Provision of immunoglobulins to suckling piglets can enhance post-weaning growth performance

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ABSTRACT

In this experiment the hypothesis that providing a supplementary source of bovine milk immunoglobulin G (IgG) to suckling piglets increases post-weaning growth performance was tested.

The litters from eight multiparous Large White x Landrace sows received oral supplements by syringe. Three piglets in each litter received oral doses of whey globulin concentrate (WGC) which contained 6% IgG. A second group of three piglets per litter received oral doses of whey protein isolate (WPI) to approximate the amino acids supplied in WGC but without IgG's. A third group of three piglets per litter received oral doses of water (CONT) to simulate the oral dosing procedure. The daily supplement of WGC and WPI provided 0.7 g per day of age of ideal protein during the first week and 1.4 g per day of age thereafter. The oral doses were provided twice daily at 09.00h and 15.00h from day 2 to day 24 of lactation. For the statistical analysis, a linear model including sex, sow and treatment as fixed effects, and live weight at birth as covariate was fitted to the data.

The average daily gains measured over the suckling period (24d) were not atatistically significantly different between the three groups with the control gaining 249gd^{-1}, WGC gaining 259gd^{-1} and WPI gaining 264gd^{-1}. The provision of either WGC or WPI did not increase the average daily gain up to weaning, possibly because the piglets reduced their intake of sow's milk. To determine the effect of supplemental IgG, the most valid comparison is between WPI and WGC because the supply of ideal protein, and the time taken to provide each oral dose, were similar. Piglets receiving WGC grew 12% faster than WPI from transfer (62d) to slaughter (85kg) ($P < 0.05$), and 8% faster from birth to slaughter ($P < 0.05$). These findings indicate that the provision of IgG during early life can lead to long term advantages in growth rate.

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TABLE OF CONTENTS

CHAPTER 3.

CHAPTER 4.

CHAPTER 5.

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADG	Average daily gain
ADGT	The total gain of body weight
d	day
DE	Digestible energy
FCE	Feed conversion efficiency
g	gram
gd^{-1}	gram per day
GE	Gross energy
GLM	General Linear Models procedure
h	hour
Ig's	Immunoglobulin's
IgA	alpha chains
IgD	delta heavy chains
IgE	epsilon chains
IgG	gamma chains
IgM	mu chain
kg	kilogram
kJ	Kilojule
LSM	Least square means
M	Maintenance
n	number of pig
NZ	New Zealand
R^2	Coefficient of variation
SAS	Statistical Analysis System
SE	Standard error
USA	United State of America
WPI	Hydrolysed whey protein isolate
WGC	Whey globulin concentrate

CHAPTER 1

INTRODUCTION

Both the suckling and weaning periods are critical phases in a pig's life. During these two periods piglets often display poor growth or weight loss, low levels of voluntary food intake and in some instances, diarrhoea, morbidity and death (11.8% during the suckling period) (MLC, 1994) and 6% during the first two weeks after weaning (Lecce, 1979; Musgrave *et al.*, 1991; Pajor *et al.*, 1991).

The weaning weight of a piglet has an influence on the post-weaning performance. The smaller and younger a piglet is at weaning the poorer will be its growth rate in the post-weaning period (Campbell, 1989). A piglet that is heavier at weaning will take fewer days to reach market weight than a lighter piglet (Mahan and Lepine, 1991; Goodband *et al.*, 1993; Pollmann, 1993).

Piglet growth rate during the suckling period is usually much less than its potential. Piglet growth is limited by the amount of milk they obtain from the sow. Sow milk production peaks during days 10 to 14 of lactation after which time it is only sufficient for piglets to attain about 50% of their growth potential (Campbell and Dunkin,1983; Dunshea *et al.*, 1995; Toner *et al.*, 1996).). With increasing numbers of nursing piglets per sow, the amount of milk available to each piglet is decreased (Whittemore and Elsley, 1979) and may limit growth rate. The sow can not produce adequate nutrients when litters are very large or sow's milking ability is impaired (English and Edwards, 1996). Furthermore, the energy: protein ratio of sows milk is inadequate to promote maximum muscle development in the young piglet (Etienne and Noblet, 1993).

Weaning presents several unique problems not experienced in other phases of pig growth. After weaning, most pigs exhibit a period of slow growth (Kornegay

et al., 1974). This may be related to inadequate development of the digestive capacity of the young piglet resulting in a poor utilization of dietary nutrients (Leibbrandt *et al.*, 1975). Newly weaned piglets often show weight loss, gastrointestinal disorder, other health and behavioural problems and occasional death (Okai *et al.*, 1976; Fraser, 1978; Alger, 1984a,b). There are frequently outbreaks of diarrhoea due to proliferation of enterotoxigenic bacteria (*Escherichia coli*) in the small intestine and/or fermentation of less digestible nutrients of the weaner diet in the large intestine (McCracken and Kelly, 1993). This 'loss' of growth may last up to 14 days from the time of weaning, representing a 25-40% reduction in growth rate *per se* compared to piglets remaining on the sow (Musgrave *et al.*, 1991; Pajor *et al.*,1991). Therefore, the provision of supplementary feed to piglets during the suckling period would stimulated earlier development of the digestive enzyme system and thereby reduced digestive disturbances and growth checks after weaning (Okai *et al.*, 1976).

Immunity in the newborn piglet is the first limited by the quantity and quality of antibodies in colostrum and by the amount the neonate is able to consume and absorb (Holland, 1990). Moreover, the initial antibody repertoire of the newborn-piglet is restricted to those antigens to which the sow has developed memory B cells (Porter, 1986). Since IgG constitutes the major immunoglobulin isotype in serum, the predominant immunoglobulin isotype in colostrum is also IgG. Immunity is further limited by the fact that many of the pathogenic agents encountered by the newborn piglet are found at mucosal surfaces where IgG antibodies are rarely found and largely ineffective. Maximum immunoglobulin absorption in newborn piglets occurs within 4-12h after suckling, and then declines rapidly due to a gradual and progressive process commonly refered to as gut closure (Westrom *et al.*, 1985). Corresponding to gut closure, immunoglobulin and protein concentrations in colostrum decrease 6h after nursing is initiated to 50% of pre-nursing values. Failure to suckle adequately

within the first 24h of birth could delay gut closure and thereby increase the possibility of pathogenic agents entering the systemic circulation. Coalson and Lecce (1973) reported that 15% of piglets that were prevented from suckling up to 4 h after birth had extremely low levels of serum immunoglobulin. Therefore, piglets born at the end of farrowing, especially where the litter size is more than eight, are found to have much lower concentrations serum of IgG than their earlier born littermates (de Passile *et al.*, 1988).

The ingestion of immunoglobulins in milk during established lactation provides defence against possible enteric infections in the suckling piglet (Porter, 1986). The prospect of using oral immunoglobulins from bovine milk to provide passive immune protection from enteric diseases has been considered for at least 35 years (Petersen and Campbell, 1955). The success of this approach depends on the ability of bovine milk immunoglobulin concentrates (BICs) to resist digestion and retain functional activity during gastrointestinal transit (Hilpert *et al.*, 1987; Zinkernagel *et al.*, 1972). Providing milk-protein and immunoglobulin to piglets increased survival rate and reduced diarrhoea compared with piglets receiving only sow milk replacer (Drew and Owen, 1988). Furthermore, the same authors showed that piglets receiving only sow milk had significantly lower average daily gains compared to piglets which received milk-protein plus immunoglubulin. Nocex *et al.* (1984) have shown that feeding colostrum with a high immunoglobulin content increased the growth rate of calves from birth to day 4. Mortality was low for all calves receiving colostrum with a high immunoglobulin. Morel *et al.* (1995) fed orally bovine milk immunoglobulin G (IgG) to weaning pigs, and suggested that sufficients amount of bovine IgG resisted digestion in the proximal and medial regions of the small intestine to prevent or treat upper gastro-intestinal tract diseases. Drew and Owen (1988) provided bovine serum immunoglobulins and porcine serum immunoglobulins to piglets from birth to 28d. The control group receiving only sow milk replacer had a survival rate lower than the piglets receiving bovine and porcine immunoglobulins (22% ,75% and 92%, respectively) and diarrhoea was more severe in the control group for the first 21 days. Nousianinen *et al.* (1994)

found that colostral immunoglobulin supplemented to neonatal calves led to improved live weight gain and lower incidence of diarrhoea during the first four weeks of life. Consequently, supplementing piglets with bovine milk protein and immunoglobulin from birth to weaning may increase weaning weight and decrease the incidence of diarrhoea both during the suckling period and post-weaning.

