggested daily requirements of gestating sows. The studies would thus appear to validate each other. Using the energy intake levels suggested by Noblet *et al.* (1990), it can be concluded that there will be no significant change in sow performance with phase feeding if the feeding levels fall within the recommended range. If the feeding level prior to the increase in intake was below the lower level, then an effect from phase feeding would be anticipated.

There is a dearth of information concerning the direct effects of hygiene levels on productivity, although there are studies on the effects of up-regulated immune responses on sow productivity. Sauber *et al.* (1999), for example, induced immune activation by injection of *Escherichia coli* lipopolysaccharides into lactating sows and found that milk protein concentrations, energy content and volume were all negatively affected. However, the effects of the two hygiene treatments in our study demonstrated no significant effect on farrowing duration, piglet birth weight, stillbirth numbers, placental efficiency, piglet survival to 72 hours or sow condition. It is possible that the imposed hygiene treatments were not sufficient to induce an observable difference in the degree of immune system activation.

On examination of the interaction between the two treatments, and their effects on the measurements taken, there is one result which is of interest. There was an apparent trend in

the change in the neutrophil : lymphocyte ratio from the beginning of the experiment to prior to farrowing. The standard feed plus standard hygiene treatment was associated with a greater increase in neutrophils and a greater decrease in lymphocytes, compared to the other treatments (Figure 1). There are several possible reasons for this difference between the two feed treatments in the standard hygiene group. One explanation for the decreased lymphocyte count is that a deficiency in trace nutrients, protein or amino acids may have been sufficient to influence the immune system and specifically lower lymphocyte numbers, without impacting on growth or productivity, although this would be unusual in farming situations (Johnson *et al.* 2001). The increased neutrophil count may simply reflect an increased presence of bacteria in the standard hygiene housing.

There was a decrease in lymphocytes from the beginning of a trial period to the end across all treatments. The most likely reason for this is the animals' stress response to reduced floor space, a barren environment, mixing, change in feeding regime and regular movement, compared to their housing prior to the beginning of the experiment, in group-housed, straw bedded shelters. It has been shown that these factors are adequate to bring about a stress response, in sows, of sufficient magnitude to alter their immune system (Amadori *et al.* 2009). Stress and exercise in sows have been found to affect the immune system by stimulation of the hypothalamus, release of corticotrophin releasing hormone, stimulating the production of adrenocorticotrophic hormone from the pituitary, which, in turn, stimulates the release of corticosteroids from the adrenal cortex. These act on lymphocyte surface receptors for cortisol and decrease lymphocyte production and function (Borysenko & Borysenko 1982; Padgett & Glaser 2003). The amounts of corticosteroids released, with even minor stress, have been shown to be sufficient to reduce lymphocyte numbers (Borysenko & Borysenko 1982).

There were several variables, apart from the imposed treatments, which affected piglet viability and sow condition. Piglet weight was significantly negatively correlated with litter size. This result was reported by Quiniou *et al*. (2002), who also found that the heavier piglets

were more likely to be male, correlating with the results from this experiment. With a fixed nutrient intake, as the litter size increases the amount of nutrients available to each foetus decreases, resulting in lower birth weights (Campos *et al*. 2012). The uniformity of the litter was affected by litter size, with decreased variance with an increase in litter size. This means that, the more piglets that were born in a litter, the closer they were in weight. The number of stillborn piglets was also affected by litter size, with the number of stillborns increasing with increased litter size. This is due to the increased duration that the piglet spends in the birth canal during farrowing (Campos *et al*. 2012). Parity also affected the number of stillbirths, with older sows producing higher numbers of stillborn piglets. This result possibly reflects hypocalcaemia in these older sows, which is common in sows over parity three and can result in a decrease in the strength of uterine contractions (Blood *et* al. 1979; Trottier & Johnson 2001). Increased stillbirth rate in a litter has previously been linked to increasing parity of the sow, increasing farrowing duration and litter size (Zaleski & Hacker 1993; Wolf *et al.* 2008).

