Improving neonatal piglet survival by alternative management techniques

By:

Julia Sophia Huser

A thesis submitted for the partial fulfilment of the requirements of the Bachelor of Science (Animal Science) with Honours

The University of Adelaide

Faculty of Sciences

School of Animal and Veterinary Sciences

Roseworthy Campus

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 another person, except when due reference is made in text.

Julia Sophia Huser

31st October 2014

Acknowledgements:

I would like to thank my supervisors Wayne Pitchford, David Lines and Kate Plush for their time, ongoing support and knowledge. A special thanks to David Lines and Australian Pork Farms Group for allowing me to run my trial at a commercial farm, seeing industry application and the opportunity to perform research in an area of personal interest. I would like to thank Tracy Kennett for moral support and technical assistance at the piggery throughout the trial. I would like to thank my loving family, friends and office for continual care and support throughout the year. I wish to acknowledge the University of Adelaide and the Cooperate Research Centre for High Integrity Australian Pork for funding this study.

Abstract:

Welfare has been a major focus in intensive pork farming in recent years yet pre-weaning mortality is still high, with 10-20% of piglets not surviving to weaning. Not only is piglet welfare compromised, but offspring mortality is major area of reproductive wastage. This trial aimed to identify if split suckling would improve piglet survival in a large commercial piggery in South Australia. In total 423 sows and their litters were used, giving a total of 4,607 piglets. The three treatments imposed were rotational split suckling, conventional split suckling and a control group. The measurements collected from the piglets included a subjective vitality score, rectal temperature, live weight, blood glucose concentration and immunocrit as an estimation of piglet colostrum absorption. There was no treatment effect of any split suckling method on survival ($P>0.05$), although overall survival in the experiment was high (~89%). Day 0 weight and temperature, and day 1 blood glucose concentration all displayed a highly significant, quadratic relationship ($P< 0.001$) with piglet survival to weaning. Piglets that were classified as compromised had a better chance of survival if they survived past 3 day of age and if day 0 weight and temperature, and blood glucose concentration at day 1 were increased (with optimal values of 1.6 kg, 38˚C and 7.6 mmol/L respectively). This implies that future efforts should be focussed to optimise birth weight, manage the temperature loss of piglets, and increase blood glucose in the first few days post parturition, in order to increase neonatal survival.

Introduction:

Piglets weaned per sow per year is a key performance indicator of pork production systems (Damgaard *et al.* 2003). Genetic selection has increased litter size (Tholen *et al.* 1996; Hansen *et al.* 2013), however with increased litter size there is an associated increase in pre-weaning piglet mortality which can be as high as 10-20% (Tuchscherer *et al.* 2000; Vallet *et al.* 2013a). This decrease in survival has both production and welfare concerns among producers. Industry is currently exploring new farrowing crate alternatives, in order to increase the welfare standards of sows. However, these alternatives may compromise the survivability of piglets due to increases in sow mobility and, therefore, amplified risk of overlay by the sow. In order to reduce the chance of overlay, piglets must be vigorous and warm. To achieve this, ingestion of colostrum is essential.

Colostrum is the first milk that the sow produces for the piglet and is energy dense and rich in antibodies and growth factors. However, it is only secreted for the first 24-36 hours following birth (Westrom 1985). Specifically, colostrum has a high concentration of immunoglobulin G (IgG) (Wang *et al.* 2008), increased lipid content (Jackson *et al.* 1995), colostral lactase (Yang *et al.* 2000), protein concentration and total solids (Al-Matubsi *et al.* 1998) compared to the milk subsequently produced during lactation. Colostrum is essential for piglet survival as piglets are born immunocompromised and with a lack of energy reserves. When piglets are first born, they are exposed to a dramatic change in environmental temperature and in order to maintain temperature homeostasis they must utilise energy to keep warm. Colostrum provides the piglet with energy for heat production as well as brain function (Le Dividich and Noblet 1981). Therefore, without colostrum, piglets may suffer from hypoglycaemia which may be fatal (Fraser and Rushen 1992; Le Dividich *et al.* 2005). Piglet immunity for non-specific immune protection also comes from the mothers colostrum, as there is negligible, placental transfer of antibodies (Curtis and Bourne 1971; Fraser and Rushen 1992; Le Dividich *et al.*

2005). As a result, insufficient colostrum ingestion leads to decreased piglet survival. Mortality rates can be up to 43% if piglets have received less than 200g of colostrum, decreasing to around 7 % when they receive more than this (Quesnel *et al.* 2012). Additionally, colostrum is essential for gut development (Burrin *et al.* 2000; Xu *et al.* 2000) and has been reported to influence post-weaning feed conversion rates (Rooke and Bland 2002).

Management techniques in the first 24 hours may improve colostrum ingestion by piglets and split suckling is one method that could achieve this. Split suckling is a maternity ward management technique that reduces teat competition within litters in the first 24 hours of life. It aims to allow the smaller piglets a chance to receive colostrum, which is essential for survival (Vallet 2013). Split suckling involves taking off the larger, first born piglets that have already ingested colostrum, thereby giving the smaller, later born piglets access to the udder with less competition. The ultimate goal is to facilitate sufficient colostrum ingestion to all piglets within the litter. This allows the smaller piglets to have a multiple sucking sessions, without competition from larger piglets, and may increase their chances of survival and reduce within litter variation in piglet weights (Tokach 2004). There are limited reports on the effectiveness of various split suckling methods under commercial conditions and the impact it has on growth and survival of piglets. Increased intensive supervision in maternity wards, including the implementation of split suckling, has been shown to improve piglet survival but it was difficult to determine if split suckling alone was responsible for this improvement (Holyoake *et al.* 1995a). Limited reports have provided evidence that split suckling impacts on increased colostrum absorption and how this affects the survival (Holyoake *et al.* 1995a).

This study aimed to quantify the benefits of split suckling piglets in the first 24 hours post-natal, under commercial conditions, and to determine if other important production parameters are affected by this husbandry technique.

Methods:

Animals

The experiment was conducted in accordance with the guidelines set out in the 'Code of Practice for the Care and Use of Animals for Experimental Purposes' and received approval from the University of Adelaide Animal Ethics Committee (017761). This experiment was conducted at a large commercial piggery in South Australia and utilised 423 sows from parities 0-7 and their litters, giving a total of 4,607 piglets. During gestation, sows were fed 2.4kg/day of a commercial gestating sow diet and group housed. Two to five days prior to the estimated farrowing date, sows were loaded into traditional farrowing crates measuring 2.5m x 1.8m with tri-bar metal flooring and containing a creep area with solid mat flooring and heat provision via a creep lamp. Sows were fed 2.5kg/day of a commercial lactation diet until farrowing, and fed *ad libitum* from farrowing to weaning.

Twelve to 24 hours following parturition, piglets were fostered to the number of functional teats on the sow's udder. The only case in which additional disturbance occurred was when piglets were observed to be losing condition. When this occurred, a new 'drop back' litter was created by removing all poor condition piglets and placing them on a weaned or recently farrowed sow depending on the age of the piglets. All piglet movement was recorded. Every piglet was given the same level of husbandry and this included the provision of additional energy if found to be weak, moved to the heated creep if cold, and destroyed via humane euthanasia if they were determined to be extremely unlikely to survive. Piglets received medication on an as needs basis for diseases such as scours or meningitis. All piglet medications were recorded. Piglets were weaned at 24 ± 6 days.

The experiment was conducted over three batches between the end of April and July 2014. Within each batch all treatments were represented equally. The farrowing location of each sow and litter was recorded.

Experimental Treatment

Each sow was randomly allocated to one of the following three treatment groups.

1. *Rotational Split Suckling* (143 sows): the rotational method of split suckling involved the whole litter being split into two groups. Groups were rotated hourly for four hours. Piglets were either in the farrowing crate with access to the udder or they were placed inside a warm, dry box at the rear of the crate.
2. *Conventional Split Suckling* (139 sows): involved separating the two to six largest piglets that had a stomach full of colostrum into a warm, dry box from the sow for two to three hours, leaving the smaller piglets on the sow with reduced competition at the udder.
3. *Control Group* (141 sows): No split suckling.