The present study was undertaken to investigate the effect of supplementation with bovine milk protein and immunoglobulin during the suckling period on piglet growth rate and incidence of diarrhoea both before and after weaning, and on growth rate to slaughter and backfat thickness at slaughter. The hypothesis tested was that supplementing piglets with a whey protein containing immunoglobulins from birth to weaning will:

1) increase weaning weight,
2) decrease the incidence of diarrhoea during the suckling period and post-weaning, and
3) improve the growth performance after weaning.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

During both the suckling and weaning periods, there are many factors which affect the growth rate of pig. Factors affecting piglet growth during the suckling period include birth weight, composition of the sow's milk , milk quantity (large litters size) and passive immunity (Harell *et al.*, 1993; Klobasa *et al.*, 1987). The weaning period imposes severe nutritional (changes from milk to solid diet) and physical (changes in environment) stressors on piglets with common consequences being low food intake and poor growth or weight loss, diarrhoea, morbidity and death for the first 7 to 14 days after weaning (Musgrave *et al.*, 1991; Pajor *et al.*, 1991; Pluske and Williams, 1996).

2.2. Growth rate

Growth in the suckling piglet is primarily limited by an insufficient intake of milk or alternative sources of nutrients. Piglets born at lighter weights, less than about 1000 g, show a marked reduction in their ability to survive (England, 1986). Piglets of lower birth weight consume less milk than their heavier counterparts causing them to grow more slowly during suckling and, after weaning, taking a greater number of days to reach market weight (Pluske *et al.*, 1995). Pre-weaning nutrition is therefore an important factor in the overall growth of piglets. Improving a piglet's pre-weaning growth rate makes a major difference to the rest of its growth cycle.

King (1996) showed that providing a bovine milk supplement during lactation increased piglets weaning weight by 2 kg.

2.3. Mortality rate

Many surveys have been carried out to classify the causes of death in neonatal piglets. Factors affecting mortality rate of piglets are small size (less than1 kg), weakness, malnourishment, infectious diseases (Dyck and Swierstra, 1978; Fahmy and Bernard, 1971; Spicer *et al.*, 1986) and immunological factors such as being deprived of colostrum (Holland, 1990). Dyck and Swierstra (1978) found that litter size and birth weight were factors influencing the incidence of piglet death. Rydhmer (1992) reported in a study of 8,134 piglets that when a birth weight was below 1kg, half of those died prior to nine weeks of age. Fahmy and Bernard (1971) found that 27% of the pigs that died pre-weaning were small, weak and malnourished. Also Spicer *et al.* (1986) found that 9% of pre-weaned piglets were small, weak and malnourished and that 27% of pre weaned piglets died of infection. In order to improve neonatal survival, effective strategies have been employed in many piggeries to actively immunize sows against virulent pathogens to which piglets are particularly susceptible, including enterotoxic strains of *E. coli* (Kohler *et al.*, 1975; Chidlow and Porter, 1979; Fahy *et. al.*, 1987; Moon *et. al.,* 1988).

2.4. Composition of sow milk

Sow's milk has a vital role in promoting piglet growth, development and protection against pathologenic microorganisms. Klobasa *et al.* (1987) have examined the composition of sow milk during lactation (Table1). They found that after 24 hours the percentage of nutrients in sow milk decreased, especially total protein and whey protein which at birth were 15.7% and 14.3%, respectively. After 72 hours they decreased to 6.4% and 3.9%, respectively. Data in Table 2 show that sow's milk on day 5 contained about 19% dry matter, 6.9% fat and 6.4% protein.

Table 1. Composition of sow's milk from birth to 28 days

Nutrients (%)	At Birth	12h*	24h	72h	7d**	14d	28d
Total Solids	25.6	18.4	17.3	19	18.3	18.2	18.1
Fat	5	4.9	5.6	6.7	6.7	6.4	6.1
Lactose	3.1	4.1	4.6	5.2	5.6	5.9	5.8
Total Protein	15.7	8.8	6.4	6.1	5.4	5.1	5.4
Whey Protein	14.3	7.0	4.6	3.7	3.0	2.7	2.8

Klobasa *et al.* (1987)

Table 2. Production and composition of sow's milk on day 5 of lactation

Item	Mean
Milk production ·sow^{-1} ·day^{-1} , kg	4.554
Energy content of milk, kcal · kg^{-1}	1,202
Dry matter, %	19.19
Ash, %	0.74
Protein (N x 6.38), %	6.41
Ether extract, %	6.88
Lactose, %	5.16

(Klaver *et al.,* 1981)

2.5. Milk yield and piglet growth

Milk yield is the primary factor limiting the growth of a piglet. Sow's milk represents the sole nutrient source for most piglets in the first 2-4 weeks of life. Thus any variation in milk yield and composition is likely to be reflected in piglet growth (Table 3).Campbell and Dunkin (1983) showed that the sow cannot provide sufficient nutrients in milk to maximise piglet growth during the first 2-4 weeks postpartum (Table 4). Furthermore, the energy: protein ratio of sow's milk is inadequate to promote maximum muscle development in the young piglet Campbell and Dunkin (1983).

Table 3. The effects of sow feeding level on milk yield and piglet growth (Hartmann and Hughes, 1996)

	Lactation feeding level	
	High	Low
Milk yield (kg/d)*	5.7	4.6
Mean piglet growth rate to weaning (g/d)	222	189
Mean piglet creep feed intake preweaning (kg)	1.4	1.7

*Mean of estimates taken on days 18 and 25 of lactation.

Table 4. The effect of suckling vs. artificial rearing on piglet growth performance and body composition from 1.8 to 6.5 kg live weight (Campbell and Dunkin, 1983)

	Suckled	Artificial reared*	
		2.8	5.2
Growth rate (g/d)	195	189	313
Body composition (g/kg)			
- Fat	164	102	159
- Protein	151	168	159

*Denotes pigs fed at 2.8 M and 5.2 (M = Maintenance)

2.6. Immunity

Effective immunity requires lymphocytes to be capable of recognizing antigens (Charles and Paul, 1994). Early immunity in neonatal farm animals depends on their obtaining antibodies via colostrum (Hopkins *et al*. 1984, Sawyer *et al*. 1977).

Immunity in the newborn piglet is first limited by the quantity and quality of antibodies in colostrum and by the amount the neonate is able to consume and absorb (Holland, 1990). Moreover, the initial antibody repertoire of the newborn is restricted to those antigens to which the sow has developed memory B cells (Porter,1986).

Several developmental aspects of a pig's immune system contribute to low immunocompentency at birth for example, specialized epitheliochorial placentation does not allow the passage of maternal antibodies (immunoglobulins, Ig) to the fetus. Thus piglets are born without the safeguard of passive immune protection (Holland, 1990), no inherent immunity against disease (Spooner *et al*., 1987) and for the first crucial weeks of their life are dependent on immunoglobulins (Igs) from their mother's colostrum and milk.

The immune system of the new born piglet is also anatomically and functionally immature, making survival dependent on the passive transfer of maternal antibodies in colostrum and milk (Stokes and Bourne, 1989) which provide the first source of immune protection. Consequently, various mechanisms have evolved to allow the passive transfer of humoral immunity from the mother to her offspring (Guidry, 1985).The newborn piglet must obtain its passive immunity from the maternal immunoglobulins (IgG, IgA, and IgM) secreted into colostrum (Kruse, 1983). Furthermore, the ingestion of immunoglobulins in milk during established lactation provides defence against possible enteric infections in the suckling piglet (Porter, 1981).

The piglet also obtains innate protection from 'non-antibody factors' in the colostrum and milk (Reiter, 1978). Therefore, failure to ingest sow's colostrum and milk predisposes piglets to infection from environmental pathogens. In many piggeries, a high percentage of these piglets die before they reach weaning age. There are some indications that effective immunological grant in the neonatal hours is associated with enhanced immunological ability in later life (Varley and Cole. 1976a,b, 1978).

Furthermore, the immune system is significantly affected by the physiological stress that accompanies adverse environmental conditions (Kelley, 1980). Hot and cold ambient temperatures have an affect on the pig's resistance to a wide variety of microbes such as pasturella, salmonella, pneumococci, streptococci, staphylococi, enterotoxigenic *Escherichia coli*. The environmental conditions can affect immunity in the new born pig. For example cold exposure early in the life of baby pigs reduces their serum levels of passively acquired, colostrum-derived immunoglobulins (Blecha and Kelley, 1981).

2.6.1. Immunoglobulins (Igs)

Immunoglobulins are proteins made in B-cells (one of the two major classes of lymphocytes) that possess antibody activity and are made up of four polypeptide chains, two identical heavy chains joined by dissulphide bonds. Gamma globulins are a fraction of the plasma proteins which are associated with immunity and resistance to disease. They provide the immune response, i.e. antibodies to react with antigens, such as bacteria or foreign proteins. All antibody molecules are globulins but not all serum globulins are antibodies. By electrophoretic separation of serum proteins, antibody globulins are localized in the gamma globulin and occasionally beta globulin regions. The antibody portions of the serum globulins are referred to as immunoglobulins.