The effect of block on the sow revealed some unexpected significances. Block 1 sows gained significantly less weight than those in all other blocks. The weight gain in block 1 was lower than the average litter weight (therefore the sows in block 1 lost weight). At the time of this block the weather was much warmer than in other blocks. According to the Australian Government Bureau of Meteorology the average ambient temperature for the April block was 25.3°C during the day compared to the other blocks, which were all under 19°C during the day (Appendix). This temperature difference may explain the differences between the sow weight gains.

It is known that high environmental temperature tends to cause a reduction in voluntary feed intake in pigs, since normal intake can generate body heat which cannot be dissipated to the environment (Schinckel 2001). However, in the current study, feed intake was assured despite environmental temperature. Huynh *et al.* (2005) showed that temperatures above 22°C result in clear metabolic changes in gestating sows, including increased respiration, increased water-

to-feed-ratio, decreased appetite and increased rectal temperature. They suggest that in modern pigs signs of heat stress can occur at even moderate temperatures and that these pigs can have high metabolic activity and heat production (Huynh *et al.* 2005). This would correlate with our decrease in sow weight, in block 1, in which the temperature was an average of 25.3°C.

Interestingly, the ratio of neutrophils to lymphocytes differed between block 2 and all other blocks, with both an increase in neutrophils and a decrease in lymphocytes. This alteration of the ratio in block 2 may be linked to the change in season from summer to autumn (Appendix). As previously stated, block 1 was much warmer than all other blocks. Studies of trends in human disease have demonstrated that at the change of season, such as occurred during block 2, there is commonly an increase in the incidence of infectious disease. This pattern is mirrored in animal disease (Grassly & Fraser 2006). Block 2 was also found to be significantly different to block 4 when comparing survival of the piglets to 72 hours after farrowing, and this trend could also be linked to the change in season occurring within block 2.

Cromwell *et al*. (1989) suggested that the increase in feed cost over the last 4 weeks of gestation, in phase-fed sows, is offset by the increased piglet survival and increase in the number of pigs per litter at weaning. Clearly, in this experiment, this is not the case, as there was no change in the weight of the piglets or their survival to 72 hours post farrowing. However, the effect of our treatments on the litter performance from 72 hours to weaning was not observed and recorded.

In the absence of an effect of hygiene, the next step to determining whether there are any positives to support the use of phase feeding, is to examine the effect on lactation. King *et al.* (2006) found that when feed intake was increased, at any time between day 66 and day 101 of gestation, it linearly reduced voluntary feed intake in the subsequent lactation. Reduced feed intake in lactation leads to an unwanted weight loss during lactation, which in turn can affect

milk production and subsequent reproduction (Kim *et al.* 2009; Long *et al.* 2010). Increased feed intake in late gestation may also increase the incidence of agalactia, a failure to secrete milk following farrowing (Miller *et al.* 2000). Phase feeding, regardless of environmental hygiene, does not have an effect on the viability of the litter at birth but it may have negative effects on the subsequent lactation. It is worth noting that King *et al* (2006) suggested there may be beneficial effects of phase feeding in gestation but only when applied in consecutive parities.

There are a plethora of studies in the area of immune system stimulation on swine productivity, using injection of such agents as *Escherichia coli* lipopolysaccharides (Webel *et al.* 1997; Williams *et al.* 1997a, Williams *et al.* 1997b, Williams *et al.* 1997c; Sauber *et al.* 1999; Urakubo *et al.* 2001; Gabler & Spurlock 2007; Smith *et al.* 2007). However, none have studied how the nutritional requirements of gestating sows may be altered when the immune system is activated. The next step in this line of research would be to use this method to bring about an immune system response and observe the effect on the nutritional requirements and the productive efficiency of the sows during gestation. Study of this area could be used to see if, with a definite immune challenge, there is a need for increased feed intake in gestating sows.