The first two treatments were implemented between the hours of 0700 and 1100 before any piglet cross fostering occurred to ensure the split suckling event was conducted on the birth sow.

Data collection

Only sows that had farrowed the previous night were included in the investigation. For each litter the sow identification, parity, litter size and functional teat number was recorded.

Litter size was counted when treatment had commenced and so was defined as number of live piglets, i.e. did not include the piglets which were born alive and had died before treatment had commenced. On day 0, all piglets received an individual identification ear tag, were weighed, recorded for rectal temperature, sexed and scored for vitality (Table 1).

Table 1: Subjective vitality score (0-3) adapted from Herpin et al. (1996)

Vitality score	
0	Dead
0.5	Alive but no noise, barely moving
1	Moving slightly
1.5	Movement, stands up willingly
2	Must make noise, movements confident
2.5	Makes noise, some attempts of escaping (when holding must try to look at you), rapid movements
3	Actively looking for something, moving around in box, makes noise and attempts to escape, when holding resists restraints.

On day 1, the two largest and two smallest piglets from each litter were chosen as 'focus piglets' (n = 1751). Each focus piglet had their rectal temperature taken, a day 1 vitality score (Table 1) and a 3 ml blood sample collected from the jugular vein using a 21g needle into serum blood tubes. Glucose was recorded immediately after blood collection (Accu-chek, Australia). After glucose analysis, the blood was stored at 4°C overnight. The following day, blood tubes were centrifuged at 3000 rpm for 30 minutes and duplicate serum samples were then frozen at -20°C and stored for later analysis.

All pre-weaning deaths were recorded along with a cause of death. Survival was treated as three traits: survival during the first three days, from days 4-7, from day 8-weaning and the combined trait from day 0-weaning.

Immunocrit analysis

Serum samples from individual piglets were measured using a previously validated estimation of IgG concentration (Vallet *et al.* 2013b). One hundred microliters of piglet serum was mixed with the equivalent amount of 40% ammonium sulphate solution. Samples were then centrifuged at 3000 rpm in haematocrit micro capillary tubes for five minutes. The Ig's from the blood serum were de-proteinased by the ammonia sulphate which produced a precipitate. The length of Ig precipitate in the micro capillary tube was divided by the length of solution allowing a measure of the proportion of Ig in the blood (Vallet *et al.* 2013b). Immunocrit is defined as a proportion and therefore does not have any units.

Summary statistics

The range, raw means and measure of variation are reported for all traits (Table 2).

Table 2: Summary statistics of the measurements collected from piglets between day 0 to day 21, including weight, rectal temperature, vitality score, blood glucose concentration, immunocrit proportion and survival.

	n	*min*	*max*	*mean*	*Standard deviation*	*CV %*
Weight day 0 (kg)	4607	0.43	2.66	1.44	0.36	25
Temperature day 0 (˚C)	4602	32	40	37.95	1.01	3
Vitality score day 0	4607	0.5	3	2.16	0.58	27
Temperature day 1 (˚C)	1759	32	40.1	38.37	0.97	3
Vitality score day 1	1759	0.5	3	2.38	0.62	26
Glucose day 1 (mmol/L)	1744	0.6	11.6	6.15	1.55	25
Immunocrit	1736	0	0.34	0.15	0.05	33
Survival d0-weaning	4607	0	1	0.89	0.31	35
Survival 0-3 days	4607	0	1	0.94	0.23	24
Survival 4-7 days	4352	0	1	0.98	0.13	13
Survival d8-weaning	4119	0	1	0.96	0.19	20

Data analysis

The traits analysed were survival from birth to weaning at approximately 21 days and components (0-3 days, 4-7 days, day 8-weaning), glucose concentration and immunocrit. Survival traits were analysed as binary traits with a generalised linear mixed model using a logistic transformation. Birth sow and rearing sow were fitted as random effects (those fostered more than once were treated as if they had stayed with first foster sow). Fixed effects included sex (male or female), split suckling treatment (rotational split suckling, conventional split suckling, and control), batch (1-3), and the covariates day 0 weight (0.47-2.66kg), immunocrit (0.00- 0.34), glucose (0.6- 11.6 mmol/L) and day 0 temperature (32.0- 40.0 ˚C). Non-significant effects were removed from the model. Quadratic effects of covariates were tested as these were expected for traits like day 0 weight effects on survival where very small and very large piglets are likely to have lower survival rates. Glucose concentration and immunocrit were analysed with an equivalent liner mixed model but without themselves being included as covariates.

Prediction of means was done for "average" and "compromised" piglets. Average piglets had a day 0 weight of 1.44kg, day 1 blood glucose of 6.15mmol/L, immunocrit proportion of 0.15 and day 0 rectal temperature of 38˚C which were used for prediction of means. Predictions for average piglets, for example, were estimated across the range of weights at the average glucose, immunocrit and temperature and similarly for each covariate. Compromised pigs were defined as having an average day 0 weight of 0.7 kg, day 1 blood glucose of 2.0 mmol/L, immunocrit proportion of 0.05 and day 0 rectal temperature of 33 ˚C. The percentile values of each covariate was calculated to determine the proportion of compromised piglets at that level of performance. For day 0 weight, 0.7 kg was the 2.0 percentile. For day 0 rectal temperature, 33 ˚C was the $5x10^{-5}$ percentile. This seems extreme but the data was not normally distributed in that most were in the range 36-40˚C but there were some pigs that had very low temperatures. For day 1 blood glucose, 2.0 mmol/L was the 0.4 percentile. For immunocrit, 0.05 was the 2.3 percentile. Significance was defined as $P<0.05$, given the large data set and need for commercial application of results, much more emphasis was placed on results with $P<0.001$.

Results:

The overall survival rate was 89% of piglets from 0 to weaning and this was a function of 94% 0-3 days, 98% 4-7 days and 96% from day 8 to weaning (Table 2). Of all the survival traits analysed, there was no significant effect of either of the split suckling treatments (Table 3). Immunocrit, which was an indication of colostrum intake, was related to survival, but the split suckling treatments did not affect immunocrit. The interaction between split suckling and day 0 weight was tested to see if split suckling had an effect on very small piglets, but this was also not significant for survival. Split suckling by litter size interaction was only significant for survival 8- weaning and for immunocrit and only at the $P<0.05$ level.

Batch was only highly significant for survival from 0-3 days and for immunocrit ($P<0.001$). Litter size was highly significant for immunocrit ($P<0.001$) and of low significance ($P<0.05$) for survival 0-3 days but was not significant for the other survival traits. There were no significant interactions between sex and any of the traits. The interaction between batch and sow parity was only significant for glucose concentration. Day 0 vitality was only fitted for glucose and immunocrit and was highly significant for both ($P<0.001$; Table 3). As there was only low significance for batch, sow parity and sex there were no further analysis done on these traits. Cross fostering status was only significant for survival 0- weaning ($P<0.05$; Table 3).