Immunoglobulins have two aspects to their function: antigen binding associated with the V domains, and a multiplicity of effector and control functions

associated with the rest of the molecule. IgG, IgA and IgM immunoglobulins are reactive with the stimulating antigen in some detectable manner (Logan *et al.*, 1974; Charles and Paul, 1994).

2.6.2. Structure of immunoglobulins

Each monomeric unit of immunoglobulin is composed of four polypeptide chains as show in Figure 1. The two heavy (H) chains, each with a molecule weight of approximately 55,000, are held together with as many as five disulfide bonds. There are five classes of serum immunoglobulin: IgM, IgD, IgG, IgA, and IgE, which differ by their heavy chains; these are denoted by μ, δ, γ, α, and ε, respectively. The whole immunoglobulin molecule arose in evolution from a single ancestral domain. Since then, each domain has evolved along its own lines, and acquired specialised functions (Charles and Paul, 1994).

2.6.3.The classes of immunoglobulin and effector functions

IgM class antibodies are the first produced in an immune response. The size of the IgM molecule makes it the most efficient of the immunoglobulin at agglutinating microorganisms and fixing complement and this may explain its early appearance.

IgG class antibodies thus initiate the lysis of certain pathogens and enhance phagocytosis. IgG is able to distribute itself between the intra-and extra-vascular compartments. In domestic animals, IgG is transferred from the dam to neonate by colostrum. It is absorbed from the gut and provided systemic immunity.

IgA class antibodies provide immunity by hindering the attachment of pathogens to their cellular substrates and in particular to alimentary tract epithelium. The secretion of IgA also plays an important role in defence of the respiratory system.

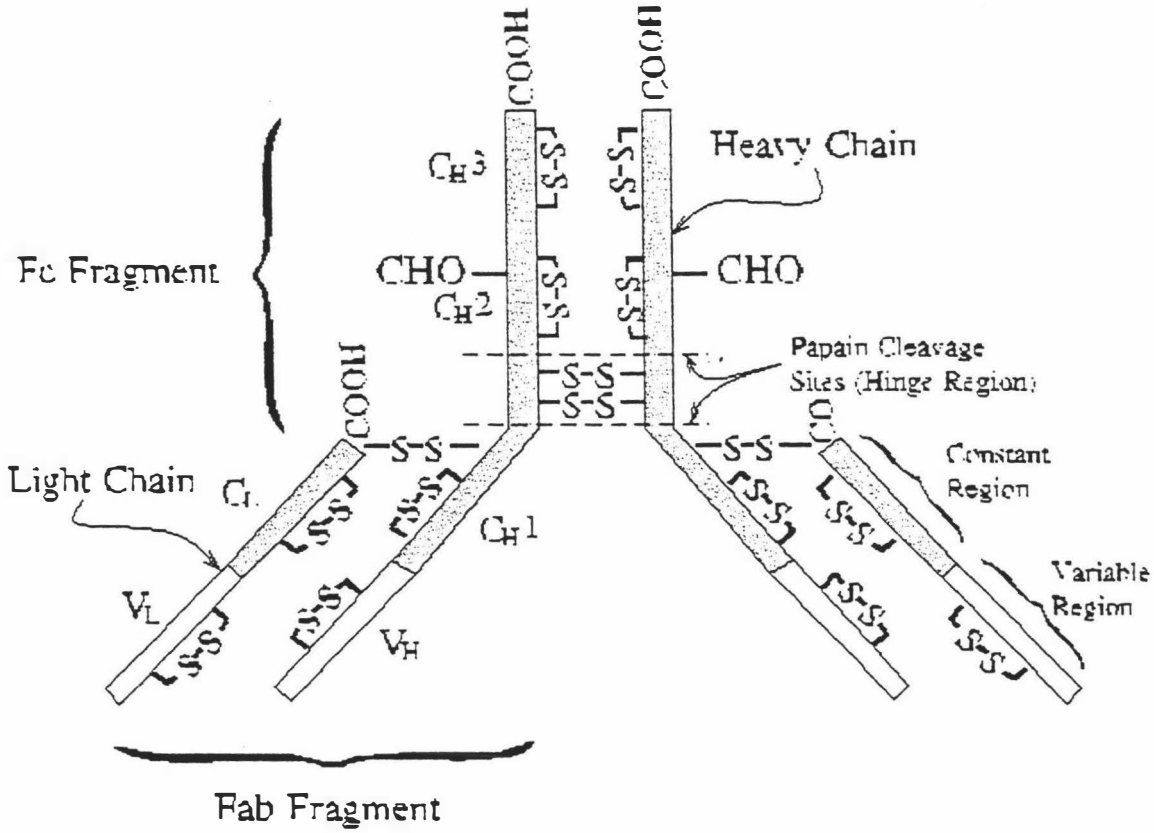

Figure 1 Structure of Immunoglobulin (Bigley, 1975)

IgD class antibodies are present only in very low concentrations in blood, but are present at the surface of B lymphocytes where they probably functions as antigen receptor.

IgE class antibodies are the cause of allergic reactions and degranulation involves the release of vaso-active amines which are responsible both for the allergic sequelae and for attracting eosinophils to the site.

2.6.4. Immunological protection

The concentrations of the colostral immunoglobulins of the sow are high at birth and decline during the first 24 h after parturition (Figure 2). Maximum immunoglobulin absorption in newborn pig occurs within 4-12h after birth, and then declines rapidly due to a gradual and progressive process commonly referred to as gut closure (Westrom *et al*. 1985). During gut closure, colostral immunoglobulins are absorbed across the jejunal epithelium and into lymphatic vessels (Holland, 1990) of the piglet and the transport of macromolecules ceases (Westrom *et al*., 1984). Changes associated with this closure develop along the small intestine at different times after birth, with transport terminating in the duodenum, jejunum and ileum at about 2h, 2d, and 3d after birth, respectively (Murata and Namioka, 1977). Absorbed immunoglobulins, along with other colostral proteins, then enter the circulation (serum) with intestinal-lymph through the thoracic duct. Serum antibodies have been detected as early as 3h after birth (Porter, 1986). By 48h after birth gut closure is complete. After gut closure, the immunoglobulins in ingested milk continue to provide local protection against microbial pathogens in the gastrointestinal tract of the piglet. Corresponding to gut closure, immunoglobulin and protein concentrations in colostrum decrease to 50% of pre-nursing values by 6h after nursing is initiated (Friend *et al*., 1962; Hendrix *et al*., 1978).

Piglets born at the end of farrowing, especially when the litter size is more than eight, are found to have much lower concentration of serum IgG at 6h after birth

than their littermates (Hendrix *et al*., 1978). It is important that the newborn piglet receives an adequate colostrum intake during the first hours after birth, before the onset of typical milk secretion, because the passage of the large antibody protein molecules does not occur from the sow to the foetus in *utero* during gestation (Hemmings and Brambell, 1961).

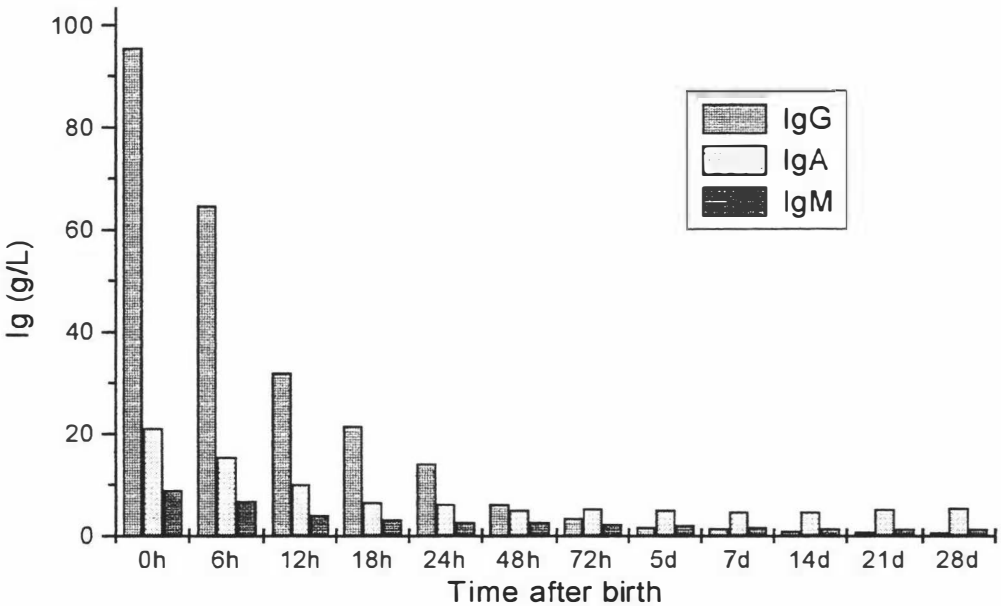

Figure 2. Changes in immunoglobulins during lactation (Klobasa *et al.*, 1987)

IgG is the predominant immunoglobulin in colostrum (80%) (Bourne ,1976). At birth, Klobasa *et al.* (1987) found that the immunoglobulin G (IgG) concentrations is approximately 95.6mg/ml and after 72 hours it had decreased to a 3.5mg/ml. As the most important form of immunologic protection to the neonatal pig is the transfer of colostral immunoglobulins from the dam (Tizard, 1987), the successful transfer of immunoglobulins from the dam to the new born depends on the amount consumed and absorbed by the neonate (Selman, 1973). Morel *et al.* (1995) fed orally bovine milk immunoglobulin G (IgG) to pigs after weaning, and suggested that bovine IgG were presented in the proximal and medial regions of the small intestine in amounts sufficient to prevent or treat upper gastro-intestinal tract diseases.