In conclusion, this study shows that the pattern of feeding during late gestation had no effect on sow condition or reproductive outcomes, suggesting that sows can be fed at a constant level throughout gestation, known as flat rate feeding, as long as this intake falls within the range of recommended nutritional requirements of sows. Similarly, the data from the hygiene treatments showed no effect on reproductive productivity and no change to the sows' body condition, as well as no sign of increased immune response, as assessed by neutrophil: lymphocyte ratios. The hypothesis was that an increase in feed allowance, from day 86 to 112 of gestation, would not alter piglet birth weight or viability when gestating sows were housed in high hygiene conditions; this part of the hypothesis was proven. It was expected that a

difference with feeding level in sows housed in standard hygiene condition, due to the requirements of their immune systems would be observed; this part of the hypothesis was disproven. It was believed that there would be an increase in piglet viability with high feed in the standard hygiene groups, but that the higher feeding level would not alter the production targets in high hygiene settings. However, it would seem that, with conventional hygiene levels in production settings, immune system activation is not altered sufficiently to alter the nutritional requirements of a gestating sow. The results of this study support flat feeding and standard hygiene practices throughout gestation, as it is unlikely that there will be a positive economic response to increased feed or improved hygiene in late gestation.

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Appendix: Mean monthly temperatures

Appendix Table 1: Monthly temperature means with the time of each block highlighted

			Block 1	Block 2	Block 3	Block 4	
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
32.7	29.5	27.1	25.3	18.9	15.5	15.1	15.6
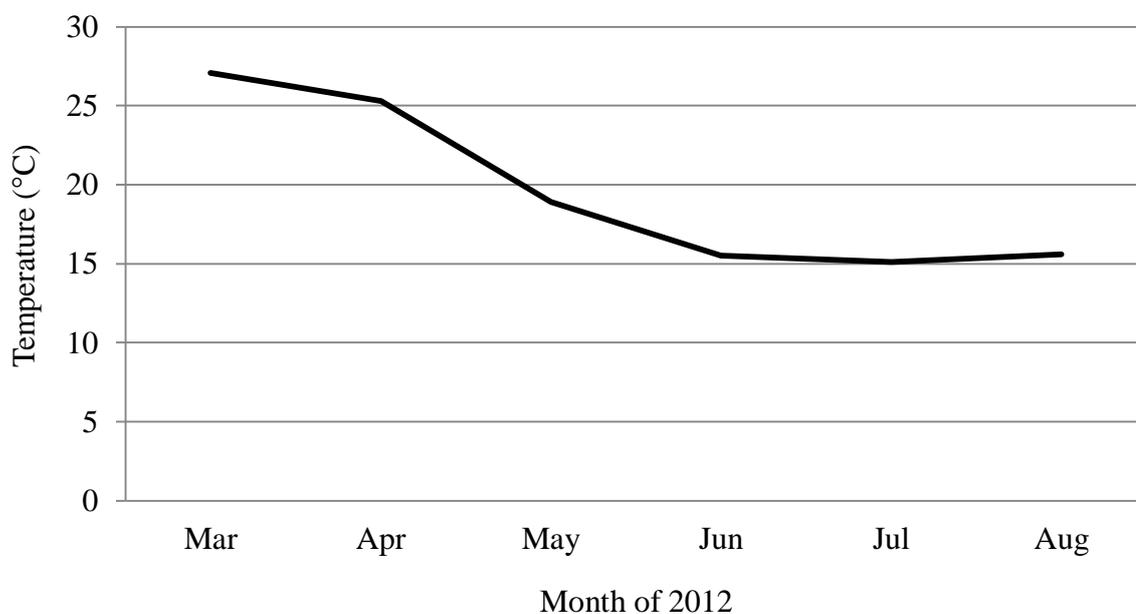
Appendix Figure 1: Mean daily temperature in the months during which the experiment took place.