Table 3: Tests of significance from full model

	Survival 0 - weaning	Survival 0-3 days	Survival 4-7 days	Survival 8 - weaning	Glucose concentration	Immunocrit
Batch	ns	***	ns	**	*	***
Day 0 weight	***	***	***	***	***	***
Day 0 temperature	***	***	ns	ns	***	***
Day 0 vitality	-	-	-	-	***	***
Litter size	ns	*	ns	ns	ns	***
Day 0 weight^2	***	***	*	ns	***	***
Day 1 glucose	***	***	ns	ns	-	-
Day 1 glucose^2	***	***	***	Ns	-	-
Day 0 temperature^2	***	***	ns	Ns	***	***
Immunocrit	*	ns	ns	ns	-	-
Batch x Sow parity	ns	ns	ns	ns	**	ns
Sex	ns	ns	ns	ns	ns	ns
Split suckling treatment	ns	ns	ns	ns	ns	ns
Split suckling treatment x Day 0 weight	ns	ns	ns	ns	*	ns
Split suckling treatment x Litter size	ns	ns	ns	*	ns	*
Split suckling treatment x Day 0 weight^2	ns	ns	ns	ns	*	ns
Foster	*	ns	ns	ns	ns	ns

* = P<0.05, **= P<0.01, *** = P<0.001, ns = not significant, - not fitted in model

Survival

A number of covariates were closely related to survival (Table 3) and are, therefore, the focus of the remainder of the thesis. For average piglets, a curvi-linear relationship between birth weight and survival was identified with an optimal birth weight being 1.9kg (Figure 1) for the highest survival to weaning. The survival of compromised piglets was lower but exhibited a similar relationship with birth weight. For these piglets, when a birth weight of 1.75kg was reached, survival increased from 2.3% (at 0.5kg) to 34% from day 0 to 3, where the impact of birth weight on compromised piglets was greatest (Figure 1).

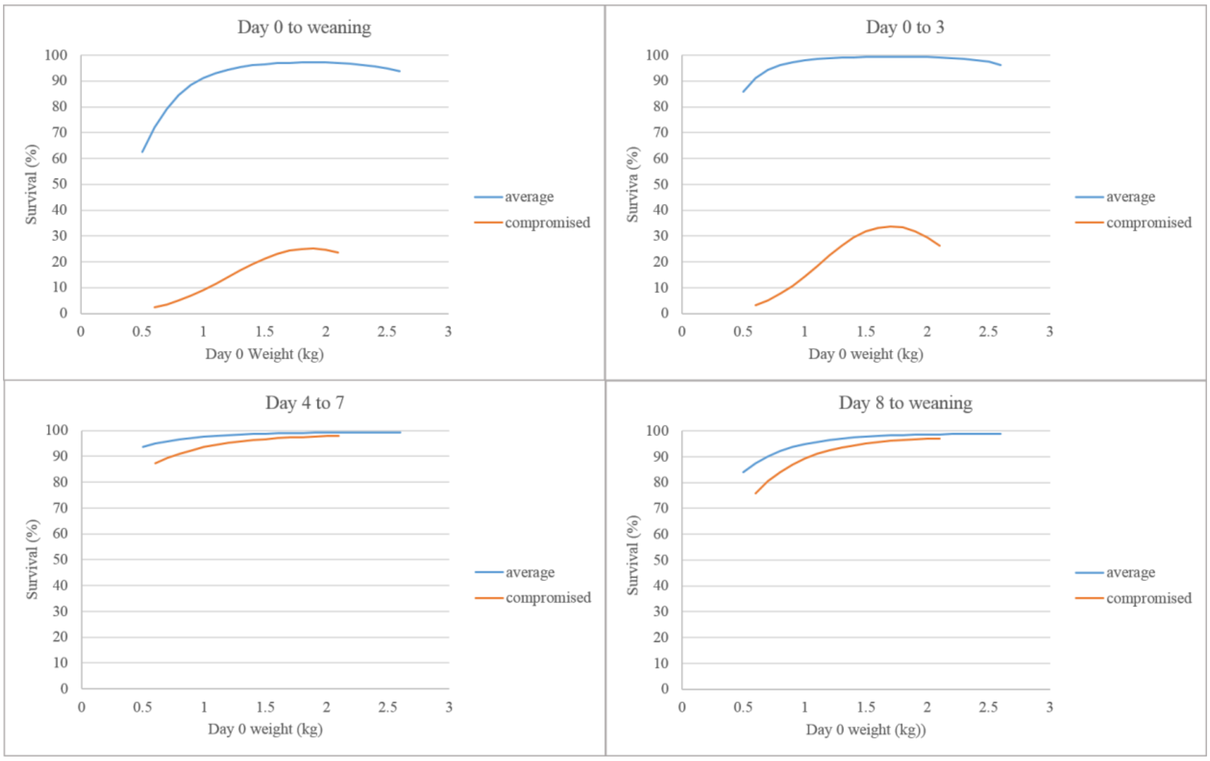

Figure 1:The relationship between survival (%) and day 0 weight (kg) for average piglets (predicted means at average day 0 temperature of 38 ˚C , immunocrit of 0.15 and blood glucose of 6.15mmol/L) and compromised piglets (piglets which had a day 0 temperature of 33˚C , immunocrit of 0.05 and blood glucose of 2.0mmol/L).

For average piglets, a positive relationship between rectal temperature and survival was identified with an optimal rectal temperature of 40˚C for the highest survival to weaning. From 33 to 38 ˚C, the increase in survival from day 0 to weaning was approximately 20% for both average and compromised piglets (Figure 2). Temperature of compromised piglets had a very large effect on survival in the first three days with an increase from 32 to 38 ˚C being associated with survival increasing from 5 to 45% (Figure 2).

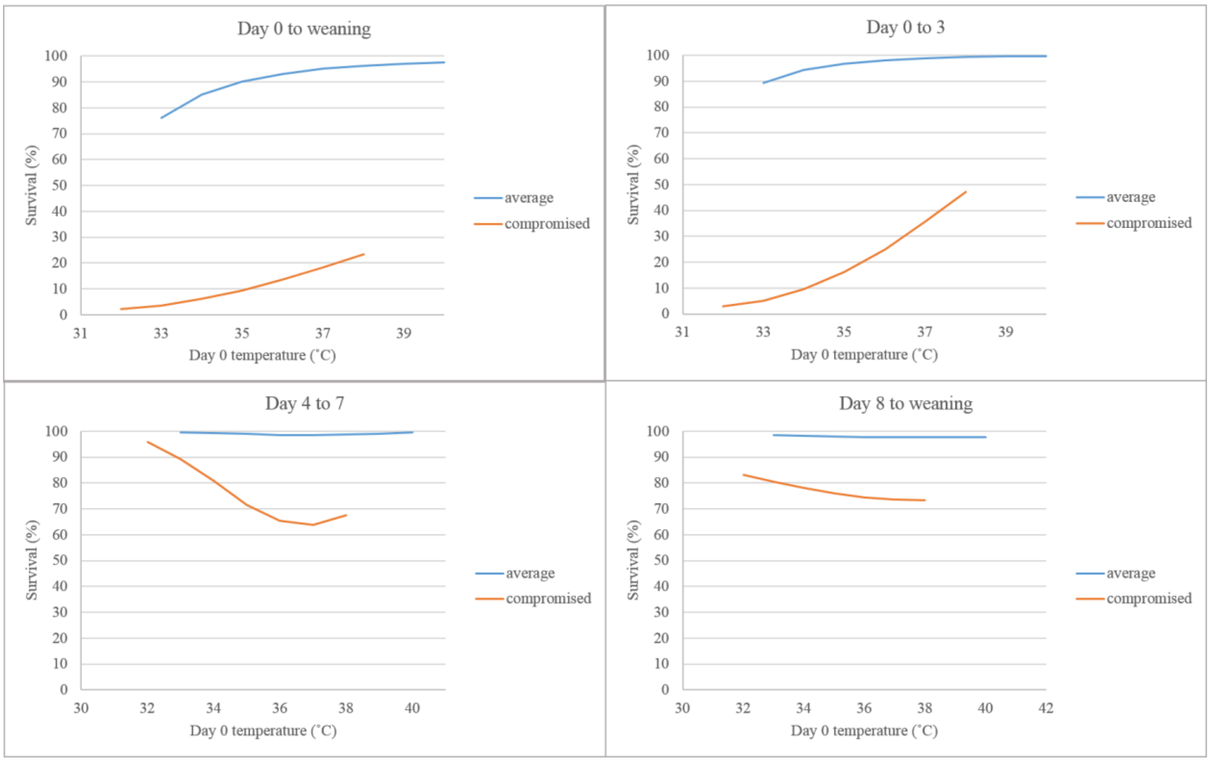

Figure 2: The relationship between survival (%) and day 0 rectal temperature (˚C) for compromised piglets (piglets selected which have a day 0 weight of 0.7 kg , immunocrit of 0.05 and blood glucose of 2.0mmol/L) and average piglets (piglet which have a predicated mean at average day 0 weight of 1.44 immunocrit of 0.15 and blood glucose of 6.15mmol/L).