2.7. Nutrition

Nutrition is one of the key factors affecting pig performance after weaning. It plays a role in immunity which can be enhanced to help control diarrhoea. The baby pig has specific dietary requirements due both to the stress of weaning and the poor development of its gut.

2.7.1. Feed supplements

Generally, supplementation of liquid feed or a solid feed to piglets increases weaning weight. One of the most important justifications of creep feeding is that it stimulates earlier development of the mature digestive enzyme system and thereby reduces digestive disturbances and growth checks following weaning. Supplying a suitable creep feed may help piglets adjust to the change from the liquid diet of their mothers' milk to a dry diet and may result in modification of gut flora and adaptations in gut secretion (e.g. digestive enzymes) that may help to reduce the growth check after weaning.

Providing supplementary feed advantage piglets with low birth weights, as they are less successful in competing with their larger and heavier littermates for

teats during suckling bouts, and consequently ingested less colostrum (Hendrix *et al.,* 1978; de Passille *et al.,* 1988). Hence low-birth weight piglets grow more slowly during suckling and after weaning, and they will take a greater number of days to reach market weight (Campbell and Dunkin, 1983). Appleby *et al.* (1992) found that creep food intake was positively associated with weight gain in the week before weaning.

Baro *et al.* (1996) also found that feeding protein to new born pigs was an effective means of improving growth. Low-protein diets reduce the pig's ability to resist infection. Pigs fed a diet containing 12% protein suffered more severe pneumonia lesions than pigs fed a 16% protein ration (Straw and Wasson, 1985). However, if pre-weaning consumption is low, the immune system is primed and the response at weaning may be very damaging to the gut lining and may have long-term effects (Newby *et al.*, 1985). Both weaning weight and the associated nursery feeding program can affect post-weaning performance in the subsequent growing-finishing period (Mahan and Lepine, 1991), possibly via improved development. Supplement feeding helps developing the mature digestive enzyme system and hence reduced digestive disturbances and growth checks following weaning.

2.8. Conclusion

There are considerable economic advantages associated with increasing the weaning weight of pigs. Pre-weaning nutrition is such an important factor in the overall growth of piglets. Weaning weight and associated nursery feeding program can affect performance both immediately post weaning and in the subsequent growing-finishing period. IgG provides passive local immunity in the gastrointestinal tract and may help protect pigs from against enteric disease. Bovine milk immunoglobulin concentrates (BICs) have been proposed for providing passive immunity against various enteric pathogens. They have been investigated as safe and effective alternative agents for preventing or treating

diarrhoea diseases caused by various enteric pathogens (Mietens *et al.,* 1979; Brussow *et al.*, 1987; Lyerly *et al.*, 1991; Lecce *et al.,* 1991; Tacket *et al.,* 1992; Tacket *et al.*, 1988;). Bovine-derived milk products have the advantage over other potential sourses of immunoglobulins, such as porcine plasma, of being readily available and, in many case, being less expensive.

CHAPTER 3

MATERIALS AND METHODS

3.1. Animals and treatment groups

Seventy two Duroc X (Large White X Landrace) male and female piglets from multiparous sows of the Pig Research Unit, Massey University, Palmerston North, New Zealand were used. The experiment was conducted over four time periods (blocks) with the piglets from two litters being used in each period. Hence, a total of eight litters were used in the entire experiment. At two days of age, nine piglets from each litter were randomly assigned to three treatment groups (three piglets per litter per treatment):

1. Suckling from dam and supplemented with water (Control group);
2. Suckling from dam and supplemented with hydrolysed whey protein isolate (WPI group) (WPI; Alatal 821 hydrolysed whey protein isolate, New Zealand Dairy Board, Wellington N.Z.) derived from bovine milk; or
3. Suckling from dam and supplemented with whey globulin concentrate (WGC group) (WGC; colostrx® colostrum supplement, Protein Technology, Inc.1 Santa Roza, California, USA), derived from bovine milk and containing immunoglobulin G.

3.2. Diet supplementation method

Piglets were supplemented (WPI or WGC) twice daily at 9.00 am and at 3.00 pm from day two until weaning at day 24. The composition of WPI and WGC is presented in Table 5. The amount fed to the piglets (Table 6) was calculated from crude protein WPI and WGC (900 and 800, respectively) and the percentage of the ideal protein content of WPI (0.93) and WGC (0.63) (Baker, 1993). The milk was mixed up of 30 percent milk powder and 70 percent water once daily in the morning and the

milk left over from the morning feeding was kept in the fridge and warmed up to feed the piglets in the afternoon.

Table 5. Composition of hydrolysed whey protein isolate (WPI) and whey globulin concentrate (WGC) (g/100g (air dry basis))

	WPI	WGC
GE (MJ/g)	20.59	21.97
CP (g/kg)	800.00	900.00
IgG (%)	-	6.00
Asparticacid (%)	10.56	9.41
Threonine (%)	4.71	6.36
Serine (%)	3.33	4.08
Glutamic acid (%)	16.66	15.02
Proline (%)	4.72	4.91
Glycine (%)	2.08	1.68
Alanine (%)	5.56	4.47
Cysteine(%)	1.17	1.56
Valine (%)	5.20	5.43
Methionine (%)	2.14	1.91
Isolusine (%)	5.77	5.73
Leusine (%)	12.18	9.65
Tyrosine (%)	3.33	2.88
Phenylalanine (%)	3.66	2.89
Histidine (%)	2.22	1.72
Lysine (%)	10.47	8.23
Ammonia (%)	1.68	1.47
Arginine (%)	2.86	2.22

Table 6. Amount of hydrolysed whey protein isolate (WPI) and whey globulin concentrate (WGC) for milk supplemented piglets between 2 and 24 days of age (30% milk and 70% H_2O)

Age of piglet (days)	WPI g/d/piglet	WGC g/d/piglet	Ideal protein g/d/pig
2 - 4	3.5	4	2
5 - 8	8.8	10	5
9 - 12	26.5	30	15
13 - 16	35.5	40	20
17 - 20	44.0	50	25
21 - 24	53.0	60	30

Before supplementing, all the piglets were put in a crate separate from their mother for one hour to encourage them to drink the supplement when being fed. Piglets were orally supplemented by a syringe fitted with plastic tubing that was put in to the mouth and passed in the throat of the piglet.

3.3. Measurements

3.3.1. During supplementation

The piglets were weighed on days 0 ,4, 8, 12, 16, 20 and 24 in the morning before receiving their supplement. From day 21, they were given access to a dry pre-weaning feed (Table 7).

Table 7 Composition of diet fed to pre-weaning pigs[1]
(Creep food)

Ingredient Name	Percentage of Total Mixture
Barley	23.00
Flaked wheat	23.25
Fishmeal	2.50
Skim milk powder	31.25
Dried peas	2.50
L- Lysine	0.08
Methionine	0.05
Meat bone meal	3.00
Dried blood	1.25
Soya bean oil	5.00
Soya bean meal	2.50
Salt	0.13
Sugar	5.00
Pig starter premix (Vitamins)	0.50
Endox (antioxidant)	0.013

[1] DE = 13.62 MJ/kg CP = 19%

3.3.2. Post weaning

On day 25 the dam was removed from the piglets, but the piglets remained in the farrowing crate for three days in order to decrease the stress of weaning. All piglets were moved to the weaner accommodation on day 28. Within each time period the piglets from each treatment group in the litter (control group, WPI group and WGC group) were housed together after weaning. At this stage, piglets were fed a commercial weaner feed (Table 8) *ad libitum* until nine weeks of age. They were weighed at weekly intervals at 09.00h in the morning. They remained in the pens until nine weeks of age. At nine weeks of age the pigs from all treatment groups were returned to the Pig Research Unit until they reach a slaughter weight of at about 85kg. Live weights were recorded and backfats thickness were measured with ultra-sound immediately prior to slaughter.