Over the range of glucose concentrations recorded, the relationship between glucose and survival was similar to that of temperature and survival. For average piglets, a positive relationship between day 1 blood glucose concentration and survival was identified with an optimal day 1 blood glucose concentration of 7.6 mmol/L for the highest survival to weaning (Figure 3). The survival of compromised piglets was lower but the relationship with blood glucose was stronger than for average piglets. For compromised piglets, blood glucose was very strongly related to survival in the first 3 days, in that from 2 to 7.5 mmol/L, survival increased from 5 to 50% (Figure 3).

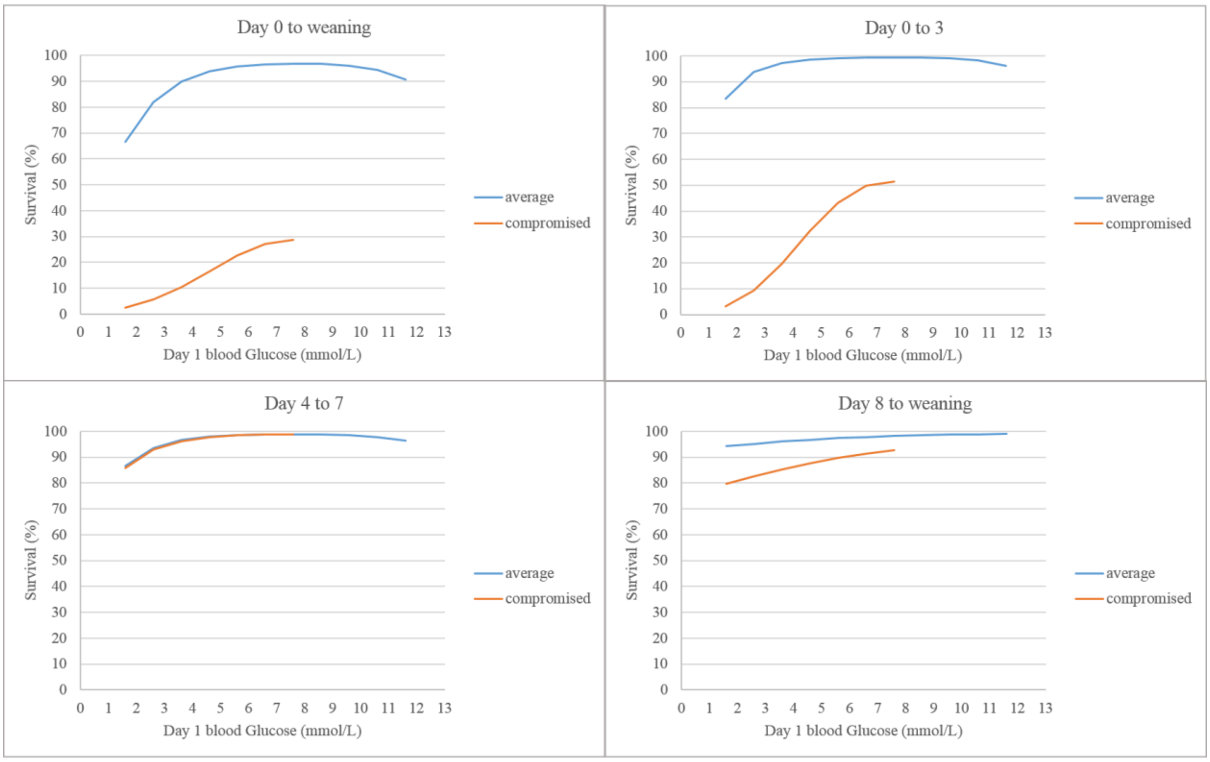

Figure 3: The relationship between survival (%) and day 1 blood glucose concentration (mmol/L) for compromised piglets (piglets selected which have a day 0 weight of 0.70 kg, immunocrit of 0.05 and day 0 rectal temperature of 33˚C) and average piglets (piglets which have a predicted mean at average day 0 weight of 1.44 , immunocrit of 0.15 and day 0 rectal temperature of 38 ˚C).

The relationship between immunocrit and survival from day 0 to weaning was much smaller than the other traits examined, but was still significant (P<0.05; Table 3 and Figure 4). The survival of compromised piglets was lower but exhibited a similar relationship of immunocrit compared to the average piglets. In general, higher immunocrit was associated with higher survival The survival in average piglets from 0 to weaning only increased from 94 to 98% with increasing immunocrit (Figure 4). The effect was greater for those piglets defined as compromised during the period day 8 to weaning, with an increase in survival of 8.7% when immunocrit was increased from 0 to 0.15.

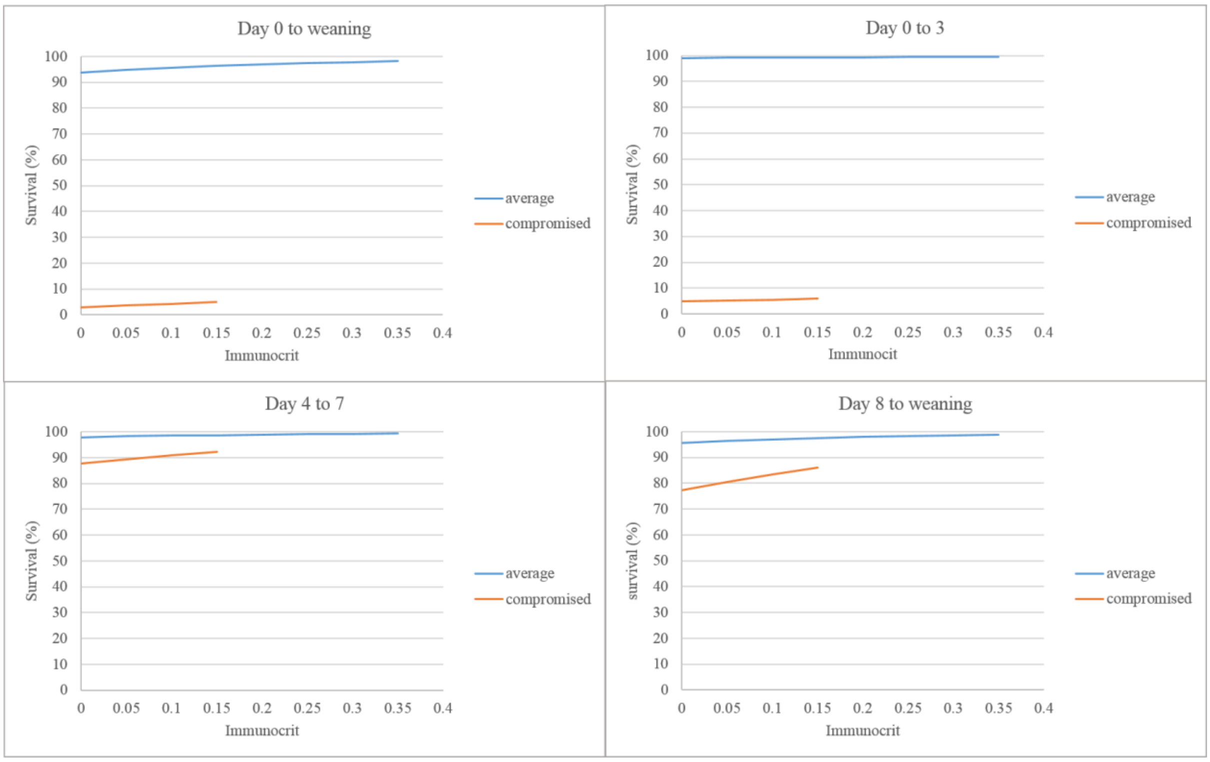

Figure 4: Shows the relationship between survival (%) and immunocrit (proportion) of compromised (piglets selected which have a day 0 weight less than 0.7 kg, day 0 rectal temperature of 33˚C and day 1 blood glucose of 2.0mmol/L) and average piglets (piglet which have a predicated mean at average day 0 weight of 1.44, day 0 rectal temperature of 38˚C and day 1 blood glucose of 6.15mmol/L).

Immunocrit:

The relationships between the following traits did not differ between average and compromised piglets and so the following are presented for the average piglet. A quadratic relationship between day 0 weight and immunocrit was identified (Figure 5). For these piglets, immunocrit was the highest of 0.14 when piglets had a birth weight of 1.6kg, whereas piglets which were born with a day 0 weight of 0.5 kg the immunocrit was only 0.11 (Figure 5). There was a positive relationship between day 0 rectal temperature and immunocrit of average piglets exhibiting higher rectal temperatures following birth recording a higher immunocrit at one day of age (Figure 6). Immunocrit decreased with the increased litter sizes, for every increase of one piglet in the litter, immunocrit declined by 0.0020 ± 0.0004 ($P<0.05$; Figure 7).

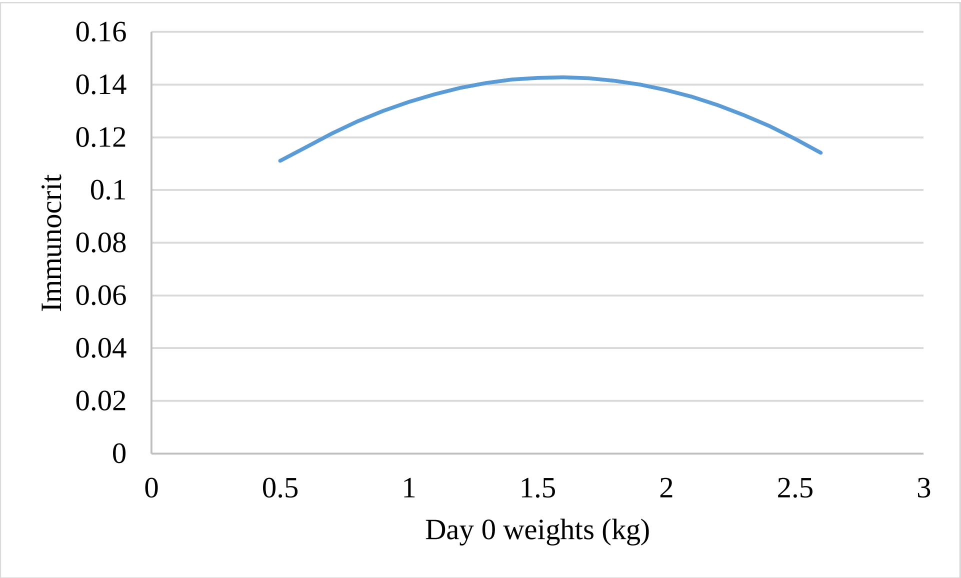

Figure 5: Average piglets day 0 weights (kg) and its relationship with immunocrit.

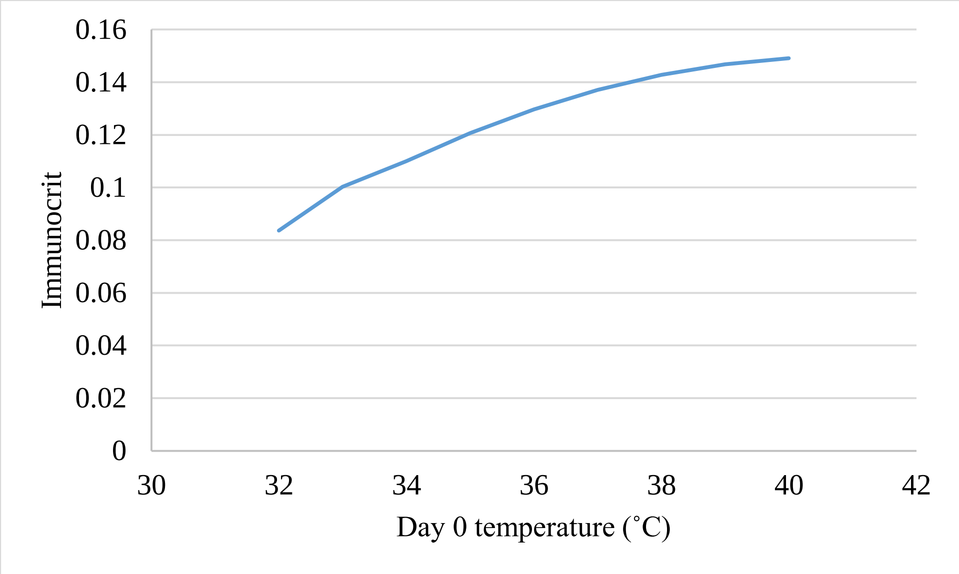

Figure 6: Average piglet's day 0 rectal temperature (˚C) and its relationship to immunocrit.

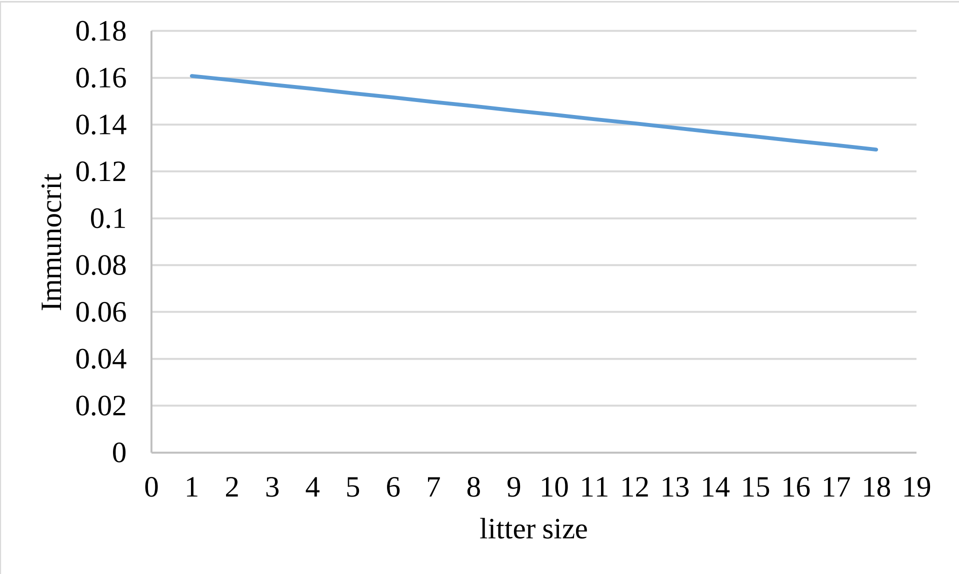

Figure 7: Average piglets which come from large to small litters sizes (at treatment application) and its relationship between immunocrit.

Glucose:

There was no significant difference in the relationship between blood glucose between average and compromised piglets, so the following figures are presented for the average piglet. A quadratic relationship between day 0 weight and blood glucose level on day 1 was identified (Figure 8). The optimal birth weight of 1.9 kg resulted in the highest blood glucose concentration (6.4 mmol/L). Glucose was associated with temperature with an increase from 33 to 38 °C resulting in an increase in glucose from 4.5 to 6.2 mmol/L (Figure 9). A negligible correlation between day 1 blood glucose concentration and immunocrit was identified (r = 0.18).