Table 8 Composition of diet fed from weaning to transfer (commercial weaners)[1]

Ingredient Name	**Percentage of Total Mixture**
Barley	40.70
Flaked wheat	20.00
Meat bone meal	7.50
Skim milk powder	7.50
Dried peas	7.50
Soya bean meal	12.50
Dried blood	2.50
Soy bean oil	1.00
Salt	0.25
Methionine	0.01
Pig starter premix (Vitamins)	0.50

[1]DE = 13.08 MJ/kg CP = 15%

3.3.3. Diarrhoea

The incidence and severity of diarrhoea was recorded daily for piglets from day 2 until to day 24. Diarrhoea was estimated using the following scale: 1 = normal, no fluid; 2 = soft , mostly solid; 3 = runny, mostly fluid; 4 = watery, all fluid; and 5 = watery with blood (Nocek *et al.*, 1984).

3.3.4. Corrected weight and age

Because of pigs were slaughtered at slightly different weights and ages. A corrected weigh at 150 days of age and a corrected age at 85 kg live weight were calculated .to compare between treatment groups. These corrected values were made by using the average daily gain from 62 days to slaughter for each pig.

3.4. Statistical analysis

The General Linear Models procedure (GLM) of SAS (Statistical Analysis System, 1995) was used to perform on analysis of variance and to estimate the effects of factors and covariables. The following model was used:

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \varepsilon_{ijk}$$

where

μ is the overall mean ;

α_i is the effect of the i^{th} litter;

β_j is the effect of the j^{th} treatment;

γ_k is the effect of the k^{th} sex;

ε_{ijk} is the random error.

CHAPTER 4

RESULTS

The results presented are from 61 piglets because one piglet was culled due to a sore leg, five piglets died due to reasons unrelated to the experiment and the ultra-sound backfat data for five other pigs were not obtained.

4.1. Liveweight

There were no differences in liveweight between the pigs in the control, WPI or WGC treatment groups during the suckling period, at weaning or at 62 days of age. Both birth weight and litters influenced the weight at weaning and at 62 days of age ($P < 0.05$ and $P < 0.01$, respectively) (Table 9). The weight at slaughter, and the corrected liveweight at 150 days of age, of pigs fed WGC was approximately 5 kg heavier ($P<0.05$) than pigs in either the WPI or control groups (85.04, 79.52 and 79.32kg vs 86.09, 79.56 and 82.97kg, respectively) (Table 9).

4.2. Backfat and Slaughter age

Backfat at slaughter was not affected by the feeding treatments although differences between litters ($P < 0.1$) were detected. The number of days from birth to slaughter, were not significantly different between the control or WPI or WGC treatment groups , but the corrected age at 85kg was at least 6 days ($P < 0.01$) less for pigs fed WGC than for all other pigs (Table 9).

Table 9. Least square treatments means for weight from birth to slaughter (kg), ultra sound backfat thickness, age at slaughter, corrected weight at 150 days (kg) and corrected age at 85 kg (days), and probability values for birth weight, litter, sex and treatment

Parameter	Control (n=22)	WPI (n=20)	WGC (n=19)	Pooled SE	R^2	Probability value (P=) Birth weight	Litter	Sex	Treatment
Birth weight (kg)	1.62	1.62	1.62	0.00	0.00	-	0.52	0.16	0.98
Weaning weight (kg) (24days)	7.43	7.77	7.69	0.21	0.56	0.001	0.006	0.60	0.50
Weight at 62 days	23.77	24.01	23.26	0.66	0.52	0.001	0.001	0.41	0.73
Weight at slaughter (kg)	79.32[a]	79.52[a]	85.04[b]	1.41	0.34	0.03	0.16	0.46	0.01
Age at slaughter (days)	144.00	150.00	149.00	4.34	0.34	0.05	0.11	0.15	0.26
Ultra sound backfat (mm)	12.35	11.85	11.95	0.30	0.32	0.69	0.01	0.67	0.46
Corrected weight at150days (kg)	82.97[a]	79.56[a]	86.09[b]	1.70	0.50	0.07	0.01	0.03	0.04
Corrected age at 85kg (days)	156.19	161.66	149.57	3.67	0.44	0.04	0.10	0.53	0.07

[a,b] = Significant difference between treatment ($P<0.05$) (Duncan-Test) SE = standard error R^2 = coefficient of variation

4.3. Average daily gain

Total average daily gain (ADGT) from day two to slaughter was significantly ($P < 0.05$) higher for the WGC group (565g d^{-1}) than the control group (545gd^{-1}) and the WPI group (521gd^{-1}) (Table 10). Also average daily gain from weaning (24 days) to slaughter and 62 days of age to slaughter were significantly ($P < 0.05$) higher for the WGC group (664 and 722gd^{-1}) than the control group (643 and 691gd^{-1}) and the WPI group (603 and 638gd^{-1}). There was no significant treatment differences in the average daily gain between the pigs in the control, WPI or WGC treatment groups during the suckling period or between weaning to 62 days of age (Table 10). The average daily gain of piglets during to suckling period and up to 62 days of age depended
($P < 0.05$) on the litter and piglet birth-weight.

4.4. Diarrhoea

Four piglets supplemented with WPI and one piglet from the control group had diarrhoea score 3 from day 15 to day 17 during the suckling period. No piglets supplemented with WGC had diarrhoea at any time.

Table 10 Least square means for average daily gain from birth to slaughter (kg), for pigs supplemented with water (control) whey protein isolate (WPI) or whey protein concentrate (WGC). Probability values for birth weight, litter, sex and treatment

Parameter	Control (n=22)	WPI (n=20)	WGC (n=19)	Pooled SE	R^2	Probability value (P=) Birth weight	Litter	Sex	Treatment
Average daily gain (2 to 24 days old) (g/day)	248	263	259	9	0.44	0.0002	0.004	0.66	0.52
Average daily gain (24 to 34 days old) (g/day)	212	214	189	8	0.70	0.051	0.0001	0.65	0.33
Average daily gain (34 to 62 days old) (g/day)	504	500	486	16	0.46	0.001	0.001	0.45	0.60
Average daily gain (34days to slaughter) (g/day)	$643^{a\,b}$	603^{a}	664^{b}	15	0.46	0.64	0.07	0.03	0.02
Average daily gain (62days to slaughter) (g/day)	$691^{a\,b}$	638^{a}	722^{b}	20	0.42	0.22	0.02	0.04	0.02
Total average daily gain (g/day) (from 2 days to slaughter)	545^{a}	521^{a}	565^{b}	11	0.48	0.12	0.01	0.04	0.03

$^{a\,b}$ = Significant difference between treatment ($P < 0.05$) (Duncan-Test) SE = standard error R^2 = coefficient of variation

CHAPTER 5

DISCUSSION AND CONCLUSION

The hypothesis that provision of supplemental bovine milk protein that contains immunoglobulin would increase weaning weight, decrease the incidence of diarrhoea during the suckling period and immediately post-weaning, and improve the post-weaning growth performance was partially supported in this study.

The weaning weight and weight of piglets at 62 days were not significantly different between treatment groups. This is in contrast to similar work by King (1996), in which the provision of a bovine milk *ad libitum* to piglets during the suckling period increased the weaning weight of pigs by 2 kg in average. There are number of reasons that may explain the difference between King's (1996) data and the results from the current experiment. First, the voluntary intake of the milk supplement used by King was 458 ml per pig per piglet which is more than the average of 110 ml fed by syringe in the current work. Given the potentially wide variation in the intake of a supplement between piglets within litters (Pluske *et al.*, 1995), the amount of WPI and WGC fed to each piglet in the current experiment was controlled so that possible differences in growth performance could be attributed to the presence or absence of immunoglobulins in the supplement rather than differences in the amount of energy or protein consumed. Moreover, the amount milk that each piglet consumed was not controlled.

A second possible reason for the lack of response in weaning weight in the current experiment is that the piglets which received WPI or WGC may have consumed less milk from the sow; i.e., WPI and WGC may have substituted rather than supplemented the intake of sow's milk. The piglets were separated from the sow for one hour prior to the morning and afternoon feeding of the

milk-based products or water (for the control piglets). This was done in an attempt to encourage them to quickly consume the milk-based products.

Despite this measure, the length of time taken for piglets to consume the milk-based products was longer than anticipated, and approached 15 minutes towards the end of the suckling period. The piglets that received only water (control group) consumed their allocated volume of water much quicker and were returned to the sow within about 3 minutes. Hence, the piglets that received WPI or WGC were separated from the sow for up to 3 hours per day Assuming a constant suckling interval of about 45-50 minutes (Auldist *et al.*, 1995), the piglets could have missed out on about 4 suckles which could equate to nearly 15% of their normal number of suckles each day. Therefore, their feed intake (sow milk plus supplement) may not have been much longer than the control group.