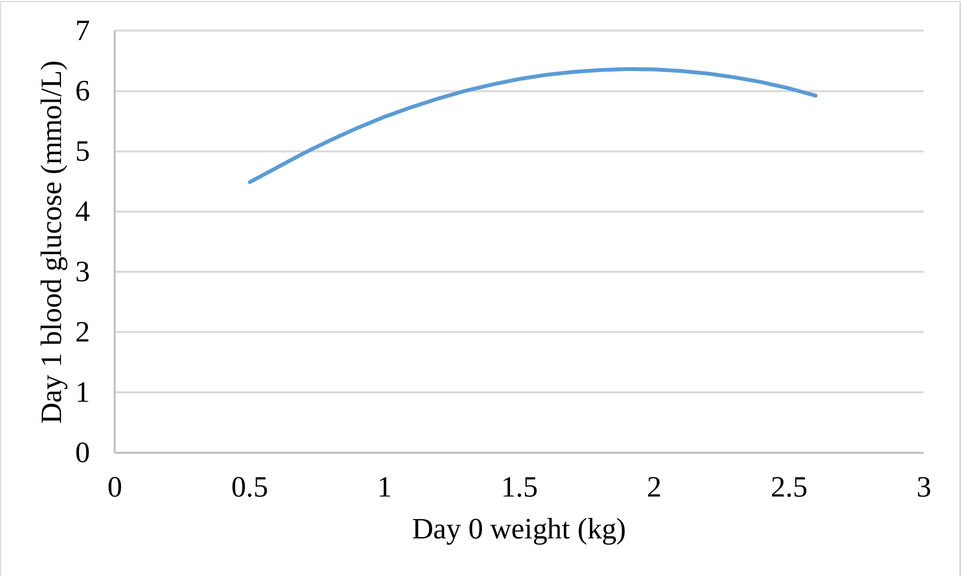

Figure 8: The average piglets day 0 weight (kg) and its relationship with day 1 blood glucose (mmol/L).

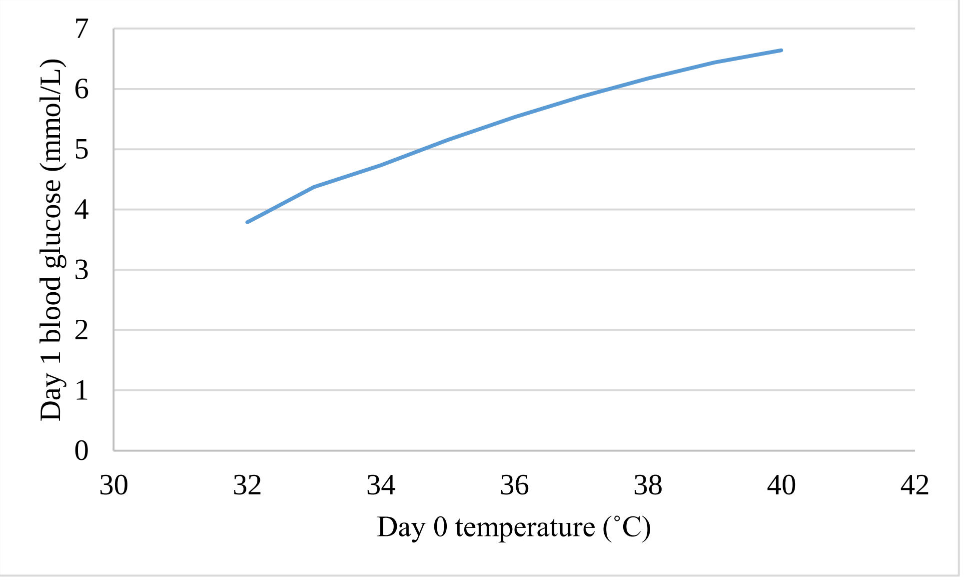

Figure 9: The average piglets day 0 rectal temperature (˚C) and its relationship with day 1 blood glucose (mmol/L).

Discussion:

Split Suckling effect on survival

The study included high numbers of sows and piglets and despite multiple statistical models being fit, there was no effect of split suckling treatment on piglet survival. This was surprising given the finding of Vallet (2013) who reported an increase in survival of 3.4% with split suckling. One possible explanation for this discrepancy is the reported relatively high survival rate in the present investigation. Over 89.5% of piglets survived to weaning (Table 2). The survival rate in the study reported by Vallet (2013) was considerably lower in control sows (84.9%) than that reported here. So, by implementing split suckling they improved survival to the same mean level in the present investigation. It could be argued that the rate of gain in survival would be more difficult at higher survival rates. One possible reason for the high survival rates could be the increased level of supervision provided. The labour associated with the collection of measurements in this trial meant that there was consistently a researcher in the maternity ward along with farm staff performing routine sow checks and neonatal care for newly born piglets. This may have increased survival across all treatments including the control litters as all piglets received more frequent attention than would be standard practice (Holyoake *et al.* 1995b).

There are other possible alternate explanations for split suckling having no impact on survival. Mortality prior to treatment application was not recorded. There may also have been a flaw in the treatment application as colostrum absorption by piglets is greatest in the few hours following birth (Sangild 2003). All litters born over-night were split suckled in the morning so piglets could have been anywhere between two to 16 hours old. Thus, some litters may be outside the critical window (6-12 hours) for maximum colostrum absorption by the piglets gut (Svendsen *et al.* 1986; Sangild 2003). Whilst no effect of split suckling, sex or sow parity was identified, other key measures were shown to be highly significant for survival and these included weight and rectal temperature measured on day 0, and blood glucose concentration measured on day 1. This study did find that piglets which are classified as compromised had the biggest improvement in survival when these traits were managed.

Day 0 weight effects on survival

Studies show that the relationship between birth weight and survival is not linear but better described as a asymptotic curve, with an estimated optimal 93% pre-weaning survival of piglets with a birth weight of 1.6kg (Knol *et al.* 2002). It has been noted that piglets weighing less than 0.87 kg have only a 71.2 % chance of survival (Smith *et al.* 2007), the present results support this (Figure 1). Novel findings of this investigation were that not only was there a curvi-linear relationship between birth weight and survival, but that this differed with piglet state (ie. average or compromised). This indicates that not only does birth weight affect survival, but how ‘lighter’ weighing piglets survival chances are also influenced, by other factors such as those examined (blood glucose concentration, rectal temperature and immunocrit).

In addition to the decreased survival of lighter piglets, there was some evidence heavier ones were also at a disadvantage with regards to survival. This effect was greatest when analysed from day 0 to 3 and is most likely explained by the influence of hypoxia. Hypoxia results in damage to the brain impacting negatively on thermoregulation and vitality (Herpin *et al.* 1996). Hypoxia occurs to larger piglets at birth as they can get caught in the birth canal, resulting in limited oxygen intake during the birthing process, and negatively impacting on survival rate during the first three days (Edwards 2002). There was no relationship between birth weight and survival between day 4 to 7 as all potentially hypoxic piglets had already died (Figure 1).

Day 0 temperature effects on survival

A piglet's ability to produce heat and sustain warmth is essential for survival (Herpin *et al.* 2002; Hales *et al.* 2013). This was confirmed by the findings of the present study where rectal temperature at day 0 was positively correlated to survival (Figure 2). Piglets are born into a cold environment (relative to uterine temperature), are wet with amniotic fluid, and have no brown fat and limited white fat stores for energy (Trayhurn *et al.* 1989). When they get cold, their chance of being competitive at the udder decreases, as they use their energy to maintain core body temperature or try to increase their body heat by lying near the sow (Edwards 2002). For smaller piglets, this is exacerbated as they use more of their energy for thermoregulation due to increased surface area relative to body weight (volume) so they lose heat more rapidly (Hales *et al.* 2013). The effect of piglet temperature on survival was largest on survival in the first three days, and this effect was greater for compromised than average piglets.

Most piglets will die of hypothermia in the first three days and therefore when survival rate between day 4 to 7 was examined, there were only a few compromised piglets that fell in the 32˚C category. The validity of this may have to be questioned due to the small number of piglets in this category. Most of the compromised piglets between day 4 and 7 had a day 0 temperature of between 35 to 39˚C. They survived longer, but still had a lower survival rate and may have died not from poor thermoregulation, but due to the lack of colostrum ingestion, hence a lack of energy and immune function (Edwards 2002).

Day 1 blood glucose effect on survival

The findings from this study indicate that blood glucose concentration was extremely important for survival especially in piglets defined as compromised. Some blood glucose levels were high, and may be indicative of liver glycogenolysis as previous studies have indicated that the rise of plasma glucose of some piglets is due to stimulation of liver glycogen (Le Dividich and Noblet 1981; Puppe *et al.* 2008). Liver glycogen can be rapidly metabolised after birth as piglets are trying to cope with their new surroundings, this allows them to get energy for heat production and to fight for a teat and start to suck (Le Dividich *et al.* 2005). Blood sample collection occurred on day 1 and so, if a piglet died in the first day there was no glucose record. Therefore, the relationship between glucose concentration and survival day 0 to weaning may be actually be steeper than indicated (Figure 3).

Baxter *et al.* (2008) showed that piglets which died had a blood glucose level of less than 3.25 mmol/L on day 1 after birth. The current work indicates that where piglets recorded than 3.60 mmol/L blood glucose and were defined as ‘compromised’ (low temperature and low day 0 weight) they had less than 19% survival. After birth, piglets use glucose from glycogen stores to shiver (a mechanism for heat production) and hence regulate body temperature to maximise their chance of survival (Herpin *et al.* 2002).

Body temperature and glucose were positively correlated. However, it cannot be ascertained if temperature decline was the cause of the increased glucose (to provide energy for shivering) or that the increased glucose caused the higher temperature. The chilled piglets may have used their glycogen reserves to thermoregulate but as they were cold, they did not consume sufficient colostrum to maintain blood glucose levels, and therefore survival may be affected. This is supported by the fact that both glucose and immunocrit were affected by body temperature (Figure 6 and 9). Blood glucose was included as a measurement in this investigation as we hypothesised it would be related with colostrum ingestion. However, this study found that there was not a strong correlation between the two. This poor correlation may be due to glucose being metabolised into glucose the liver via glycogenolysis as well as absorbed from colostrum (Pegorier 1982). Glucose was extremely important for early survival of piglets which were compromised and colostrum ingestion was essential for survival after eight days.

Immunocrit effect on survival

Immunocrit was measured as a crude but effective quantification of IgG in the piglet's serum and subsequently a measure of colostrum ingestion (Vallet *et al.* 2013b). IgG is the main antibody passed from sow to piglet through the colostrum (Curtis and Bourne 1971; Nguyen *et al.* 2013). In the present trial treatment had no significant effect on the immunocrit reading. These findings contradict those of (Vallet 2013) who indicated that split suckling improved smaller sized piglets and piglets which are born later in the birthing process access to colostrum (Vallet 2013). This discrepancy may have been due to missing the crucial window of colostrum absorption by piglets. Sows may have farrowed during the early afternoon or early hours of the evening but treatment implementation occurred the next day and could be up to 16 hours after farrowing, reducing the piglets ability to absorb colostrum. Immunocrit had a small but significant relationship with survival from day 0 to weaning (Table 3).

Piglets that were classified as compromised had immunocrit values which ranged between 0.00 and 0.15. Therefore, we could not predict outside of this data range and so conclusions cannot be drawn to whether increasing colostrum ingestion (as measured by immunocrit) in compromised piglets above 0.15 would have an impact on survival. There was a larger increase in survival between day 8 and weaning in those classified as compromised (Figure 4). This increase in survival is most likely due to an improved level of passive immunity and so protection from disease from greater ingestion of colostrum from the sow (Nguyen *et al.* 2013).

Immunocrit

Piglets which recorded the highest immunocrit reading displayed an optimal birth weight of 1.6 kg. Many studies have shown that piglets which are born heavier are generally more vigorous and therefore assert themselves at the udder to ensure that they get a functional, high yielding teat, resulting in increased milk consumption (Rosillonwarnier and Paquay 1984; Orihuela and Solano 1995). Piglets with a low day 0 weight, had low immunocrit readings. This may be due to small piglets being born late in the litter and so had less access to the udder, as well as being less competitive as they used their energy to thermoregulate. Some heavier piglets also recorded lower readings which may be explained by the impact of hypoxia on vitality and reduced colostrum ingestion as explained above (Herpin *et al.* 1996) (Figure 5).

The effect of day 0 temperature on immunocrit shows that warm piglets at day 0 are more likely to ingest more colostrum (Figure 6). This may be because they can use energy stores to fight for a teat instead of spending so much energy on thermoregulation (Tuchscherer *et al.* 2000). From the data herein it is unclear if the piglets were cold due to limited access to colostrum or whether low body temperature reduced the ability to consume colostrum. Either way, both temperature and colostrum absorption appear to be strongly linked.

Litter size is an important factor in piglet accessibility to functional teats. As litter size increases the competition for functional teats increases (Hales *et al.* 2013). Additionally, large litters appear to have more piglets of low birth weight (Damgaard *et al.* 2003) which decreases their ability of establishing a sucking position and may also inhibit their access to colostrum or milk in general (Nguyen *et al.* 2013). Litter size in the present trial was recorded at the time of treatment and did not take into account any piglets that died prior to this. In this herd mortality prior to this is likely to be less than 1%, however, the effect of litter size on colostrum ingestion may have been greater as piglets that perished would have competed for colostrum but were not measured for immunocit. Individual piglets from larger litters ingested less colostrum when compared to piglets that come from medium or small litters (Figure 7). The effect of immunocrit on litter size may have been bigger if number of piglets born alive was recorded rather than the number of piglets who had a treatment imposed. Additionally, this trial only sampled the two largest and two smallest piglets within each litter so colostrum absorption from the whole litter was not measured as accurately as if done on all piglets.

Conclusion:

The aim of this trial was to determine the effect of split suckling on piglet survival under commercial conditions. It was shown that with good maternity ward supervision of perinatal sows and piglets, split suckling did not impact on piglet survival to weaning. The largest impacts on survival were birth weight, temperature shortly after birth, and glucose concentration at day one of age. The effect of these traits on survival was bigger for compromised piglets than the average for the population. Further research in this area is needed in order to increase the survival of piglets deemed compromised. Focus of this research should be given to optimising piglet birth weight, increasing glucose stores *in utero* or absorption post natal, and limiting body temperature loss to the environment.

Acknowledgements:

The author would like to acknowledge the University of Adelaide and the Cooperate Research Centre for High Integrity Australian Pork for funding this study. Thanks to Australian Pork Farms Group for the provision of animals and facilities. The author wishes to thank David Lines & Tracy Kennett for technical assistance and expertise at the piggery throughout the trial with the support of the farrowing house staff, Professor Wayne Pitchford for statistical analysis and ongoing support and Dr. Kate Plush for statistical and laboratory assistance. Jessica Rayner was also helpful with laboratory assistance. The author wishes to acknowledge Lauren Staveley and Alice Weaver for training in laboratory procedures.

References:

Al-Matubsi, HY, Bervanakis, G, Tritton, SM, Campbell, RG, Fairclough, RJ (1998) Influence of dietary protein of diets given in late gestation and during lactation on protein content and oestrogen concentrations in the colostrum and milk of gilts. *Animal Science* **67**, 139-145.

Baxter, EM, Jarvis, S, D'Eath, RB, Ross, DW, Robson, SK, Farish, M, Nevison, IM, Lawrence, AB, Edwards, SA (2008) Investigating the behavioural and physiological indicators of neonatal survival in pigs. *Theriogenology* **69**, 773-783.