A third possible reason for the lack of effect of feeding WPI or WGC on weaning weight is that the stress associated with providing the supplements may have jeopardised the growth performance of the piglets. As described above, the total supplementation time was lengthy (longer than anticipated) and the piglets were subjected to prolonged periods of handling while the supplements were fed by the syringe and plastic tubing passed to the back of their mouth. It was noted that some piglets did not appear to enjoy the taste of the products, especially WPI which was bitter, and hence their twice daily handling may not have been a positive experience. Hemsworth *et al.* (1995) have clearly shown that growth performance of pigs is responsive to both positive and negative experiences that pigs may encounter.

The present work confirms that growth performance of pigs during their growing-finishing phase can be increased by providing suckling pigs with bovine milk that contains immunoglobulin. Piglets fed WGC reached slaughter weight at an earlier age than piglets supplement with WPI or water (control).

The average daily gain (ADG) from weaning (24 days) to slaughter, and from transfer (62 days) to slaughter were significantly ($P < 0.05$) higher for the WGC group than the control or WPI groups. This meant that pigs which had received

WGC during the suckling phase reached slaughter weight 5-8 days earlier than control pigs or those that have received WPI.

The presence of immunoglobulins (predominantly IgG) 6% in the WGC product may have improved gut development in the young pig which led to persistent increases in either food consumption or digestibility. Weaning is often associated with a decline in the activity of gut enzymes (Shields *et al.*, 1980) and a disruption of gut structure (Pluske and Williams, 1988). While some of these changes can be attributed to the change from a liquid feed (sow's milk) to a dry weaner ration and the stressors associated with weaning (Pluske and Williams, 1996), impaired gut structure and function may also be associated with the presence of enteric pathogens that may be present at subclinical or clinical levels.

An effective response to pathogenic organisms in the gastrointestinal tract relies, in part, on an increase in the local concentration of immunoglobulins. Immunoglobulins contained in milk can provide local protection in the small intestine in pigs until weaning (Wilson, 1974) and the provision of immunoglobulins beyond just the first few days after birth can increase piglet survival (McCallum *et al.*, 1977). Drew and Owen (1988) found that the provision of either porcine or bovine immunoglobulins in a sow milk replacer up to 14 days of age increased piglet growth rate from birth to 14 days of age and also from 14 to 28 days of age, reduced the severity of diarrhoea, and increased the survival of piglets during the first 4 weeks of life. The Ig present in WGC may be associated with a change in the crypt/ villus ratio, the crypts becoming relatively deeper (Stokes *et. al.*, 1994). Morel *et al*. (1995) found that sufficient amounts of oral bovine IgG, similar to that used in the current study,

resist digestion in the upper gastrointestinal tract and remain active.

The provision of WGC in early life in the present experiment may have reduced the incidence or severity of enteric infections as shown by the fact that no WGC piglets display diarrhoea as any time. Thus providing long-term advantages in growth performance by reducing damage to the structure of the gut and subsequently improving gut function. This long-term advantage in growth performance occurred independent of any change in weaning weight or weight at 62 days of age. These data suggest that the improved growth performance of pigs that are weaned heavier (e.g., Harrell *et al*., 1993), may not necessarily be due to their higher body weight *per se*, but rather by improved gut function. The point at which improved gut structure leads to an increase in growth performance may depend on many factors such as the extent of exposure to pathogens, feed intake and diet composition. Variations in these factors may account for why differences in weaning weight are sometimes, but not always, observed in piglets that receive extra immunoglobulins during the suckling period.

The incidence of diarrhoea in the current experiment was low for all pigs and hence no clear conclusion can be reached about the potential role of WGC or WPI in reducing the incidence or severity of diarrhoea. A similarly non-conclusive result was found by Varley *et al*. (1986) who provided immunoglobulins to piglets on day 1 of life, but found that their control and treatment pigs both had very high survival rates. Under the conditions of apparently minimal exposure to gut pathogens in the current experiment, no piglets fed WGC had diarrhoea during the experiment, but one control pig and four pigs fed WPI had diarrhoea during the suckling period. Under conditions of more severe exposure to enteric pathogens, WGC may lead to a more significant reduction in the incidence or severity of diarrhoea. As shown by Schollum *et al*. (1996) who reported a reduction in the incidence of diarrhoea for piglets fed Bovine IgG after a challenge with *E. coli*.

The beneficial effect on subsequent growth performance arising from the provision of WGC during the suckling phase may have been due to an increase in food conversion (i.e., improved digestion or utilisation of feed consumed) or by an increase in feed intake. Feed intake was not measured during the current experiment, but further work should include an assessment of the intake responses, and the food conversion ratio, during the growing and finishing phases.

An interesting finding, unrelated to the provision of the milk-derived supplements to piglets, was the consistently significant effect of birth-weight and litter on growth performance both before and after weaning. Both of these factors may have influenced the intake of sow's milk. Heavier piglets are usually better able to compete for a desirable teat and may even push smaller piglets off their teat during milk let-down (Thompson and Fraser 1986). Other factors, such as differences in the degree of immuno-competence, or the degree of maturity of gastrointestinal tract or other organs at birth, may also contribute to the positive association birth weight and subsequent growth performance. The 'litter effect' may indicate that different sows produced different amounts of milk which, in turn, may have led to different intakes of immunoglobulins and growth factors by their piglets. Such an effect should have had a minimal impact on the results of the current experiment, because the three treatment groups were allocated within litters. The importance of birth weight on subsequent pig performance should not be ignored in future work.

From the results of the present study it can be concluded that providing a supplement of bovine milk protein that contains IgG during the suckling period lead to long-term advantages in growth rate. The number of days required for pigs supplemented with WGC to reach market weight was 5-10 days less than for the other groups. Providing immunoglobulin-enriched supplements during the suckling period may be cost effective for producers due to short time period of supplementation, and important longer term improvements in growth rate and reduction in the incidence of diarrhoea.

Further work should include:

(i) estimates of the intake of sow's milk to evaluate possible substitution of sow's milk with the supplementary feed,

(ii) measurements of feed intake immediately post-weaning and during the growing-finishing periods, and hence the feed conversion ratio (FCR), to determine if the improved post-weaning growth, as observed in the current study, is due to increased feed intake or increased efficiency of growth (e.g., through improved digestibility of nutrients), and

(iii) an investigation into alternative methods of providing the supplementary milk-based products (e.g., nipple- or trough-feeding system) to optimise the voluntary intake of the supplements under commercial pig farming condition.

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APPENDICES

Live-weights and age of the piglets from birth to slaughter

Treat.	No.	Age1 (d)	Lw1 (kg)	Age2 (d)	Lw2 (kg)	Age3 (d)	Lw3 (kg)	Age4 (d)	Lw4 (kg)	Age5 (d)	Lw5 (kg)
1	1	0	1.7	5	2.6	8	3.3	12	4.5	16	5
1	2	0	1.6	5	2.6	8	3.4	12	4.7	16	5.8
1	3	1	1.5	4	2	8	3.2	12	3.7	16	4.7
1	4	1	1.2	4	1.8	7	3.7	11	3.6	15	4.5
1	5	1	1.7	4	2.4	7	2.7	11	4.4	15	5.6
1	6	1	1.8	4	2.8	7	3.3	11	4.9	15	6.2
1	7	0	1.5	4	2	8	3.3	11	3.4	15	3.8
1	8	0	1.7	4	2.5	8	2.3	12	4.5	16	5.2
1	9	0	1.3	4	2.4	8	3.8	12	4.5	16	5.3
1	10	1	1.4	4	1.6	8	3.6	12	3.2	16	4
1	11	1	1.9	4	2.7	8	3.6	12	5	16	5.7
1	12	1	1.8	4	2.7	8	3.6	12	4.8	16	5.7
1	13	1	1.7	5	2.6	9	4.8	12	4.7	16	5.9
1	14	1	1.9	5	3.4	9	2.8	13	6.4	17	8.1
1	15	1	1	5	1.9	9	3.9	13	3.9	17	5.1
1	16	1	1.6	5	2.7	9	4.2	13	5.2	17	6.4
1	17	1	1.7	5	3	9	2.3	13	5.3	17	6.6
1	18	1	1.2	5	1.8	9	5.2	13	2.9	17	3.6
1	19	0	2.2	4	3.5	10	4.5	13	6.1	17	7.6
1	20	0	1.9	4	3	10	2.1	13	5.1	17	6.4
1	21	0	1.2	4	1.4	10	4.9	13	2.3	17	3.1
1	22	0	1.9	4	3.2	10	2.1	13	5.8	17	7.3
1	23	0	1.6	4	2.4	10	4.9	13	4.7	17	6.1
1	24	0	1.4	4	1.9	10	4	13	3	17	4.3

Treat = Treatment No. = Pigs identification Lw = Liveweight of pigs

Treat 1 = Control, Treat 2 = WPI, Treat 3 = WGC

To be continued

1.2.

Treat	No.	Age6 (d)	Lw6 (kg)	Age7 (d)	Lw7 (kg)	Age8 (d)	Lw8 (kg)	Age9 (d)	Lw9 (kg)	Age10 (d)	Lw10 (kg)
1	1	20	5.4	24	5.9	28	6.8	34	9.6	41	12
1	2	20	7.1	24	7.9	28	8.6	34	11	41	14
1	3	19	5.8	23	6.8	27	7	33	8.3	41	11
1	4	19	5.7	23	6.2	27	7.1	33	9.2	40	11
1	5	19	6.9	23	7.7	27	8.4	33	11	40	14
1	6	19	7.2	23	8.2	27	8.4	33	9.8	40	12
1	7	19	4.4	24	4.9	28	6	35	8	40	9.8
1	8	19	6.2	24	7.6	28	8.5	35	10	42	13
1	9	19	6.1	24	7	28	7.2	35	8.9	42	11
1	10	19	4.6	24	5.3	28	5.7	35	7.3	42	8.2
1	11	19	7.1	24	7.9	28	8.7	35	11	42	13
1	12	19	7	24	7.7	28	8.5	35	11	42	13
1	13	21	7	24	7.8	28	7.6	35	9.2	42	12
1	14	21	9.1	24	10	28	9.9	35	12	42	15
1	15	21	6.4	24	7.1	28	7.3	35	8.6	42	11
1	16	21	7.6	24	7.8	28	8.1	35	9.3	42	13
1	17	21	7.6	24	8.9	28	9	35	11	42	15
1	18	21	4.3	24	4.8	28	5.3	35	7	42	11
1	19	21	9.2	24	9.9	27	10	34	11	41	14
1	20	21	7.5	24	8	27	8.4	34	10	41	13
1	21	21	3.7	24	4	27	4.4	34	5.6	41	7.6
1	22	21	8.7	24	9.6	27	9.8	34	11	41	15
1	23	21	7.4	24	8.3	27	8.5	34	9.8	41	13
1	24	21	5.7	24	6.6	27	6.8	34	8.2	41	11

Treat = Treatment No. = Pigs identification Lw = Liveweight of pigs

Treat 1 = Control, Treat 2 = WPI, Treat 3 = WGC

To be continued

1.3.

Treat	No.	Age11 (d)	Lw11 (kg)	Age12 (d)	Lw12 (kg)	Age13 (d)	Lw13 (kg)	Age14 (d)	Lw14 (kg)	Age15 (d)	Lw15 (kg)
1	1	48	14	55	22	62	26	142	86	150	91.92
1	2	48	19	55	24	62	27	142	93	150	99.52
1	3	47	11	54	15	61	17	161	78	150	69.71
1	4	47	16	54	20	61	23	147	75	150	77.77
1	5	47	18	54	23	61	27	166	86	150	73.16
1	6	47	17	54	21	61	24	141	76	150	82.71
1	7	49	14	56	19	63	24	140	82	150	89.70
1	8	49	16	56	21	63	25	146	82	150	84.76
1	9	49	13	56	18	63	21	166	79	150	66.76
1	10	49	10	56	13	63	14	188	76	150	45.78
1	11	49	18	56	23	63	27	134	80	150	92.84
1	12	49	18	56	22	63	27	134	79	150	91.64
1	13	49	15	56	18	63	22	145	85	150	89.35
1	14	49	18	56	22	63	26	128	69	150	88.36
1	15	49	12	56	18	63	22	152	58	150	56.42
1	16	49	18	56	20	63	25	132	71	150	88.80
1	17	49	20	56	23	63	28	120	75	150	98.70
1	18	49	14	56	18	63	23	138	82	150	91.28
1	19	48	19	55	24	62	25	145	88	150	92.15
1	20	48	16	55	22	62	24	138	86	150	95.08
1	21	48	11	55	14	62	15	-	-	-	-
1	22	48	20	55	25	62	25	138	80	150	89.48
1	23	48	16	55	21	62	22	-	-	-	-
1	24	48	14	55	19	62	21	145	73	150	76.95

Treat = Treatment No. = Pigs identification Lw = Liveweight of pigs

Treat 1 = Control, Treat 2 = WPI, Treat 3 = WGC

To be continued

2.1

Treat.	No.	Age1 (d)	Lw1 (kg)	Age2 (d)	Lw2 (kg)	Age3 (d)	Lw3 (kg)	Age4 (d)	Lw4 (kg)	Age5 (d)	Lw5 (kg)
2	1	0	2.3	5	3.7	8	4.5	12	6.9	16	7.8
2	2	0	1.6	5	2.6	8	3.2	12	4.6	16	5.9
2	3	0	1.3	4	1.9	8	2.3	12	3.5	16	4.7
2	4	1	1.6	4	2	7	2.6	11	3.5	15	4.5
2	5	1	1.2	4	1.8	7	2.6	11	3.7	15	4.8
2	6	1	1.4	4	2.2	7	3	11	4.1	15	5.2
2	7	0	1.6	4	2	8	2.4	11	3.4	15	4.2
2	8	0	1.7	4	2.7	8	3.9	12	5.3	16	6.3
2	9	0	1.2	4	1.9	8	2.9	12	4	16	4.9
2	10	1	1.5	4	2.1	8	2.9	12	4.1	16	4.9
2	11	1	2.1	4	2.9	8	4	12	5.4	16	6.4
2	12	1	1.7	4	1.6	8	2.1	12	2.9	16	3.3
2	13	1	1.7	5	1.9	9	4.6	12	6.3	16	7.9
2	14	1	1.3	5	2.3	9	3.3	13	4.3	17	5.2
2	15	1	1.2	5	1.9	9	3.1	13	4.7	17	5.9
2	16	1	1.8	5	2.9	9	4.2	13	5.7	17	6.8
2	17	1	1.6	5	2.6	9	3.7	13	4.8	17	5.8
2	18	1	1.3	5	2.3	9	3.5	13	4.7	17	6.2
2	19	0	2.1	4	3.6	10	4.8	13	5.6	17	6.9
2	20	0	2	4	3.1	10	4.6	13	5.3	17	6.4
2	21	0	1.4	4	2.5	10	3.9	13	4.1	17	3.8
2	22	0	1.7	4	3.1	10	4.9	13	5.9	17	7.7
2	23	0	1.6	4	2.4	10	3.7	13	4	17	4.7
2	24	0	1.4	4	2.4	10	3.9	13	4.6	17	5.5

Treat = Treatment No. = Pigs identification Lw = Liveweight of pigs

Treat 1 = Control, Treat 2 = WPI, Treat 3 = WGC

To be continued

2.2

Treat	No.	Age6 (d)	Lw6 (kg)	Age7 (d)	Lw7 (kg)	Age8 (d)	Lw8 (kg)	Age9 (d)	Lw9 (kg)	Age10 (d)	Lw10 (kg)
2	1	20	9.2	24	9.8	28	11	34	14	41	18
2	2	20	7.2	24	8	28	8.8	34	12	41	15
2	3	20	5.9	24	6.8	28	7.6	34	10	41	13
2	4	19	5.7	23	6.7	27	7.4	33	9.3	40	12
2	5	19	6.1	23	7.1	27	7.4	33	9.7	40	13
2	6	19	6.1	23	7.1	27	7.4	33	8.4	40	9.8
2	7	19	5.3	24	6.3	28	5.6	35	7.5	40	9.4
2	8	19	7.5	24	8.8	28	9.3	35	12	42	16
2	9	19	5.9	24	7.2	28	7.6	35	9.7	42	11
2	10	19	5.8	24	6.1	28	7	35	9.2	42	12
2	11	19	6.9	24	8.2	28	8.4	35	11	42	13
2	12	19	4.1	24	5.3	28	5.9	35	7.9	42	11
2	13	21	9.6	24	11	28	10	35	12	42	15
2	14	21	6.7	24	7.8	28	7.9	35	9.7	42	12
2	15	21	7.3	24	8.3	28	8.5	35	10	42	12
2	16	21	8.1	24	8.9	28	8.8	35	11	42	15
2	17	21	-	-	-	-	-	-	-	-	-
2	18	21	7.4	24	8.3	28	8.1	35	9.1	42	12
2	19	21	8.5	24	8.9	27	9.3	34	11	41	13
2	20	21	7.7	24	8.5	27	8.9	34	10	41	13
2	21	21	3.3	24	-	-	-	-	-	-	-
2	22	21	8.5	24	9.2	27	9.5	34	12	41	15
2	23	21	5.6	24	6.4	27	8	34	8.5	41	11
2	24	21	6.9	24	7.9	27	8.6	34	9.8	41	12

Treat = Treatment No. = Pigs identification Lw = Liveweight of pigs

Treat 1 = Control, Treat 2 = WPI, Treat 3 = WGC

To be continued

2.3.