Burrin, DG, Stoll, B, Jiang, R, Chang, X, Hartmann, B, Holst, JJ, Greeley, GH, Reeds, PJ (2000) Minimal enteral nutrient requirements for intestinal growth in neonatal piglets: how much is enough? *The American Journal of Clinical Nutrition* **71**, 1603-1610.

Curtis, J, Bourne, FJ (1971) Immunoglobulin quantitation in sow serum, colostrum and milk and serum of young pigs. *Biochimica Et Biophysica Acta* **236**, 319-&.

Damgaard, LH, Rydhmer, L, Lovendahl, P, Grandinson, K (2003) Genetic parameters for within-litter variation in piglet birth weight and change in within-litter variation during suckling. *Journal of Animal Science* **81**, 604-610.

Edwards, SA (2002) Perinatal mortality in the pig: environmental or physiological solutions? *Livestock Production Science* **78**, 3-12.

Fraser, D, Rushen, J (1992) Colostrum intake by newborn piglets. *Canadian Journal of Animal Science* **72**, 1-13.

Hales, J, Moustsen, VA, Nielsen, MBF, Hansen, CF (2013) Individual physical characteristics of neonatal piglets affect preweaning survival of piglets born in a noncrated system. *Journal of Animal Science* **91**, 4991-5003.

Hansen, CF, Muller, R, Kanitz, E, Tuchscherer, M, Thorup, F (2013) Porcine colostrum supplementation increases serum immunoglobulin concentration of light piglets. *Manipulating Pig Production*

Herpin, P, Damon, M, Le Dividich, J (2002) Development of thermoregulation and neonatal survival in pigs. *Livestock Production Science* **78**, 25-45.

Herpin, P, Le Dividich, J, Hulin, JC, Fillaut, M, De Marco, F, Bertin, R (1996) Effects of the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs. *Journal of Animal Science* **74**, 2067-75.

Holyoake, PK, Dial, GD, Trigg, T, King, VL (1995a) Reducing pig mortality through supervision during the perinatal period. *Journal of Animal Science* **73**, 3543-3551.

Holyoake, PK, Dial, GD, Trigg, T, King, VL (1995b) Reducing pig mortality through supervision during the perinatal period. *Journal of Animal Science* **73**, 3543-51.

Jackson, JR, Hurley, WL, Easter, RA, Jensen, AH, Odle, J (1995) Effects of induced or delayed parturition and supplemental dietary fat on colostrum and milk composition in sows. *Journal of Animal Science* **73**, 1906-13.

Knol, EF, Ducro, BJ, van Arendonk, JAM, van der Lende, T (2002) Direct, maternal and nurse sow genetic effects on farrowing-, pre-weaning- and total piglet survival. *Livestock Production Science* **73**, 153-164.

Le Dividich, J, Noblet, J (1981) Colostrum intake and thermoregulation in the neonatal pig in relation to environmental-temperature. *Biology of the Neonate* **40**, 167-174.

Le Dividich, J, Rooke, JA, Herpin, P (2005) Nutritional and immunological importance of colostrum for the new-born pig. *Journal of Agricultural Science* **143**, 469-485.

Nguyen, K, Cassar, G, Friendship, RM, Dewey, C, Farzan, A, Kirkwood, RN, Hodgins, D (2013) An investigation of the impacts of induced parturition, birth weight, birth order, litter size, and sow parity on piglet serum concentrations of immunoglobulin G. *Journal of Swine Health and Production* **21**, 139-143.

Orihuela, A, Solano, JJ (1995) Managing "teat order" in suckling pigs (Sus scrofa domestica). *Applied Animal Behaviour Science* **46**, 125-130.

Pegorier, JD, PH Girard, J Peret, J (1982) Development of gluconeogenesis in isolated hepatocytes from fasting or suckling newborn pigs. *The Journal of Nutrtion* **112**, 1038-1046.

Puppe, B, Meunier-Salaun, MC, Orgeur, P (2008) The Welfare of piglets. In 'Welfare of pigs.' (Ed. Faucitano L. Schaefer A. L.) (Wageningen Academic: The Netherlands)

Quesnel, H, Farmer, C, Devillers, N (2012) Colostrum intake: Influence on piglet performance and factors of variation. *Livestock Science* **146**, 105-114.

Rooke, JA, Bland, IM (2002) The acquisition of passive immunity in the new-born piglet. *Livestock Production Science* **78**, 13-23.

Rosillonwarnier, A, Paquay, R (1984) Development and consequences of teat-order in piglets. *Applied Animal Behaviour Science* **13**, 47-58.

Sangild, P (2003) Uptake of Colostral Immunoglobulins by the Com-promised Newborn Farm Animal. *Acta vet. scand* **98**, 105-122.

Smith, AL, Stalder, KJ, Serenius, TV, Baas, TJ, Mabry, JW (2007) Effect of piglet birth weight on weights at weaning and 42 days post weaning. *Journal of Swine Health and Production* **15**, 213-218.

Svendsen, LS, Westrom, BR, Svendsen, J, Ohlsson, BG, Ekman, R, Karlsson, BW (1986) Insulin involvement in intestinal macromolecular transmission and closure in neonatal pigs. *Journal of Pediatric Gastroenterology and Nutrition* **5**, 299-304.

Tholen, E, Bunter, K, Hermesch, S, Graser, H (1996) The genetic foundation of fitness and reproduction traits in Australian pig populations. 2. Relationships between weaning to conception interval, farrowing interval, stayability, and other common reproduction and production traits. *Australian Journal of Agricultural Research* **47**, 1275-1290.

Tokach, M (Ed. R Ball (2004) 'Dealing with variation in market weight.'

Trayhurn, P, Temple, NJ, Aerde, JV (1989) Evidence from immunoblotting studies on uncoupling protein that brown adipose tissue is not present in the domestic pig. *Canadian Journal of Physiology and Pharmacology* **67**, 1480-1485.

Tuchscherer, M, Puppe, B, Tuchscherer, A, Tiemann, U (2000) Early identification of neonates at risk: Traits of newborn piglets with respect to survival. *Theriogenology* **54**, 371-388.

Vallet, IL (2013) Use of Immunocrit to monitor a split-suckle program in commercial production. In 'International Conference on Pig Reproduction IX. Control of Pig Reproduction. Poland, Olsztyn'. (Eds H Rodriguez-Martinez, NM Soede, WL Flowers)

Vallet, JL, Miles, JR, Rempel, LA (2013a) Effect of creatine supplementation during the last week of gestation on birth intervals, stillbirth, and preweaning mortality in pigs. *Journal of Animal Science* **91**, 2122-2132.

Vallet, JL, Miles, JR, Rempel, LA (2013b) A simple novel measure of passive transfer of maternal immunoglobulin is predictive of preweaning mortality in piglets. *Veterinary Journal* **195**, 91-97.

Wang, Q, Kim, H, Cho, J, Chen, Y, Yoo, J, Min, B, Wang, Y, Kim, I (2008) Effects of phytogenic substances on growth performance, digestibility of nutrients, faecal noxious gas content, blood and milk characteristics and reproduction in sows and litter performance. *Journal of Animal and Feed Sciences* **17**, 50.

Westrom, BO, B. Svendsen, J. Tagesson, C. Karlsson, B. (1985) Intestinal Transmission of Macromolecules (BSA and FITC-Dextran) in the Neonatal Pig: Enhancing Effect of Colostrum, Proteins and Proteinase Inhibitors. *Biology of the Neonate* **47**, 359-366.

Xu, RJ, Wang, F, Zhang, SH (2000) Postnatal adaptation of the gastrointestinal tract in neonatal pigs: a possible role of milk-borne growth factors. *Livestock Production Science* **66**, 95-107.

Yang, H, Pettigrew, JE, Johnston, LJ, Shurson, GC, Wheaton, JE, White, ME, Koketsu, Y, Sower, AF, Rathmacher, JA (2000) Effects of dietary lysine intake during lactation on blood metabolites, hormones, and reproductive performance in primiparous sows. *Journal of Animal Science* **78**, 1001-9.