Treat	No.	Age11 (d)	Lw11 (kg)	Age12 (d)	Lw12 (kg)	Age13 (d)	Lw13 (kg)	Age14 (d)	Lw14 (kg)	Age15 (d)	Lw15 (kg)
2	1	48	23	55	29	62	32	134	71	150	84.04
2	2	48	21	55	23	62	26	134	75	150	87.84
2	3	48	17	55	21	61	25	134	88	150	100.84
2	4	47	16	54	20	61	22	166	74	150	61.36
2	5	47	16	54	20	61	23	159	84	150	77.09
2	6	47	13	54	27	61	20	173	78	150	59.83
2	7	49	13	56	17	63	20	166	86	150	73.16
2	8	49	20	56	25	63	29	166	71	150	58.56
2	9	49	15	56	19	63	23	159	84	150	76.89
2	10	49	15	56	18	63	24	152	84	150	82.42
2	11	49	18	56	22	63	27	133	77	150	90.43
2	12	49	13	56	16	63	20	152	80	150	78.22
2	13	49	19	56	23	63	27	126	75	150	94.16
2	14	49	16	56	21	63	24	187	91	150	61.77
2	15	49	15	56	19	63	23	138	74	150	83.48
2	16	49	20	56	24	63	28	126	74	150	93.36
2	17	-	-	-	-	-	-	-	-	-	-
2	18	49	16	56	19	63	22	152	72	150	70.42
2	19	48	17	55	22	62	26	159	89	150	81.89
2	20	48	17	55	22	62	24	145	75	150	79.35
2	21	-	-	-	-	-	-	-	-	-	-
2	22	48	19	55	24	62	28	-	-	-	-
2	23	48	15	55	19	62	22	159	82	150	75.09
2	24	48	15	55	16	62	19	-	-	-	-

Treat = Treatment No. = Pigs identification Lw = Liveweight of pigs

Treat 1 = Control, Treat 2 = WPI, Treat 3 = WGC

To be continued

3.1

Treat.	No.	Age1 (d)	Lw1 (kg)	Age2 (d)	Lw2 (kg)	Age3 (d)	Lw3 (kg)	Age4 (d)	Lw4 (kg)	Age5 (d)	Lw5 (kg)
3	1	0	1.8	5	2.9	8	3.7	12	5.2	16	6.6
3	2	0	1.6	5	2.9	8	3.6	12	5.2	16	6.5
3	3	0	1.7	4	2.6	8	3.3	12	4.7	16	6
3	4	1	1.7	4	2.7	7	3.6	11	5	15	-
3	5	1	1.3	4	2	7	2.7	11	3.4	15	-
3	6	1	1.6	4	2.3	7	3.1	11	4.3	15	5.4
3	7	0	1.5	4	2.5	8	3.5	11	4.9	15	5.8
3	8	0	1.6	4	2.6	8	3.7	12	5.1	16	5.9
3	9	0	1.3	4	2.2	8	3.1	12	4.3	16	5.1
3	10	1	1.8	4	2.5	8	3.6	12	5	16	5.9
3	11	1	1.7	4	2.1	8	3	12	4.3	16	5.2
3	12	1	1.7	4	2.3	8	3.1	12	4.4	16	5.3
3	13	1	2	5	3.4	9	5	12	5.9	16	7.6
3	14	1	1.3	5	1.4	9	2.4	13	3.5	17	4.6
3	15	1	1.1	5	2.2	9	3.3	13	4.7	17	5.9
3	16	1	1.8	5	2.5	9	3.4	13	4.4	17	5.7
3	17	1	1.1	5	1.8	9	2.7	13	3.7	17	4.8
3	18	1	1.5	5	2.7	9	4	13	5.1	17	5.9
3	19	0	2.2	4	3.8	10	5.5	13	6.1	17	7.3
3	20	0	2	4	2.6	10	4.4	13	5	17	5.8
3	21	0	1.2	4	2.2	10	3.7	13	4.1	17	5.2
3	22	0	1.8	4	2.9	10	3.8	13	4.3	17	5.4
3	23	0	1.6	4	3	10	4.7	13	5.3	17	5.9
3	24	0	1.5	4	2.4	10	3.8	13	4.3	17	5.5

Treat = Treatment No. = Pigs identification Lw = Liveweight of pigs

Treat 1 = Control, Treat 2 = WPI, Treat 3 = WGC

3.2

Treat	No.	Age6 (d)	Lw6 (kg)	Age7 (d)	Lw7 (kg)	Age8 (d)	Lw8 (kg)	Age9 (d)	Lw9 (kg)	Age10 (d)	Lw10 (kg)
3	1	20	7.8	24	8.8	28	10	34	13	41	16
3	2	20	7.9	24	8.9	28	9.3	34	12	41	14
3	3	20	7.4	24	8.3	28	9.3	34	13	41	15
3	4	19	-	-	-	-	-	-	-	-	-
3	5	19	-	-	-	-	-	-	-	-	-
3	6	19	6.2	24	7.1	28	7.9	34	9.7	41	12
3	7	19	7.1	24	8.5	28	8.6	35	11	42	13
3	8	19	7.2	24	8.9	28	9.7	35	12	42	15
3	9	19	6.1	24	7.4	28	7.1	35	9	42	11
3	10	19	6.8	24	7.8	28	8.6	35	11	42	14
3	11	19	5.9	24	7.5	28	7.7	35	9.8	42	13
3	12	19	6.1	24	6.9	28	7.5	35	9.5	42	11
3	13	21	9.2	24	10	28	10	35	12	42	15
3	14	21	5.4	24	5.9	28	5.4	35	5.3	42	7.4
3	15	21	6.9	24	7.8	28	8.2	35	10	42	13
3	16	21	7.2	24	7.8	28	7.3	35	8	42	11
3	17	21	5.9	24	6.3	28	6.4	35	7.7	42	11
3	18	21	6.3	24	6.8	28	6.8	35	7.6	42	9.8
3	19	21	7.9	24	8.9	27	9.1	34	11	41	14
3	20	21	7.1	24	7.8	27	8	34	9.8	41	14
3	21	21	6.3	24	7.1	27	7.2	34	8.6	41	11
3	22	21	6.7	24	7.2	27	7.2	34	8.8	41	12
3	23	21	6.5	24	6.5	27	6.7	34	7.8	41	9.4
3	24	21	6.9	24	7.9	27	8	34	9.4	41	12

Treat = Treatment No. = Pigs identification Lw = Liveweight of pigs (kg)

Treat 1 = Control, Treat 2 = WPI, Treat 3 = WGC

To be continued

3.3.

Treat	No.	Age11 (d)	Lw11 (kg)	Age12 (d)	Lw12 (kg)	Age13 (d)	Lw13 (kg)	Age14 (d)	Lw14 (kg)	Age15 (d)	Lw15 (kg)
3	1	48	22	55	29	62	32	134	95	150	107.44
3	2	48	21	55	26	62	31	142	86	150	91.92
3	3	48	20	55	26	61	30	134	89	150	101.84
3	4	-	-	-	-	-	-	-	-	-	-
3	5	-	-	-	-	-	-	-	-	-	-
3	6	48	16	54	19	61	24	153	85	150	83.03
3	7	49	18	56	22	63	26	152	93	150	91.02
3	8	49	20	56	25	63	29	134	87	150	99.44
3	9	49	15	56	19	63	23	-	-	-	-
3	10	49	17	56	21	63	26	-	-	-	-
3	11	49	17	56	20	63	25	134	77	150	90.04
3	12	49	16	56	20	63	24	134	73	150	85.44
3	13	49	17	56	22	63	26	159	84	150	76.49
3	14	49	9.6	56	11	63	13	145	78	150	82.35
3	15	49	18	56	21	63	25	-	-	-	-
3	16	49	13	56	16	63	20	159	91	150	83.49
3	17	49	14	56	17	62	22	145	78	150	81.75
3	18	49	11	56	15	63	18	174	85	150	66.44
3	19	48	18	55	23	62	24	138	87	150	96.68
3	20	48	17	55	22	62	23	138	86	150	95.48
3	21	48	14	55	18	62	18	159	87	150	79.69
3	22	48	16	55	21	62	22	159	92	150	85.29
3	23	48	12	55	16	62	17	145	81	150	84.95
3	24	48	16	55	21	62	21	159	90	150	82.89

Treat = Treatment No. = Pigs identification Lw = Liveweight of pigs

Treat 1 = Control, Treat 2 = WPI, Treat 3 = WGC